PROCEEDINGS

OF THE 9th CONFERENCE OF
THE INTERNATIONAL SOIL TILLAGE
RESEARCH ORGANIZATION, ISTRO

OSIJEK, 1982.
Tisak: SVUČILIŠNA NAKLADA LIBER
The beginning of the present International Soil Tillage Research Organization (ISTRO) can be traced back to 1955, when a gathering of agricultural research workers was held in Uppsala within the World Ploughing Contest. However, it was only in 1970 that a separate international organization was founded at an international conference at Silsoe, but still attached to the International Soil Science Society.

The final organization of ISTRO, also from the statutory point of view, is connected with the 6th Conference of ISTRO, held in Wageningen in 1973.

Since then, ISTRO has been expanding rapidly, as shown by the inclusion of all the continents and practically all the countries into the Organization. From the few initial enthusiasts, the membership has risen to over 1450.

The increasing interest in soil tillage can be explained by the fact that biological survival of mankind largely depends on anthropogenic soils and agricultural crops.

Soil tillage, as the mechanical intervention in the pedosphere, should be considered in view of several essential requirements. These are the permanent need of increasing productivity on the same arable areas, ameliorative tillage aimed at preserving agricultural soils as a substratum for growing high-yielding field crops, simplification and cost reduction of soil tillage, which consumes most energy in the whole process of agricultural crop production.

Out of the wide range of topics set for the 9th Conference of ISTRO, the majority of submitted papers deal with the tillage-induced changes in the soil, reduced tillage, anthropogenic soil compaction, and the new machinery and tools for soil tillage.

We are very pleased to state that the number of papers has been steadily increasing from one ISTRO conference to another. Thus, there were 48 reports in Uppsala, 68 in Stuttgart, while as many as 110 will be submitted on this Conference.

We are sure that the papers and discussions will stimulate further research in soil tillage and probably serve as guidelines for solving investigation problems of crucial importance for practical work.

With regard to the main scientific questions that will be dealt with at the 9th Conference of ISTRO, we find it necessary to stress that some of the papers were difficult to place within an appropriate theme as they treat problems touching on several themes. We have, therefore, allotted such papers to the theme...
they most logically belong to. All the papers received on time have been included into the Proceedings, and they are presented in the original form that the authors gave them. Also those papers were included which are only peripherally connected with the themes set for the 9th Conference, that is with the problems treated by the researchers in the field of soil tillage. In this way an attempt is made to bridge the gaps between bordering scientific disciplines.

Finally, it should be mentioned that the work on organizing the Conference and editing the Proceedings was mainly done by the Institute for Agroecology, Department of General Agronomy, Faculty of Agricultural Sciences, Zagreb, and by the Agricultural Institute Osijek, Department of Agrotechnics, Faculty of Agriculture, Osijek.

Considerable financial and organizational help was obtained by the Regional Committee for the 9th Conference of ISTRO in Osijek, which is made up of representatives of social, political, economic and professional organizations and firms. We are using this opportunity to express our gratitude to all of them.

Prof. Dr. Andelko Butorac
Editor of the Proceedings of the 9th Conference of ISTRO

Prof. Dr. Vladimir Mihalić
President of ISTRO
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1. AMELIORATIVE TILLAGE
The trial was performed to test two variants of pedomeliorative deep loosening of semigley lessive soils, subsoiling with heavy tine subsoiler at 80 cm depth and soil ploughing at 80 cm depth. All these land reclamation operations were compared to the ploughing at 30 cm depth. Contrary to the ploughing at 30 cm depth, pedomeliorative operations contributed to the increase of grain maize yields, as well as to the improvement of certain physical, chemical and microbiological properties of soil.

Introduction

It is generally known that soil tillage affects on the changes of physical properties of soil and that such changed condition influences on the changes of chemical and biological properties among which the changes in microbiological complex of soil play very significant role. These changes positively influenced on the relationship soil-plant in the sense of obtaining higher and more constant yields of field crops. Not rejecting a priori the trends in soil tillage by which the tillage is simplified, even almost excluded, we consider that only by means of mechanical action in soil, particularly in these instances when we have the soil of heavier mechanical composition and unfavourable stratigraphy, with working parts of agricultural machines and implements it is possible to eliminate the limiting factors and create the optimum conditions for plants development and achieving high variety and hybrid efficiencies of agricultural crops.
On the basis of such principles and in accordance with the present problems and requirements of modern field crops production, for the period 1975-1978, we have investigated the changes in pedocomplex of semigley lessivé soils in the region of East Slavonia by applying various pedo-meliorative operations of cultural practice and their influence on yields of maize.

Methods

The establishment of field cultural experiment followed after the wheat harvesting on semigley lessivé soil type, the Kara location, IPK OSIJEK. The chosen location was tilled and the trial designed by split method. Two variants of meliorative deep loosening were investigated in the trial, subsoiling with heavy tine subsoiler at 80 cm depth and deep ploughing at 80 cm depth in comparison to the standard tillage, ploughing at 30 cm depth. The main objective of this research was to determine the effects of the investigated tillage variants on the yields of grain maize and changes in physical, chemical and microbiological complex of soil. To determine the occurring changes in pedocomplex we performed the field and laboratory analyses using standard working methods.

Investigation results

Continuing our study we give some comments on investigation results, the occurring changes of physical, chemical and microbiological properties of the soil and achieved yields of grain maize according to the tillage variants and years of investigation. The obtained investigation results of physical and chemical soil properties are given in the Tables 1 and 2, and the microbiological properties on Figures 1 and 2.

Affected by applied pedo-meliorative operations of soil tillage, there occurred certain positive changes in physical, chemical and microbiological properties in relation to the standard variant of tillage. These changes are of particular importance for physical properties such as mechanical composition, specific bulk density, status of field capacity and air capacity, as well as available moisture content in soil to the plant.
Even more significant positive changes of physical soil properties occurred by soil ploughing at 80 cm depth. As per chemical properties we point out the increase of humus content, as well as pH value increase and in saturation of cation exchange capacity (V %). Under the effect of applied pedomeliorative operations, there also increased the available phosphorus (P₂O₅) to the plant, while the level K₂O remained as that of the traditional soil tillage.

All those pedomeliorative operations, that cause the changes in pedophysical and pedochemical complex, led also to the improvement in microbiological properites what resulted in formation of depth and width of "microbiological profile" in soil. The general biogenesis and ammonification microflora also improved, as well as the content of nitrogen-fixing bacteria and cellulolysators all over the depth of the investigated profile. Here we also achieved more significant changes by subsoiling, e.g. at 80 cm depth.

In addition to the above mentioned investigation, we also observed the applied pedomeliorative operations effects on the yields of grain maize (Table 3).

Table 3. Yield of maize according to the soil tillage variants, dt/ha

<table>
<thead>
<tr>
<th>Investigation year</th>
<th>Tillage variant</th>
<th>Mean value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ploughing at 30 cm</td>
<td>Subsoiling at 80 cm</td>
</tr>
<tr>
<td>1976</td>
<td>76.3</td>
<td>108.0++</td>
</tr>
<tr>
<td>1977</td>
<td>77.9</td>
<td>79.7</td>
</tr>
<tr>
<td>1978</td>
<td>79.7</td>
<td>95.6++</td>
</tr>
<tr>
<td>Mean value</td>
<td>78.0</td>
<td>94.4++</td>
</tr>
</tbody>
</table>

LSD 5% = 5.32, LSD 1% = 7.47

According to the results obtained in the first and third year of investigation, the increase of grain maize is on the level of 5% of significance, while in second year of investigation the yield increase ranked on the level of this significance and the soil tillage variant— subsoiling at 80 cm depth. Contrary to the standard variant of soil tillage, in average of all three years of investigation, the applied operations of pedomeliorative soil loosening performed in higher grain maize yields on the level of 5 and 1% of significance.
Table 1. Physical properties of soil, mean values for the period of investigation 1976-1978

<table>
<thead>
<tr>
<th>Basic tillage</th>
<th>Depth of soil in cm</th>
<th>Mechanical composition of soil</th>
<th>Bulk density</th>
<th>Porosity %</th>
<th>Field capacity</th>
<th>Air capacity</th>
<th>Available moisture mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 - 02</td>
<td>0.2 - 0.02</td>
<td>0.02 - 0.002</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ploughing</td>
<td>0 - 20</td>
<td>0.5</td>
<td>73.3</td>
<td>37.1</td>
<td>25.1</td>
<td>1.50</td>
<td>24.9</td>
</tr>
<tr>
<td>at 30 cm</td>
<td>20 - 44</td>
<td>0.1</td>
<td>39.9</td>
<td>35.6</td>
<td>24.4</td>
<td>1.59</td>
<td>41.0</td>
</tr>
<tr>
<td></td>
<td>44 - 81</td>
<td>0.8</td>
<td>32.9</td>
<td>31.1</td>
<td>35.2</td>
<td>1.65</td>
<td>39.2</td>
</tr>
<tr>
<td>Subsoiling</td>
<td>0 - 20</td>
<td>0.3</td>
<td>37.1</td>
<td>25.3</td>
<td>23.3</td>
<td>1.46</td>
<td>45.2</td>
</tr>
<tr>
<td>at 80 cm</td>
<td>20 - 44</td>
<td>0.6</td>
<td>38.9</td>
<td>35.6</td>
<td>24.9</td>
<td>1.55</td>
<td>43.5</td>
</tr>
<tr>
<td></td>
<td>44 - 81</td>
<td>0.6</td>
<td>33.3</td>
<td>31.0</td>
<td>35.1</td>
<td>1.60</td>
<td>41.0</td>
</tr>
<tr>
<td>Ploughing</td>
<td>0 - 20</td>
<td>0.3</td>
<td>37.1</td>
<td>30.9</td>
<td>29.7</td>
<td>1.46</td>
<td>46.2</td>
</tr>
<tr>
<td>at 80 cm</td>
<td>20 - 44</td>
<td>0.6</td>
<td>38.9</td>
<td>30.8</td>
<td>29.7</td>
<td>1.46</td>
<td>46.2</td>
</tr>
<tr>
<td></td>
<td>44 - 81</td>
<td>1.5</td>
<td>37.8</td>
<td>33.1</td>
<td>27.6</td>
<td>1.40</td>
<td>47.4</td>
</tr>
</tbody>
</table>

Table 2. Chemical properties of soil, mean values for the period of investigation 1976-1978

<table>
<thead>
<tr>
<th>Basic tillage</th>
<th>Depth of soil in cm</th>
<th>Humus %</th>
<th>pH n 0.1 n KCl</th>
<th>CaCO₃ %</th>
<th>Cation exchange capacity</th>
<th>mg/100 grs of soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>S (T-S)</td>
<td>T</td>
</tr>
<tr>
<td>Ploughing</td>
<td>0 - 20</td>
<td>1.45</td>
<td>5.09</td>
<td>-</td>
<td>14.1</td>
<td>6.4</td>
</tr>
<tr>
<td>at 30 cm</td>
<td>20 - 44</td>
<td>1.24</td>
<td>5.16</td>
<td>-</td>
<td>14.7</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>44 - 81</td>
<td>0.70</td>
<td>6.90</td>
<td>10.60</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Subsoiling</td>
<td>0 - 20</td>
<td>1.45</td>
<td>5.19</td>
<td>-</td>
<td>12.9</td>
<td>7.2</td>
</tr>
<tr>
<td>at 80 cm</td>
<td>20 - 44</td>
<td>1.29</td>
<td>5.08</td>
<td>-</td>
<td>17.0</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>44 - 81</td>
<td>1.00</td>
<td>5.61</td>
<td>2.40</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ploughing</td>
<td>0 - 20</td>
<td>1.13</td>
<td>6.55</td>
<td>1.91</td>
<td>44.5</td>
<td>2.2</td>
</tr>
<tr>
<td>at 80 cm</td>
<td>20 - 44</td>
<td>1.24</td>
<td>6.51</td>
<td>1.76</td>
<td>42.8</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>44 - 81</td>
<td>1.39</td>
<td>6.41</td>
<td>1.94</td>
<td>44.3</td>
<td>3.0</td>
</tr>
</tbody>
</table>
FIG 1. DYNAMICS OF total microflora and ammonificators IN SOIL FOR PERIOD 1976-1978.

FIG 2. DYNAMICS OF REPRESENTATION OF nitrogenfixers and cellulolysators IN SOIL FOR PERIOD 1976-1978.
Conclusions

The results of the investigation in pedocomplex of lessivé semigley soil and achieved grain maize yields by applied variants of meliorative cultivation allow us to draw the following conclusions:

1. On the basis of obtained results, for the main investigated parameters, some different statements could be made for single investigated parameters that the applied pedomeliorative variants of tillage influenced on the changes of main physical and chemical properties of lessivé semigley soils.

2. At the same time, affected by applied pedomeliorative operations of soil cultivation some significant changes of microbiological properties occurred, particularly with formation of depth and width of "microbiological profile", what resulted in improving of general biogenesis, ammonification microflora, as well as in the presence of free aerobic nitrogenfixing bacteria and cellulolysators.

3. The applied variants of pedomeliorative tillage, the occurring positive changes in pedocomplex respectively, caused the increase and consistency of general fertility of lessivé semigley soil what positively influenced on the yields of grain maize.

4. Significant changes in pedocomplex and significantly higher yields of maize were obtained by pedomeliorative tillage variant-subsoiling at 80 cm depth in relation both to the standard cultivation variant - ploughing at 30 cm depth, as well as to the individually investigated parameters according to the variant-ploughing at 80 cm depth.

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DEPENDANCE OF PHYSICAL AND CHEMICAL PROPERTIES OF HYDROMORPHIC BLACK SOIL/HUMOGLEY/ON THE SYSTEMS OF MELIORATIVE AND REGULAR CULTIVATION

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Novi Sad, Yugoslavia

ABSTRACT

A hydromorphic black soil of heavy texture was examined for the effect of meliorative and regular cultivation on some physical and chemical soil properties.

The following physical properties were analysed: total porosity, water and air capacity, volumic weight, water permeability and mechanical resistance. Chemical analyses included the contents of humus, total nitrogen, available phosphorus and potassium.

INTRODUCTION

From the point of crop requirements, hydromorphic black soils possess rather unfavorable physical properties. According to their mechanical composition, they are classified as heavy clayey soils. Their total porosity is lower but the volumic weight and mechanical resistance are higher than those in chernozem soil. Their water permeability is mostly unsatisfactory, and very frequently quite bad. The air capacity is low. These soils are regularly poorly aerated which undoubtedly has negative effects on the activity of plant roots and microorganisms as well as on the oxidation processes in the soils themselves./Molnar et. al., 1977 and 1979/.

The chemical properties of hydromorphic black soils are rather favorable if the soils are not exposed to salinization and alkalinization. They usually have a slightly acid reaction and high contents of humus and total nitrogen. The provision of phosphorus is either low or medium, the provision of potassium high. According
to the content of total nutrients, these soils are potentially highly fertile. However, the actual fertility of these soils is poor and variable due to the retarded processes of mineralization taking place in them./Molnar et al., 1977 and 1979/.

The basis objective of cultivation of these soils is an improvement and maintenance of a favorable physical status of the soil. The correction of the unfavorable physical status, as related to the requirement of different crops, is not feasible by applying conventional systems of cultivation but rather by the meliorative cultivation to a larger depth./H. Schulte Karring, 1970/.

Field experiments with different methods and depth of meliorative cultivation and different depth of regular cultivation and intensity of fertilization in the three-crop rotation wheat-sugar-beet-corn were established in order to determine suitable systems of cultivation of hydromorphic black soils. In the trials we followed the effect of the above factors on crop yields as well as the effect of the meliorative and regular cultivation on some physical and chemical soil properties.

MATERIALS AND METHODS

A field experiment was established on heavy hydromorphic black soil with regulated water regime. A detailed description of physical and chemical properties of the soil was given in the papers of Molnar et al. from 1977 and 1979.

The experiment, established in 1976, included the following variants of meliorative cultivation:
1. Plowing to 45 cm
2. Subsoiling to 60 cm
3. Subsoiling to 45 cm

The preceding crop was sunflower. After sunflower harvest, the plot was disk-harrowed to chop harvest residues. The gradual tillage after the method of Todorović, 1960 was performed at short intervals to the depths of 15, 30, and 45 cm, without adding manure or calcium carbonate. The subsoilings were performed approximately at the same time. Brenig's subsoiler was used in early October. The furrows were 75 cm apart. The quality of subsoiling was satisfactory since only the surface soil layer 0-20 cm had high moisture while the layer 20-60 cm had much lower moisture. Both variants of subsoiling were subsequently plowed at 30 cm crosswise.

To evaluate the protracted effects of meliorative cultivation, the following variants of regular cultivation were included
into the experiment starting from 1977:

1. Disk harrowing
2. Plowing to 15 cm
3. Plowing to 30 cm
4. Plowing to 45 cm

Taking into consideration the expected interaction between the depth of cultivation and the intensity of fertilization, the following doses of mineral fertilizers were applied:

a. Control /Without fertilizers/
b. Medium dose /NPK=110:96:64=270 kg/ha/
c. High dose /NPK=160:144:96=400 kg/ha/

The examined crop rotation included wheat, sugar beet, and corn.

The total area of the experiment, together with the protective belt, was 6.27 ha. The size of basis plot for regular tillage was 300 m², for fertilization 100 m². The experiment had four replications.

To determine changes in physical and chemical properties of the soil, samples were taken from the soil layer to 60 cm in the variant of medium fertilization after the harvest of each crop. In 1977, the samples were taken from each 10 cm, in the subsequent years, from each 15 cm. The following physical properties were analysed: total porosity, water and air capacity, volumic weight, water permeability, and mechanical resistance. Chemical analyses included the contents of humus, total nitrogen, available phosphorus and potassium.

Conventional laboratory methods were employed for the determination of the above physical and chemical properties.

RESULTS AND DISCUSSION

Physical soil properties.

Fig.1 shows the immediate effects of meliorative cultivation on the total porosity and water and air capacity.

The graph shows that all three methods of meliorative cultivations increased the total porosity, from the original value of 41-42 vol.% to 48-51 vol.%. The air capacity increased significantly, from 6 vol.% to 10-12 vol.%. The water capacity remained on the same level. It may be concluded that meliorative cultivation significantly increased the incidence of macropores whereas the incidence of capillary pores was not changed much.
Fig. 1. Effect of meliorative cultivation on the total porosity and water and air capacity.

Meliorative cultivation affected positively the volumic weight and water permeability.

Tab. 1. Effect of meliorative cultivation on the volumic weight and water permeability.

<table>
<thead>
<tr>
<th>Variants and depth /cm/</th>
<th>Before meliorative cultivation</th>
<th>Flowing 45 cm</th>
<th>Subsoiling 60 cm</th>
<th>Subsoiling 45 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>1.35</td>
<td>1.33</td>
<td>1.35</td>
<td>1.36</td>
</tr>
<tr>
<td>10-20</td>
<td>1.49</td>
<td>1.31</td>
<td>1.43</td>
<td>1.41</td>
</tr>
<tr>
<td>20-30</td>
<td>1.52</td>
<td>1.35</td>
<td>1.42</td>
<td>1.41</td>
</tr>
<tr>
<td>30-40</td>
<td>1.55</td>
<td>1.35</td>
<td>1.43</td>
<td>1.40</td>
</tr>
<tr>
<td>40-50</td>
<td>1.59</td>
<td>1.51</td>
<td>1.45</td>
<td>1.52</td>
</tr>
<tr>
<td>50-60</td>
<td>1.63</td>
<td>1.57</td>
<td>1.50</td>
<td>1.60</td>
</tr>
</tbody>
</table>

K - Darcy /cm/sec /

<table>
<thead>
<tr>
<th>Variants and depth /cm/</th>
<th>0-10</th>
<th>10-20</th>
<th>20-30</th>
<th>30-40</th>
<th>40-50</th>
<th>50-60</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>2,13.10^{-4}</td>
<td>2,12.10^{-3}</td>
<td>1,85.10^{-3}</td>
<td>1,60.10^{-3}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-20</td>
<td>1,25.10^{-5}</td>
<td>4,06.10^{-4}</td>
<td>1,04.10^{-3}</td>
<td>3,84.10^{-3}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-30</td>
<td>1,96.10^{-5}</td>
<td>2,04.10^{-4}</td>
<td>4,60.10^{-3}</td>
<td>8,50.10^{-4}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30-40</td>
<td>1,53.10^{-5}</td>
<td>2,23.10^{-3}</td>
<td>2,00.10^{-4}</td>
<td>5,00.10^{-4}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40-50</td>
<td>2,74.10^{-5}</td>
<td>4,92.10^{-4}</td>
<td>6,60.10^{-4}</td>
<td>2,0.10^{-5}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50-60</td>
<td>1,77.10^{-4}</td>
<td>2,00.10^{-5}</td>
<td>1,24.10^{-5}</td>
<td>6,60.10^{-5}</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A reduction in volumic weight and an increase in water permeability occurred in all variants of meliorative cultivation.

Meliorative cultivation decreased the mechanical resistance.
of soil with all methods of subsequent deepening of plowing layer /Fig. 2/. These data were obtained one year after the meliorative cultivation.

The properties discussed above were followed in the years after the meliorative cultivation in the variants of regular cultivation. The examined parameters varied considerably in the test years, rendering the determination of the protracted effect of meliorative cultivation per individual variants of regular cultivation impossible. Therefore we restricted ourselves to following the changes in the examined properties depending on the depth of regular cultivation.

Fig. 3 shows the changes in total porosity and water and air capacity in the period 1978-

![Mechanical Resistance Diagram](image)

**Fig. 2** - Effect of meliorative tillage on the mechanical resistance

![Disking and Plowing Diagrams](image)

**Fig. 3** - Effect of the depth of regular cultivation on the total porosity and water and air capacity/three-year average/
Comparing the variants of regular cultivation, we found that the variant of disk harrowing had a significantly lower total porosity than the tilled variants in all test years. The variants of tillage at 15 cm had a lower total porosity in the layers 15-30 and 30-45 cm than the variants of tillage at 30 and 45 cm.

Water capacity was not appreciably affected by regular cultivation indicating that this practice increases only the incidence of macropores while the incidence of micropores remains at the same level.

The higher incidence of macropores, brought about by deep cultivation, produced the highest air capacity in the variant of tillage at 45 cm and the lowest capacity in the variant of disk harrowing in all test years.

Volumic weight had pronounced variations from year to year. Still, the effect of regular cultivation was perceptible /Table 2/. The variant of disk harrowing had a larger volumic weight than the tilled variants. The variant of tillage at 15 cm had a larger volumic weight in deeper layers than the variants of tillage at 30 and 45 cm.

Tab.2 - Effect of the depth of regular cultivation on the volumic weight / three - year average /

<table>
<thead>
<tr>
<th>Depth /cm/</th>
<th>Disking</th>
<th>Plowing to 15 cm</th>
<th>Plowing to 30 cm</th>
<th>Plowing to 45 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15</td>
<td>1.40</td>
<td>1.34</td>
<td>1.35</td>
<td>1.35</td>
</tr>
<tr>
<td>15-30</td>
<td>1.49</td>
<td>1.42</td>
<td>1.37</td>
<td>1.36</td>
</tr>
<tr>
<td>30-45</td>
<td>1.46</td>
<td>1.43</td>
<td>1.43</td>
<td>1.39</td>
</tr>
<tr>
<td>45-60</td>
<td>1.52</td>
<td>1.51</td>
<td>1.51</td>
<td>1.53</td>
</tr>
<tr>
<td>LSD 0.05</td>
<td>0.07</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSD 0.01</td>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig.4 shows the effect of regular cultivation on the mechanical resistance of soil in the test years.

The disk harrowing produced the highest mechanical resistance. With the variants of tillage, the values of mechanical resistance changed with time. In 1978, mechanical resistance was approximately the same in all three tilled variants. In 1979, however, mechanical resistance in the variant of tillage at 15 cm approached the value obtained with disk harrowing, especially in deeper soil layers. Finally, in 1980, the variants of regular cultivation were fully differentiated regarding the values of mechanical resistance.

These results helped us conclude that the mechanical
Fig. 4 - Effect of the depth of regular cultivation on the mechanical resistance of hydromorphic black soil—besides other factors—depends considerably on the depth of regular cultivation. With a shallow soil cultivation the value of mechanical resistance significantly increases with time.

Chemical soil properties

This part of the study was limited to the determination of the contents of humus, total nitrogen, available phosphorus and potassium.

Fig. 5 and 6 show the three-year (1978-1980) average contents of humus, total nitrogen, available phosphorus and potassium.

Humic content is determined by pedogenetic processes and its changes under the effect of cultural practices is quite slow. A period of three years is too short for significant changes in the contents of humus and total nitrogen to take place, as exemplified in Fig. 5. The contents of humus and total nitrogen were not changed in the test period by the regular cultivation exercised.

It was observed that the humic content in the soil layer 0-15 cm was lower by 0.20 - 0.30% than that in the layer 15-30 cm with all variants of cultivation. This is most likely related to the intensity of the processes of mineralization in these soil layers.
Fig. 5 - Effect of the depth of regular cultivation on the contents of humus and total nitrogen /three-year average/

The contents of total nitrogen and humus was not changed during the period of the trial by different tillage depths. Nevertheless, the content of total nitrogen was higher in the surface soil layer in all variants of tillage. It is probable that the C/N ratio in the layer 0-15 cm was higher than in the layer 15-30 cm.

Fig. 6 - Effect of the depth of regular cultivation on the vertical distribution of available phosphorus and potassium /three-year average/
Fig. 6 shows the vertical distribution of readily available phosphorus and potassium.

The contents of available phosphorus and potassium in the soil layer 0-15 cm were highest in the variants of disk harrowing and tilling at 15 cm. The shallow cultivation accumulated available phosphorus and potassium in the layer 0-15 cm. Consequently, their contents in the layers 15-30 and 30-45 cm were considerably lower than in the variants of tillage at 30 and 45 cm. The deep cultivation secured a more favorable vertical distribution of phosphorus and potassium as well as their higher concentration in deeper soil layers which contain the major part of the active rhizosphere of plants. /Bakermans and DeWit, 1970; Buhtz et al., 1970/

REFERENCES

EFFECT OF MELIORATIVE AND REGULAR CULTIVATION AND FERTILIZATION OF HYDROMORPHIC BLACK SOIL /HULISLEY/ ON THE YIELDS OF WHEAT, CORN, AND SUGARBEET GROWN IN THREE-CROP ROTATION

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ABSTRACT

We examined the effect of different methods and depth of meliorative cultivation, different depth of regular cultivation, and different intensities of fertilization on the yields of wheat, corn, and sugarbeet grown in three-crop rotation on hydromorphic black soil.

INTRODUCTION

The cultivation of hydromorphic black soils is a complex and delicate task on account of unfavorable physical properties, primarily a high clay content and a high specific resistance, of these soils and short spans of time when these soils are suitable for cultivation. The problem is further complicated by inadequate implements for and system of cultivation.

The cultivation of such anormal soils is expensive to the point of bringing into question the economy of plant production established on them. Recent increases in the price of fuel which result from the global energy crysis only aggravated the problem. It is thus not accidental that solutions are sought after of reducing the costs of production maintaining the yields at the level which ensures the economy of plant production. The necessity of developing more rational systems of soil cultivation than the traditional one is emphasized for heavy soils as opposed to soils with lighter texture.
Unfavorable physical properties of heavy soils, e.g. heavy texture, low total porosity, high compaction and mechanical resistance, poor water permeability and poor water-air and heat properties, make the yields of the crops grown on them low and dependable on weather conditions in spite of high investment into production. /Stojković et al. 1978/.

The objective of this experiment was to find a suitable system of cultivation of hydromorphic soils. Field trials which included different methods and depths of meliorative cultivation, different depths of regular cultivation, and different levels of fertilization were conducted in a three-crop rotation wheat-sugarbeet-corn. The trials were to provide answers to the following questions: 1/ which methods and depths of meliorative cultivation are suitable for the examined soils and 2/ what is the protracted effect of meliorative cultivation on the yields of wheat, corn, and sugarbeet in combination with the depth of regular cultivation and the intensity of fertilization.

MATERIALS AND METHODS

A field experiment was established on heavy hydromorphic black soil with regulated water regime. A detailed description of physical and chemical properties of the soil was given in the papers of Molnar et al. from 1977 and 1979.

The experiment, established in 1976, included the following variants of meliorative cultivation:

1. Plowing to 45 cm
2. Subsoiling to 60 cm
3. Subsoiling to 45 cm

The preceding crop was sunflower. After sunflower harvest, the plot was disk harrowed to chop harvest residues. The gradual tillage after the method of Todorović, 1955 was performed at short intervals to the depths of 15, 30, and 45 cm, without adding manure or calcium carbonate. The subsoilings were performed approximately at the same time, Brenig's subsoiler was used in early October. The furrows were 75 cm apart. The quality of subsoiling was satisfactory since only the surface soil layer 0-20 cm had high moisture while the layer 20-60 cm had much lower moisture. Both variants of subsoiling were subsequently plowed at 30 cm crosswise.

To evaluate the protracted effects of meliorative cultivation, the following variants of regular cultivation were included.
into the experiment starting from 1977:

1. Disk harrowing
2. Plowing to 15 cm
3. Plowing to 30 cm
4. Plowing to 45 cm

Taking into consideration the expected interaction between the depth of cultivation and the intensity of fertilization, the following doses of mineral fertilizers were applied:

a. Control / without fertilizers /

b. Medium dose /NPK=110:96:64=270 kg/ha /

c. High dose /NPK=160:144:96 = 400 kg/ha /

The examined crop rotation included wheat, sugarbeet, and corn.

The total area of the experiment, together with the protective, belt, was 6.27 ha. The size of basis plot for regular tillage was 300 m², for fertilization 100 m²: The experiment had four replications.

Wheat, corn, and sugarbeet yields and other important yield components were determined for individual variants of cultivation and fertilization in all experimental years. The results obtained were calculated variation statistically.

RESULTS AND DISCUSSION

For the sake of clarity, the results of different variants of meliorative cultivation and systems of regular cultivation and fertilization are discussed for each crop separately.

Winter wheat

Table 1 shows wheat yields and yield components realized immediately after the meliorative cultivation.
The variant of tillage to 45 cm brought significantly highest wheat yields. This variant had better seedbed preparation than the other variants and the consequence was a larger number of plants per m² both in spring and at harvest. The increased grain yield in this variant resulted from the larger number of spikes at harvest, larger grain yield per spike, and larger 1000-grain weight than in the variants of subsoiling.

The protracted effects of meliorative cultivation in combination with different depth of regular cultivation and different intensities of fertilization were followed in the subsequent years. Three-year average yields for the period 1978-1980 are shown in Fig.1.

Winter wheat yields were much more dependent on the intensity of fertilization than on the depth of tillage. High doses of fertilizers brought considerably higher yields than medium doses. The yields obtained in the control variant were outstandingly low. Such effects of fertilizers, especially nitrogen, may be explained by slow mineralization processes in spring months, i.e., in the period of an intensive uptake of nutrients.

The effects of the depth of tillage on winter wheat yields were less expressed. Comparing the variant of disk-harrowing with the variants of plowing, we found significant differences in the control variant without fertilization, small differences in the variant with the medium dose of fertilizers, and no differences in the variant with the high dose of fertilizers. This may be explained by the fact that the variant with disk-harrowing usually had a lower concentration of readily available nitrogen in spring than the variants with plowing. The results of Arnott and Clement, /1966/ support this conclusion. The observed interaction between the depths of tillage and the intensity of fertilization is extremely important because it indicates the possibility of designing a system of more rational
cultivation and more economic production.

There were no significant differences in grain yields among the variants of plowing at either level of fertilization.

Corn

Table 2 shows the effects of different variants of meliorative cultivation on the yields and yield components of corn.

Table 2.- Corn yields and yield components with different methods of meliorative cultivation

<table>
<thead>
<tr>
<th>Meliorative cultivation</th>
<th>Yield at 14% moisture t/ha</th>
<th>No of plants/ha at harvest</th>
<th>1000-grain-weight yield per ear gr</th>
<th>Grain moisture content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plowing to 45cm</td>
<td>5.92</td>
<td>45.900</td>
<td>253.8</td>
<td>141.6</td>
</tr>
<tr>
<td>Subsoiling to 60cm</td>
<td>6.37</td>
<td>46.200</td>
<td>268.6</td>
<td>149.9</td>
</tr>
<tr>
<td>Subsoiling to 45cm</td>
<td>6.04</td>
<td>44.100</td>
<td>266.3</td>
<td>146.2</td>
</tr>
</tbody>
</table>

LSD 0.05 0.46 17.0 11.4

LSD 0.01 0.61 22.6 15.2

Different methods of meliorative cultivation did not have significant effects on corn yields and yield components.

The protracted effects of meliorative cultivation in combination with different depths of regular cultivation and different intensities of fertilization were also followed. Three-year average yields for the period 1978-1980 are shown in Fig. 2.

Corn differed from winter wheat in its reaction to the depth of regular cultivation and the intensity of fertilization. The variant of disk-harrowing brought significantly lower yields than the variants of plowing at all three levels of fertilization. Corn and sugar beet require high total porosity of the surface soil layer /Sipos, 1973/ which, in our case, was not secured by disk harrowing.

Comparing the yields of corn in the variants of plowing, it may be seen that the medium and high doses of fertilizers brought higher yields
after the plowing at 30 cm than at 15 cm. However, the plowing deeper than 30 cm did not bring yield increases on the three-year average; the high dose of fertilizers, moreover, brought significant yield reductions.

The effect of fertilization was highly pronounced but less so than it was the case with winter wheat. The yield of the control variant was significantly lower than those in the fertilized variants - it ranged between 5 and 6 t/ha. The effect of fertilization was found to depend considerably on the depth of plowing - it was higher with the plowed variants which is related to a more efficient use of nutrients after plowing.

Sugarbeet

Table 3 shows the effect of different methods of meliorative cultivation on the yields of root and sugar, and yield components of sugarbeet.

Tab. 3. Root and sugar yields and yield components of sugarbeet depending on the methods of meliorative cultivation

<table>
<thead>
<tr>
<th>Meliorative cultivation</th>
<th>Root yield t/ha</th>
<th>Sugar yield t/ha</th>
<th>Sugar content %</th>
<th>No of plants at harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plowing to 45 cm</td>
<td>44.9</td>
<td>8.97</td>
<td>17.1</td>
<td>91,000</td>
</tr>
<tr>
<td>Subsoiling to 60 cm</td>
<td>51.9</td>
<td>8.79</td>
<td>17.0</td>
<td>88,000</td>
</tr>
<tr>
<td>Subsoiling to 45 cm</td>
<td>47.6</td>
<td>8.47</td>
<td>17.8</td>
<td>87,500</td>
</tr>
<tr>
<td>LSD 0.05</td>
<td>0.45</td>
<td>0.57</td>
<td>0.9</td>
<td>4.600</td>
</tr>
<tr>
<td>LSD 0.01</td>
<td>0.60</td>
<td>0.76</td>
<td>1.2</td>
<td>6.100</td>
</tr>
</tbody>
</table>

The variant of subsoiling to 60 cm brought highest yields of roots and sugar. There were no significant differences between the variants of gradual tillage and subsoiling to 45 cm. The methods of meliorative cultivation did not have high effects on the content of sugar and number of plants at harvest.

The protracted effects of meliorative cultivation in combination with different depths of regular cultivation and different intensities of fertilization were followed in the subsequent years. Three-year average yields of sugarbeet for the period 1978-1980 are shown in Fig. 3.
The yields of sugarbeet were more dependent on the depth of regular cultivation than those of wheat and corn. The variant of disc-harrowing brought significantly lower yields than the variants of plowing at all three levels of fertilization.

The differences in sugarbeet yields among the variants of plowing were much more pronounced than those found with the other two crops. The variant of plowing at 15cm brought significantly lower yields at either level of fertilization than the variants of plowing at 30 and 45 cm. However, no significant different could be found between the latter two variants of plowing in the control variant without fertilization and the variant with the medium dose of fertilizers. Moreover, the deeper plowing significantly reduced the yields of sugarbeet in the variant with the high dose of fertilizers.

The effect of fertilization on the yields of sugarbeet was quite pronounced. The unfertilized control variant had significantly lower yields than the fertilized variants at all plowing depth. Furthermore, the variant with the high dose of fertilizers secured a significantly higher yield in relation to the variant with the medium dose of fertilizers. It ensues from these results that the requirements for NPK nutrients of sugarbeet as well as wheat and corn are higher when these crops are grown on hydromorphic black soils than when they are grown on chernozem soil and its subtypes. Similarly with the previous two crops, sugarbeet was more intensively affected by fertilizers in the variants of plowing than in the variant of disk harrowing.

Fig. 3 - Sugarbeet yields depending on the depth of regular cultivation and the intensity of fertilization /average 1978-1980/
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THE PRODUCTIVITY OF PSEUDOGLAY IN SLAVONIA AND THE CHEMICAL CHANGES WHICH OCCUR IN THE SURFACE LAYER AFTER MELIORATIVE TILLAGE

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ABSTRACT

The soils found in the region of Slavonia vary in their productivity and in their physical and chemical characteristics. Some of the arable land has a very low level of productivity and yields on it fluctuate according to varying climatic conditions. The soil in such cases is characterized by its acidity, unfavourable water-air relationship, poor plant-feeding capacity, and a multilayered profile with an impermeable horizon. Since these soils cover an underlying loess and since the impermeable layer reaches to a depth of 30-80 cm, it was appropriate to apply meliorative tillage and fertilizing in order to increase the productivity of this lessive pseudoglay. Our research has shown that, after meliorative tillage, the surface layer was richer in calcium and that its acidity (pH 4.5) changes to neutrality (pH 6.7). The deep loosening simply normalizes the water-air relationship in the soil. Following the application of such meliorative measures, corn yields increased: over three years, the average yield after meliorative tillage to a depth of 100 cm and fertilization was 90.8 dt/ha, by contrast with a 53.55 dt/ha yield in a control field. These results justify the taking of such agromeliorative measures.

INTRODUCTION

Within the hydromorpheme soil class, pseudoglay covers the largest surface area in Yugoslavia at more than 1.2 million ha. In Croatia, this figure stands at approximately 500,000 ha, and in Slavonia at some 120,000 ha (Škorić, 1977). Pseudoglay is a soil with an unfavourable profile structure (A-B-Bg-C) and the impermeable Bg horizon is usually found to a depth of 30-80 cm. Pseudoglay is a low productivity soil, mainly because of its unbalanced water-air relationship, acidity, and low content of most nutrients. Neugebauer (1963) and Janeković (1967), Racz (1967) and Resulović (1971) have studied Yugoslavia's pseudoglay, and...
Müchenhausen (1962) has investigated it in terms of soils with similar characteristics. We ourselves have undertaken research into the problem into the problem of solving pseudoglay's low level of productivity (Škorić & Mihalić 1964; Mihalić et al. 1967; Butorac 1972; Mađarić et al. 1971; Mihalić & Butorac 1972; etc), while Mušac et al., 1974a, 1974b, describe some of our experience over a number of years.

MATERIAL AND METHODS

The properties and productivity of lessive pseudoglay were studied at Lacići in the commune of Donji Miholjac. According to Janeković's research (1967), pseudoglay at Lacići developed from lessive soil upon a carbonate eolic sediment. The soil here had a very unfavourable structure with the typical nature of a very wet pseudoglay. In the autumn of 1965 a static field trial was conducted to test the effect of different methods and depths of soil tillage on the yields of wheat and maize grown in crop rotation. The variation in ploughing were as follows: deep loosening (depth 100cm, distance 100cm); and ploughing at depths of 25cm (control), 40 and 100cm. Each differently ploughed section was also treated with three levels of fertilizer, while the control was left unfertilized. The highest fertilizer rate was 240 kg N, 360 kg P₂O₅, and 480 kg K₂O/ha. During the subsequent years we observed the effect of the meliorative tilling and fertilization: in each variation, the tillage depth was 25cm and the fertilizer rate 120 kg N, 120 kg P₂O₅, and 120 kg K₂O/ha. After several years of study, we took samples from surface layer and profile of all the tillage and fertilizer variation (1965 being unfertilized) for chemical analysis. The soil reaction and humus were tested by the usual methods (Škorić 1965); phosphorus and potassium levels available to plants were determined by the AL-method (Egner et al. 1960); calcium in 1n NaCl, magnesium in 0.5n NaCl, manganese in 1n NH₄-acetate (Rameau 1970); copper in 1n HCl, zinc in 1n KCl (Šlavickaja et al. 1968); boron in hot water (Berger and Truog 1938); and molybdenum in oxalate extract (Purvis and Peterson 1956). Iron was extracted in 10% HCl (Knickmann 1955). Phosphorus, boron and molybdenum were determined spectrophotometrically, potassium by emission, and other elements by atomic absorption.
CHARACTERISTICS OF THE SOIL

The mechanical analysis of the soil was investigated to 200cm depth of profile (Janeković 1967). A smaller proportion of sand and larger amount of clay was found in the 50-60cm layer (Table 1).

Mechanical Analysis of Pseudoglay at Lacići (Janeković 1976)

Table 1

<table>
<thead>
<tr>
<th>Soil Particle Size</th>
<th>Depth of Profile (cm) and Percentage of Soil Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-20cm</td>
</tr>
<tr>
<td>Sand (0.02-2mm)</td>
<td>52.7</td>
</tr>
<tr>
<td>Silt (0.02-0.002mm)</td>
<td>29.8</td>
</tr>
<tr>
<td>Clay (below 0.002mm)</td>
<td>17.5</td>
</tr>
</tbody>
</table>

The profile also varied in its chemical properties: below a depth of 40cm it had a higher soil reaction and contained greater amounts of iron and plant available calcium, magnesium and copper, but smaller amounts plant available phosphorus, potassium, manganese, zinc and molybdenum (Table 2).

Table 2

Chemical Properties of the Pseudoglay Profile (Mušac et al. 1974a)

<table>
<thead>
<tr>
<th>Soil Property</th>
<th>Depth of Profile(cm), Tillage 25cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-20cm</td>
</tr>
<tr>
<td>Soil reaction (pH)</td>
<td></td>
</tr>
<tr>
<td>pH/H₂O</td>
<td>5.8</td>
</tr>
<tr>
<td>pH/KCl</td>
<td>4.4</td>
</tr>
<tr>
<td>Humus (%)</td>
<td>1.3</td>
</tr>
<tr>
<td>Phosphorus (mg P₂O₅/100g of soil)</td>
<td>7.0</td>
</tr>
<tr>
<td>Potassium (mg K₂O/100g of soil)</td>
<td>8.0</td>
</tr>
<tr>
<td>Calcium (%) Ca</td>
<td>0.25</td>
</tr>
<tr>
<td>Magnesium (%) Mg</td>
<td>0.12</td>
</tr>
<tr>
<td>Iron (%) Fe</td>
<td>2.60</td>
</tr>
<tr>
<td>Manganese (ug Mn/g)</td>
<td>7.0</td>
</tr>
<tr>
<td>Copper (ug Cu/g)</td>
<td>2.4</td>
</tr>
<tr>
<td>Zinc (ug Zn/g)</td>
<td>2.5</td>
</tr>
<tr>
<td>Boron (ug B/g)</td>
<td>traces (0.05-0.1)</td>
</tr>
<tr>
<td>Molybdenum (ug Mo/g)</td>
<td>0.33</td>
</tr>
</tbody>
</table>
RESULTS

Changes in the Chemical Properties of the Surface Layer

The manner and depth of tilling had a varied effect on the chemical properties of the surface layer (0-20cm). The greatest changes occurred after meliorative tilling (to a depth of 100cm) when the impermeable layer of soil was broken up and mixed with other parts of the profile. Deep loosening had no significant effect upon the chemical properties of the surface layer, since the natural succession of soil horizons was maintained (Table 3).

Chemical Properties of the Surface Layer Some Years after Meliorative Tillage (Mušac et al. 1974a)

<table>
<thead>
<tr>
<th>Soil Property</th>
<th>Manner and Depth of Tilling</th>
<th>Loosening (cm)</th>
<th>Ploughing (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil reaction (pH)</td>
<td></td>
<td>100 x 100 cm</td>
<td>25 40 100 cm</td>
</tr>
<tr>
<td>pH/H2O</td>
<td>5.8</td>
<td>5.6</td>
<td>5.7</td>
</tr>
<tr>
<td>pH/KCl</td>
<td>4.5</td>
<td>4.5</td>
<td>4.7</td>
</tr>
<tr>
<td>Humus (%)</td>
<td>1.3</td>
<td>1.3</td>
<td>1.1</td>
</tr>
<tr>
<td>Phosphorus (mg P2O5/100g of soil)</td>
<td>10.0</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Potassium (mg K2O/100g of soil)</td>
<td>14.0</td>
<td>17.0</td>
<td>16.0</td>
</tr>
<tr>
<td>Calcium (%)</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Magnesium (%)</td>
<td>0.17</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>Iron (%)</td>
<td>2.05</td>
<td>2.60</td>
<td>3.01</td>
</tr>
<tr>
<td>Manganese (ug Mn/g)</td>
<td>7.0</td>
<td>7.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Copper (ug Cu/g)</td>
<td>4.4</td>
<td>2.4</td>
<td>2.0</td>
</tr>
<tr>
<td>Zinc (ug Zn/g)</td>
<td>1.5</td>
<td>2.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Boron (ug B/g)</td>
<td>traces (0.05-0.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Molybdenum (ug Mo/g)</td>
<td>0.30</td>
<td>0.30</td>
<td>0.10</td>
</tr>
</tbody>
</table>

After meliorative ploughing, the soil reaction changed from an acidic to more neutral one; the amounts of humus, phosphorus, potassium, manganese, zinc and molybdenum decreased; while the levels of calcium, iron and magnesium showed an increase.

Soil Productivity

Meliorative soil tilling had a significant effect upon the water-air relationship of the soil and upon its productivity. Our research over a period of years has shown that through meliorative tilling alone (to a depth of 100cm) maize yields are...
increased to 65.75 dt/ha, as compared with 53.55 dt/ha from the control fields, which were ploughed to depth of 25cm. The best results were obtained where meliorative tilling was combined with meliorative fertilization (Table 4). Our research on wheat has shown that meliorative tilling produces a smaller improvement than that achieved with maize, but also that meliorative fertilizing has a greater effect than that found with maize (Mušac et al. 1974 b).

Maize Yields (hybrid OPH 14) Following varying Soil Tillings and Fertilizings of the Pseudogley (Mađarić et al. 1971)

Table 4

<table>
<thead>
<tr>
<th>Year</th>
<th>Control</th>
<th>Meliorative fertilizing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Loosening Ploughing (cm)</td>
<td>Loosening Ploughing (cm)</td>
</tr>
<tr>
<td></td>
<td>100x100 25 40 100</td>
<td>100x100 25 40 100</td>
</tr>
<tr>
<td>1967</td>
<td>69.69 73.72 80.09 80.63</td>
<td>86.66 87.59 94.21 100.53</td>
</tr>
<tr>
<td>1968</td>
<td>50.54 44.66 46.02 75.22</td>
<td>76.78 64.38 59.34 88.34</td>
</tr>
<tr>
<td>1969</td>
<td>44.74 42.68 39.11 41.15</td>
<td>71.82 67.27 55.71 81.38</td>
</tr>
<tr>
<td>Average</td>
<td>54.99 53.55 55.09 65.67</td>
<td>78.42 73.08 73.08 90.08</td>
</tr>
</tbody>
</table>

LSD 5% 4.83 6.32 9.10
LSD 1% 6.66 5.37 7.73

CONCLUSIONS

By the application of meliorative tilling, the productivity of soil with a multi-layered profile and an impermeable horizon may be increased.

Deep ploughing significantly alters the physical and chemical characteristics of soil. The surface layer changes its reaction from an acidic to neutral one as a result of its being mixed with the subsoil, which is rich in calcium carbonate. The destruction of the impermeable layer also leads to a normalization of the water-air relationship, that is, stagnant water is removed from the vicinity of the root system.

The natural succession of horizons is preserved in the loosening of the soil, that is, the soil’s chemical characteristics are not altered and only the water-air regime is improved.
Meliorative soil tillage gives its best results when combined with meliorative fertilizing. By comparison with normal tilling and fertilizing, maize yields are improved by meliorative tilling (to depth of 100cm) by approximately 10 dt/ha (at the control fertilizing rate), and by 17 dt/ha after meliorative fertilizing.

These agromeliorative measures are, therefore, extremely valuable and the investment made in them is soon repaid through increased yields.

REFERENCE


SOME PROPERTIES OF DRAINAGE FILTERS USED IN AGRICULTURE

by

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Institute for Development of Water Resources

Jaroslav Černi, Beograd, Yugoslavia

ABSTRACT

Embedding of filter materials around and over drain tubes up to the plough layer has been increasingly used in drainage practice. The purpose of filters is to protect drain tubes from clogging, provide better flow towards drain and enable faster discharge of surplus surface water to the drain tubes by means of transferable filters.

The use of filters has both technical and economical importance since their use involves quite high costs.

From among a large number of various filter materials used in protection of drains "filter plastica" made of unvoven fabric PES-250 g/m² and gravel "Moravac" were tested.

Filter plastica was tested on physical models-cases in laboratory conditions. The models were filled with loamy sand and soil.

In experimental drainage fields and in the some soils filter plastica and gravel have also been tested in numerous placing alternatives.

INTRODUCTORY NOTES

The use of filter material around and above drain tubes to the plough horizon is spreading in national and international drainage practice.

The main purpose of filter material with light soils is avoiding pipe clogging, and with heavy clays allowing free flow into drains of surface and subsurface waters.

Mud silting of drains may lead to a lower drainage rate or ultimate clogging. The clogging hazard is higher for light soils with the prevailing grain size between 0.2 mm and 0.02 mm. Finer particles than 0.02 mm generally pass
through filters and do not settle in pipes. Mud siltation in drain tubes is negligible for clays with a high percentage of particles finer than 0.02 mm even without drainage filter (1, 3, 4, 8). However, envelopes are useful with these soils too, because they improve water flow condition around the drain.

The research in many experimental drainage fields, where clay and plastic corrugated drain pipes were used, has shown that in clay arable soils drainage filters should by all means be placed in ditches above the drains to faster conduct surplus water from the field surface and from the soil around the drain (1, 5, 9).

FUNCTION AND USE OF DRAINAGE FILTERS

The prevailing opinion until recently was that drainage filters were efficient only if used in soils with high water table. This opinion has gradually been abandoned by most land users coping with surplus surface water (1,4,9).

Accepted drainage solution for elimination of surplus water, from clay soils in particular, encouraged a complex research in the function and need of filters for a faster discharge of surplus surface and subsurface water.

Studies of the quality, effect and selection of filter materials for various drainage conditions indicated at two main drainage filters (3, 4, 9, 10, 11) from the functional aspect.

- Transferable or hydrological filters have one function: to drain fast surplus surface water from poorly permeable soils through filter placed above drain to plough horizon;

Transferable filters are very important for drainage of hydromorphous clay soils. Excessive water is the main limitation for a better utilization of such soils in the spring and frequently also in the autumn.

- Protective filters are placed around the drain to prevent penetration of soil particles into the drain and its siltation;

Protective filters are also important for use in arid regions where the main drainage hazard is high ground water, rich in water-soluble salts, and soils with the dominating percentage of particles larger than 0.02 mm. Protective filters are various. In arid conditions, gravel or coarse sand is used, and in humid regions, various organic materials and gravel.

Protective filters made of fabric are the latest development. Their use is growing in some countries, such as Czechoslovakia, Netherlands, U.S.A., West Germany (1, 2, 3, 4, 7, 9). They are increasingly used also in Yugoslavia since
LIQ-Osijek perform the production of unvowen plastic fabric.

Some unvowen fabrics have been used in transferable filters, which makes them universal \(1, 4, 9\).

**TEST METHODS**

Some filter materials were tested on physical models in laboratory and in experimental drainage fields to study their effects and practical usability. Several types of protective and transferable filters were tested on heavy and light soils.

Filter plastica PES-250 g/cm\(^2\), as protective, and "Hasura" one-side-protected unvowen fabric plastica, as transferable filter, were tested on various models in Laboratory (Fig. 1).

![Fig. 1 ALTERNATIVE LABORATORY CASE MODELS FOR DRAIN ENVELOPES OF UNVOWEN FABRIC "PLASTICA"](image)

Effects of various plastic envelopes were estimated in relation to sediment content in drainage water and permeability of envelopes.

Models were perspecs cases: 1.0 m long, 0.25 m wide and 1 m deep.

Cases were filled simultaneously with soil and water.

Water was fed to the cases in various intervals, depending on soil permeability, from graded water tanks mounted above the cases. Each water rate amounted to about 100 mm to an area of 0.25 m\(^2\).

During the test, rainfalls were simulated of various duration and intensity. Breaks between single applications of water rates simulated dry periods between rainfalls.

Various tests on incorporated drainage material with protective or transferable function were conducted in experimental fields at Kovin, Nelindvor near Donji Miholjac, and Boka near Zrenjanin.
Several various protective or transferable filter materials were used in 1980 on drains (Fig. 2) in hydromorphous clay soils at Nelindvor.

Investigations in experimental field at Kovin were used at the reference data for estimate of the effects of various gravel filters above drains. Grain size distribution of soils in experimental drainage fields at Kovin and Nelindvor is shown in Fig. 3.

DISCUSSION OF TEST RESULTS

MODEL TESTS IN LABORATORY

Permeability values for LIO filters PES-250 and PES-PA-PP-301 D were determined on Darcy apparatus in the Hydraulic Laboratory of the Jaroslav Černí Institute at 5 H head difference. For pressures up to 11 K Pa the permeability coefficient K varied from $6.8 \times 10^{-3}$ to $3.0 \times 10^{-4}$ m/s (7).

Similar tests with the unused PES-250 filter but at constant water level, on models in laboratory (Fig. 1) gave the permeability K values of $1.18 \times 10^{-4}$ m/s.

The amount of silt discharged with drainage water (Fig. 4), was the lowest in case of the filter spirally enveloping the drain in case B during several months of the experiment after each water application. Sediment content in
drainage water was higher in case C with the filter only covering the drain, which was explained by unprotected lower half of the drain. Total amount of
sediment in the drain was the highest in case A without envelope.

Laboratory grading analysis of drainage water sediment (Fig. 4) has shown that most of particles finer than 0.02 mm passed through the envelopes, while coarser particles adhered to the envelopes forming an additional natural filter.

The amount of sediment in drainage water from case B, after the fifth application of water, was 5 g of air-dry soil per 100 mm of water applied to the soil. Percentage of dry soil in drainage water sediment from case C was higher by 50%, and in that from control case by about 200%, than in drainage water from case A.

Similar protective effects against drain siltation, according to some investigations (1, 2, 9), by a variety of other filters: rhy straw, cocofibres, wool wool, and trevira fabric. The protective capacity of these materials in drain filters is in a selective packing of grains coarser than 0.02 mm on their surface, which improves the filter (1). Similar conclusions, were reacted by some other researches (3), that most of organic drainage filters or those of glass render a higher resistance to water penetrating the drain, thus decreasing the drainage rate. Straw and corncob drain-filters, tested in Nelindvor experimental field (5, 6), exhibited similar effects, unlike gravel tested in the same field.

No deterioration was noted on plastic drain envelope by PES-250 g/m² placed in 1978 (4) in loamy silt at Valpovo, and in 1979 (4) in humogley at Kovin. Moreover, these envelopes showed to had increased in volume in the wet soil condition. This could be explained by the capability of the textile fibres to regain quickly their original state. Thus a drainfilter of unwoven fabric "breathes" letting fine particles pass through it and holding the coarser grains on its surface.

Model (Fig. 5) tests confirmed the mentioned observations.

The percentage of particles finer than 0.02 mm in samples from drainwater sediment after each successive application of water was lower, indicating the rate of labile bound fine particles' passage through envelope. At the end of the last water application already, the sediment was found to contain 80% of particles finer than 0.02 mm - a significant change from 100% dominance at the beginning of the test. The percentage of particles coarser than 0.02 mm in the sediment, at the final stage of the experiment, indicated an increasing rate of these particles in the grain size distribution. This phenomenon allows the formation of a natural filter layer on drainfilter surface.
The grain size distribution of sediment on the filter PES-250 suggests a similar process (Fig. 5). The longer use of the filter, the greater accumulation of the particles coarser than 0.02 mm.

Samples of filter plastica in cases B and C were tested for permeability and the obtained values approximated $8 \times 10^{-6}$ m/s, after the end of the experiment. Similar tests were made for soils in cases, and the obtained soil permeability values were around $7 \times 10^{-7}$ m/s.

On model D with transferable filter (Fig. 1) the amount of sediment in drainage water was smaller (about 2 g per 100 mm of water - much lower) than in cases A or B (Fig. 4).

Permeability coefficient $K$ on model D varied through the test period from 3 to 6 $\times 10^{-5}$ m/s. This high permeability of unwoven fabric 301-D indicated its high drainage capacity from clay soil.

High permeability values of filter plastica after the long experiment (several months), under highly inconvenient laboratory conditions compared to those in nature, indicated that filter PES-250, and even more 301-D, in clay soil had much higher permeability than the soil.
FIELD TESTS IN EXPERIMENTAL DRAINAGE FIELD

Data concerning drainage runoff, groundwater and precipitations in the experimental drainage field at Kovin were taken for basic parameters in determining surplus surface water drainage effects.

Gravel filter was placed in various ways above drains spaced 20 m and 40 m apart (Fig. 6) for drainage test.

![Diagram of filter placements](image)

**Fig. 6** ALTERNATIVE FILTER PLACING IN EXPERIMENTAL DRAINAGE FIELD AT KOVIN

In addition to constructed drainage in the autumn 1977 soil was shattered to a depth of 60 cm.

Grain size distribution curve of soil (Fig. 3) showed the percentage of particles smaller than 0.002 mm between 60 and 73 percent to the depth of 130 cm. Below this depth, the soil was somewhat lighter in texture.

Typical time selected for analysis was February 1978 with a total depth of 120 mm of rain on water-saturated soil. As an indicative short period was selected – the sequence between 14 and 17 February with the precipitation depth of 51.8 mm (Fig. 7).

The effects of gravel filters were analysed for both drainage alternatives of 20 m and 40 m drain spacing and for filter placing patterns as shown in Fig. 6.

It was observed, that a system of PVC corrugated pipes spaced 20 m apart, pipe diameter 80 mm, drain pipeline slope of 0.15%, and continuous gravel filter to plough horizon, drained 39.7 mm in three days. It is an efficient solution
for prompt surplus water drainage. In a cost estimate, based on 62 m³ of gravel per hectare of drainage area, and drains 20 m apart, gravel comprises 40% of the cost, what makes it a costly solution.

The solution with discontinuous filter to the plough horizon only in small depressions also gave very high effects. Around 31 m³ of water was removed by drains within three days. The amount of gravel used in the alternative was around 13 m³, which comprised 10% of total cost per hectare of drainage system.

The alternative of continuous layer of gravel 5 cm around the drain lagged in surplus water drainage effects behind the former two alternatives. In this very heavy clay soil, where restitution of soil compaction above drains (6, 9) takes place within 3-5 years after the drainage facilities have been constructed, protective filter has not a significant function in prompt surplus water drainage from soil surface. In this case, permeability rate of soil depends on its physical-mechanical properties.

Drainage without filter is even less satisfactory as inferred from experimental drainage in similar conditions but various regions, after 4-5 years of operation. Some conclusions were reached in Czechoslovakia (9) for drainage of heavy soils.

Effects of surplus surface water drainage, with the drains 40 m apart and
continuous gravel filter to the plough horizon, were satisfactory. The amount of gravel used was about 30 m$^3$/ha, which made the construction cost high. Drainage rate of about 25 mm per hectare, in this alternative, was accomplished using mole drains a few months earlier.

Surplus water drainage effects with discontinuous drainage filter were lower. Compared to the same alternative with drains 20 m apart, drainage rate in this case of 40 m drain spacing was lower by about 12 mm/day.

Experimental drainage without filter removed 13 mm of water per day - a low effect for the pipe and mole drainage system set up in autumn 1977 (5).

Water tables in alternative drainage fields at the time of discharge measurement and since then are given on Tab. 1.

**Table 1 - Groundwater level in the experimental field at Kovin**

<table>
<thead>
<tr>
<th>Drainage rate</th>
<th>Depth to water table - m</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14 Feb.</td>
<td>16 Feb.</td>
</tr>
<tr>
<td>Drains 20 m apart</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Drains 40 m apart</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>Without drainage-</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>-Control plot</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Groundwater levels and waterlogging, alfalfa hay yields in the first year (spring 1978), for the experimental field for which drainage rates are given, were the following:

(a) drain spacing 20 m  - 9.3 t/ha  
(b) drain spacing 40 m  - 6.5 t/ha  
(c) control without drains  - 4.8 t/ha  

Hay yields for alternatives (a) and (b) in 1979 were higher by 30%.

Before the drainage facilities were provided, the soil in the experimental field was tilled and sown only once in two or three years, and the losses were quite high due to the high production costs and low yields.
CONCLUSION

Use of drainage filters in agriculture, especially in hydromorphous clay soils, is very significant for irrigation practice.

This subject is given much space in literature. Various aspects of the use of diverse drainage filters and their characteristics are frequently considered.

Information about specific effects of individual drain filters on prompt removal of surplus surface water, however, are infrequent.

Large hectarage of hydromorphous clay soils in Yugoslavia, their high capability in many cases, and the fact that large complexes of these soils are in public sector, have directed the research for economical and engineering solutions.

Among a large number of various drainage materials increasingly used in Yugoslavia in protective or transferable drain filters, conventional gravel filter and filter fabrics (PES-250 g/m² and 301-D of LIO production, Textile Industry, Osijek) were tested in alternative placings above drains.

Some of the results, both in laboratory model investigations and experimental field drainage presented in this paper, indicate the qualities, economic aspect, and other parameters important for implementation of the tested drainage materials in agriculture.

REFERENCES.

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This work contains results of changes of chemical properties of a series of soil formed on clay marl. These materials represent depots from open coal mines that were converted into arable layer by means of reclamation measures.

By investigating changes of chemical properties of soil in three minesoils of different age i.e., 1, 4 and 13 years we have found out that new arable layer is formed in about 13 years approximately 15 cm deep (orchard). During the above period humus accumulation in this layer reached $2.37\%$, available phosphorus increased by $1.5$ times and available potassium by $3.5$ times. This is the result of anthropogenous effect indicated by us as favourable tendency in formation of arable layer. However, these favourable effects were accompanied by some adverse processes such as: increase of active Ca and clay content and rainfall waterlodging.

Identification of such adverse processes enables us to take necessary measures for their mitigation or elimination.

INTRODUCTION

Open mines of different minerals led to very serious soil damages. Such method of exploitation is very aggressive as it has frontal approach and includes all areas in certain region. It is not possible to exclude i.e., protect high quality soils from such effects. About $7,500$ ha of arable land is lost in Yugoslavia every year under open mines. Exploitation of minerals leaves devastated areas in the form
of deep and wide craters and whole new hills of deposited material. Box (quot. Shaller et al, 1978) says: "I doubt seriously that we will ever see less drastic disturbance of our landscape than we have today". This indicates rather adverse future of the soil and confronts us with the question of how to mitigate intensity of these processes. One of very important measures of mitigation of such heavy losses in soil is reclamation. Some areas in Yugoslavia have already been reclaimed although such areas are considerably smaller than accumulation of damaged ones (Filipović et al, 1981).

This work describes the rapidness of arable layer formation on reclaimed clay marl soils as well as the processes involved. The purpose is to eliminate or mitigate adverse processes in the future through better knowledge and understanding of their nature.

1. CHARACTERISTICS OF LOCATIONS OF INVESTIGATION

Investigation area is located in North-Eastern part of Bosnia. Mining activities (open mines) led to destruction of considerable areas of this region so that today it gives a picture of real devastated area (industrial desert). Smaller part of so destroyed area has been reclaimed and fruit and field crops successfully grown on them.

As regards climate characteristics the area is characterised by average annual rainfall of 953 mm. It has rather unfavourable pattern during a year. In average, 42% of average annual rainfall occurs in winter period (October - March) and 58% in spring period (April - September). Potential evapotranspiration (PET) in summer period is 85% and in winter only 15% of annual total. There is a disharmony in rainfall pattern and potential evapotranspiration. Results of such disharmony are surplus of water in cold and its shortage in warm seasons of year. On the basis of recorded data on rainfall, calculation of PET and reserves for easily available humidity of 100 mm water balance for a series of 55 years has been defined (Vlahinić et al, 1978).
It has been defined that average yearly surpluses of water are 315 mm and shortages 55 mm. The sum of yearly surpluses and shortages of water vary significantly from year to year.

Geologically, overburden itself is clay marl while limestone participates to a lesser extent.

Reclamation of part of the area was carried out in 1966, by means of so called direct method, without application of special arable layer. 5 waggons of manure per ha were applied as well as 25 mtc/ha of phosphorus fertilizer, 12 mtc/ha of potassium fertilizer (40%) and 10 mtc/ha of N-fertilizer. In subsequent years 1,5 kg per tree was added.

2. METHOD OF INVESTIGATION

The investigation covered three minesoils of different age i.e. 1, 4 and 13 years. Samples were taken from depths ranging between 0 and 20 cm.

The following properties were investigated: texture, skeleton content, pH, humus, CaCO, active Ca, available phosphorus and potassium.

3. RESULTS OF INVESTIGATION

Results of investigation are shown in Tables 1 and 2.

![Table 1](image)

Soil Texture (%) and Skeleton Content

<table>
<thead>
<tr>
<th>Age of soil in years</th>
<th>Depth cm</th>
<th>mm</th>
<th>Sand (2-0,06)</th>
<th>Silt (0,06-0,002)</th>
<th>Clay (&lt;0,002)</th>
<th>Skeleton %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-20</td>
<td></td>
<td>40,55</td>
<td>32,93</td>
<td>26,52</td>
<td>66,0</td>
</tr>
<tr>
<td>4</td>
<td>0-20</td>
<td></td>
<td>36,60</td>
<td>35,00</td>
<td>38,20</td>
<td>40,0</td>
</tr>
<tr>
<td>13</td>
<td>0-20</td>
<td></td>
<td>18,52</td>
<td>35,54</td>
<td>45,94</td>
<td>23,5</td>
</tr>
</tbody>
</table>
Table 2

Chemical Properties

<table>
<thead>
<tr>
<th>Age of soil in years</th>
<th>Depth of soil in cm</th>
<th>pH in H2O</th>
<th>nKCl %</th>
<th>Ca in %</th>
<th>Active Humus</th>
<th>Available in % of soil Mg/100 g of soil F2O5 K2O</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-20</td>
<td>8,40</td>
<td>7,50</td>
<td>38,2</td>
<td>-</td>
<td>0,86</td>
</tr>
<tr>
<td>4</td>
<td>0-20</td>
<td>8,10</td>
<td>7,20</td>
<td>42,5</td>
<td>-</td>
<td>1,51</td>
</tr>
<tr>
<td>13</td>
<td>0-20</td>
<td>8,20</td>
<td>7,20</td>
<td>36,1</td>
<td>33,5</td>
<td>2,37</td>
</tr>
</tbody>
</table>

3.1. Soil Texture and Skeleton Content

It can be seen from Table 1 that in youngest minesoil skeleton content was 66,0%, in 4 year old 40,0% and in 13 year old 23,5%. The data obtained show that in relatively short period its content decreased thus indicating relatively rapid process of desintegration i.e. the process of physical destruction of marl skeleton. In practical terms this is very important as it indicates that the process of fine earth formation is rather rapid from such material and under such conditions.

As regards soil texture it can be seen that soil development is accompanied by pronounced increase of clay content which almost doubled in 13 years. Clay accumulation under conditions of high skeleton content leads to improved water retention and nutrient content properties of such soil.

3.2. Change of Chemical Properties

The data contained in Table 2 indicate that such soil has rather high pH value ranging from (in H2O) 8,20 to 8,40. As regards total CaCO3 content it is high both in fresh "soil" as well as in the oldest member of this series. This content ranged between 36,1 to 42,9%. It is particularly important to emphasize that there is also high quantity of active Ca. Its high content (33,5%) which will be formed and possibly increased in further process of physical destruction of skeleton may lead to debalance in nutrition with
certain elements, particularly iron, and cause chlorisis.

Humus content was gradually increasing from year to year and, after 13 years, already reached 2.37%. Such rapid accumulation is a positive process which will no doubt lead to improvement of its physical and, particularly, biological properties. The result of such humus accumulation is intensive development of root system as well as decrease of organic matters mineralization process due to low content of microorganisms and pedofauna. Similar results were obtained by Hesman et al (1978) and Scaffer et al (1980). Fatkulin (1980) indicates that humin acids in young minesoils are characterised by increased content of C and H.

3.3. Occurrence of some Adverse Processes in Formation of Arable Layer

In the process of humus layer formation we have observed the occurrence of a number of processes some of which having favourable and some adverse effects on root system of plants.

Favourable processes are: accumulation of organic matter, accumulation of nutrient and formation of fine earth.

Adverse processes include: increase of active Ca content, formation of heavier i.e. clayish soil, disposition of clay particles and reduced water permeability in deeper layers.

Increase of active Ca content may, as said before, cause chlorisis with some sensitive plants. Increase of clay particles because of inadequate soil structure leads to occasional stagnation of surface water and its reduced percolation. Mechanical rinsing of clay particles through skeleton material and their illuviation in deeper layers also leads to reduced water permeability.

In respect of future direction of soil evolution, particularly through growth of biological world, formation of favourable structure and human influence, one may expect reduction of adverse processes i.e. increase of favourable
ones, which will contribute to formation of deeper and higher quality arable layer.

CONCLUSIONS

By investigating arable layer on reclaimed surfaces of different age (1, 4 and 13 years) we have found out the following:
- in the period of 13 years arable layer was formed, about 15 cm deep and with humus content of 2.37%;
- content of available phosphorus increased by 1.5 times and available potassium by 3.5 times compared to original conditions;
- during the above period some adverse occurrences were noted such as: stagnation of rainfall water in surface layer as a result of accelerated process of clay formation. Deeper layers also became poorly permeable because of migration of clay particles and their illuviation in deeper layers.

LITERATURE


THE RESPONSE OF VEGETABLE CROPS TO DEEP CULTIVATION
Stone, D.A. & Rowse, H.R.
NATIONAL VEGETABLE RESEARCH STATION, WELLESBOURNE, WARWICK, U.K.

Abstract
Thorough loosening of a sandy clay loam subsoil, in which roots normally penetrated to 70 cm, increased yields by up to 75%. Loosening to 45 cm increased the proportion of roots penetrating below 45 cm, improved water uptake from depth and relieved plant water stress as compared with ploughing to 23 cm. Computer simulation studies showed that increased rooting depth would be beneficial in all but the wettest years and this was consistent with experiment. Evidence was obtained that a combination of minimum tillage techniques superimposed on deep loosened soil could be useful for increasing yield and improving timeliness.

INTRODUCTION
Reliability of yield and continuity of supply are of prime importance to the economic production of vegetables. However, yields and timing fluctuate widely from year to year and soil to soil, creating marketing problems. Much of this variability is a consequence of the short growing season and shallow root system of many vegetable species, which render them particularly sensitive to water supply. Irrigation is therefore an important aid to management, but in England and Wales only 15% of the area of summer vegetables (excluding early potatoes) is irrigated (MAFF 1979). This is possibly because of the uncertain return on capital investment in a region with a variable summer rainfall. It is desirable therefore to develop alternative agronomic practices which make best use of water stored in the soil profile.

Many experiments have been carried out in the UK in which attempts were made to improve subsoil conditions for root growth by using fixed tine subsoilers (Russell, 1956). Yields, however, were seldom improved. Yet many subsoils are compact (Goodeham, 1976) and may never have been adequately loosened by conventional equipment. The possibility exists that if they could
be effectively loosened benefits might be obtained. In 1975, the National Vegetable Research Station started a programme of research to investigate the potential benefit of really thorough subsoil loosening and to forecast when such benefits might be obtained. This paper describes our progress.

EXPERIMENTAL PROCEDURE AND YIELD RESPONSE

Our experiments were carried out on a sandy clay loam (Stagnogleyio, argillic brown earth) having a moderately developed, medium-coarse structure to about 1 m and which had been previously cropped with spring barley for 20 years. NaHCO₃-soluble P and exchangeable K were uniform down the profile, averaging 16 and 80 mg kg⁻¹ air-dry soil respectively.

In the first experiment, thorough loosening was ensured by excavating 3 trenches 1.8 m wide x 9 m long to a depth of 0.9 m using a tractor-mounted scraper. During backfilling, care was taken to maintain the original arrangement of soil horizons, and fertilizer (300 kg N as urea formaldehyde, 200 kg P as triple superphosphate and 400 kg K as K₂SO₄ ha⁻¹) was incorporated at varying proportions down the profile. Further plots were ploughed and cultivated conventionally, but all treatments, except for an unfertilized control, received the same total amount of NPK fertilizer. Potatoes were grown in 1976, followed by broad beans. Dry matter production was increased by 13 and 75% respectively by deep loosening alone (Stone, 1982). No additional benefit from deep incorporation of fertilizer was detected.

Encouraged by these results, the original experiment was expanded by the addition of 3 similar trenches and a larger experiment was laid down using a Wye double digger operating to 45 cm (Rowse & Stone, 1980). This machine rotavates the subsoil and at the same time inverts the topsoil by ploughing (Warboys et al., 1976) while allowing incorporation of fertilizer to depth (Warboys et al., 1979). Without exception, yields of a range of contrasting crops were increased by deep loosening (Tables 1 & 2) although the effects of deep fertilizer followed no clear pattern (Table 2).

Table 1. Percentage increase in fresh weight over conventional ploughing resulting from subsoil loosening: Trench experiment.

<table>
<thead>
<tr>
<th></th>
<th>1978</th>
<th>1979</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad bean (pods)</td>
<td>22</td>
<td>63</td>
</tr>
<tr>
<td>Cabbage (total)</td>
<td>18</td>
<td>32</td>
</tr>
<tr>
<td>Leek (total)</td>
<td>8</td>
<td>17</td>
</tr>
<tr>
<td>Red beet (beetroot)</td>
<td>8</td>
<td>22</td>
</tr>
</tbody>
</table>

- 53 -
Table 2. Percentage increase in fresh weight over conventional ploughing resulting from subsoil loosening and deep incorporation of fertilizer: Double digger (DD) experiment.

<table>
<thead>
<tr>
<th></th>
<th>1977</th>
<th>1978</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DD</td>
<td>DD plus</td>
</tr>
<tr>
<td>Broad bean (pods)</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>Cabbage (total)</td>
<td>28</td>
<td>14</td>
</tr>
<tr>
<td>Potato (marketable)</td>
<td>19</td>
<td>28</td>
</tr>
<tr>
<td>Red beet ('beetroot')</td>
<td>33</td>
<td>18</td>
</tr>
</tbody>
</table>

SOIL PROPERTIES

Trenching and double digging reduced penetration resistance (Fig.1) and bulk density (1.55 → 1.32 g cm⁻³) and increased air-filled porosity at 'field capacity' (10% → 24%). Loosening had little effect on water retention but there was some evidence that drainage was improved. However, the latter was considered of little importance during the summer cropping period of these experiments.

![Penetration resistance](image)

ROOT DISTRIBUTION

Subsoil loosening consistently increased the rate of root extension, rooting depth and total root length (Fig.2) although measurements of penetration resistance (Fig.1) and visual inspection revealed no distinct cultivation pan or obvious signs of root impediment in the unloosened soil.

Double digging increased root proliferation below the depth (45 cm) of loosening, presumably because roots penetrated rapidly to the boundary between loosened and unloosened soil thereby increasing the chance of them finding a few coarse pores which penetrate to depth.
Fig. 2 Root distribution of broad beans, 29 and 79 days after 50% emergence, growing in loosened (-----) and unloosened (——) soil.

WATER UPTAKE

With all crops examined, subsoil loosening increased the rate of water uptake at depth and reduced it in the plough layer (Fig. 3). The lower rate of topsoil drying on the loosened soil may result in improved nutrient mobility and nutrient uptake.

Fig. 3 Water removal by broad beans; loosened — —, ploughed ———.

PLANT WATER STRESS

Improvements in water uptake on the loosened soil were reflected, during dry spells, by reductions in plant water stress as indicated by measurements of stomatal conductance and leaf water potential (Table 3).
Table 3. Effects of subsoil loosening on stomatal conductance and leaf water potential of broad beans in 1977: Trench experiment.

<table>
<thead>
<tr>
<th>Time (GMT)</th>
<th>Cultivation</th>
<th>Stomatal conductance (cm sec(^{-1}))</th>
<th>Leaf water potential (bar, -ve)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0853</td>
<td>Ploughed</td>
<td>0.17</td>
<td>11.9</td>
</tr>
<tr>
<td>1031</td>
<td>Ploughed</td>
<td>0.19</td>
<td>14.5</td>
</tr>
<tr>
<td>1129</td>
<td>Ploughed</td>
<td>0.13</td>
<td>12.9</td>
</tr>
<tr>
<td>1325</td>
<td>Ploughed</td>
<td>0.18</td>
<td>15.4</td>
</tr>
<tr>
<td>1434</td>
<td>Ploughed</td>
<td>0.10</td>
<td>14.9</td>
</tr>
<tr>
<td></td>
<td>Loosened</td>
<td>0.37</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>Loosened</td>
<td>0.38</td>
<td>6.8</td>
</tr>
<tr>
<td></td>
<td>Loosened</td>
<td>0.41</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>Loosened</td>
<td>0.45</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>Loosened</td>
<td>0.42</td>
<td>9.7</td>
</tr>
</tbody>
</table>

**PREDICTION OF RESPONSE**

The data suggest that the increases in yield obtained by subsoil loosening were due to reductions in plant water stress following increased rates of root extension. Crop response is likely, therefore, to vary from year to year depending on whether water uptake is improved by a deeper root system. A simulation model of crop water extraction (Rowse et al., 1978) was used to test the effect of altering the root distribution of broad beans given different weather conditions (Rowse & Barnes, 1979). In all but the wettest years, a deeper root system than that measured on the unloosened soil was found to increase water uptake. Surprisingly, only ~2% of the roots were required below 50 cm to increase uptake by 30% above that achieved when all the roots were above 50 cm.

An indication of those soils likely to benefit from deep loosening might be given by simple measurements of soil strength since it is known that root elongation is impeded by high mechanical resistance. In our trench experiment, yield decreased with increasing mean penetration resistance of the subsoil, as measured at 'field capacity' using a penetrometer having a 1 cm\(^2\) 60\(^\circ\) relieved cone. With each crop, and in both years, yield was little affected up to a resistance of about 125 N cm\(^{-2}\) but at greater resistances yield was often severely reduced. It is premature to suggest that this relationship may have broad applicability without further testing. However, work elsewhere (Gooderham, 1977) suggests that the relationship between root elongation and penetration resistance is not only similar between crop species (tomato, ryegrass, pea) but also for unstructured soils of contrasting texture.

**DISCUSSION**

Clearly, thorough subsoil loosening is a potentially important means of improving soil productivity. Yields in our experiments were increased by up to 75%, even on a soil showing no obvious signs of compaction.
and in which roots normally penetrated to at least 0.7 m. While it may be uneconomic to recommend loosening to the full depth of root penetration, shallower working, perhaps to 40-45 cm, would appear to be sufficient to enable a few roots to penetrate rapidly to greater depth. Machinery exists capable of effectively loosening soil to this depth. The Wye double digger in its prototype single-furrow version is, perhaps, too slow for commercial application, but a two-furrow model is at an advanced stage of design. Modern multi-tined, winged subsoilers (Spoor & Godwin, 1979) also look promising, and are being compared with the Wye machine at several centres in the UK.

There is an urgent need to define the degree of loosening necessary for adequate root penetration. Over-cultivation is not only wasteful of energy but it may also render the soil more liable to recompaction by subsequent traffic. The benefits we obtained persisted for at least 4 years when the soil conditions were good but were lost when subsequent ploughing was carried out under adverse conditions. Current work is examining the longevity of the effect under conventional and minimum tillage systems. Although the first year of this experiment was too wet to expect a response to deep loosening, minimum tillage gave as high yields as ploughing and, combined with beds, would have allowed earlier drilling. It may be that deep loosening followed by minimum tillage and bed systems could be a useful means of increasing yields and improving timeliness of planting and harvesting.

REFERENCES
Gooderham, P.T., 1977 Agric. Prog. (Shrewsbury), 52: 33-44
MAFF, 1979 Statistical information, Irrigation England and Wales; Special enquiry 1978
Spoor, G. & Godwin, R.J., 1979 Proc. 8th Conf. ISTRO pp 353-358
Stone, D.A. 1982 J. Agric. Sci. (Camb), in the press
AMELIORATIVE TILLAGE IN THE NORTHWESTERN CORN BELT OF THE UNITED STATES

Ward B. Voorhees

United States Department of Agriculture, Agricultural Research Service, Morris, Minnesota, U.S.A.

Abstract

The Corn Belt area of the United States is mostly situated north of the 37th north parallel, and generally is subjected to freezing soil temperatures to a depth of at least 30 cm. In the northeastern part of the Corn Belt, soils usually are annually frozen to deeper depths, and it was commonly assumed that such action would ameliorate seasonal soil compaction. Field studies in Minnesota show that freezing and thawing only partially ameliorate compacted soil. Autumn tillage may be more effective depending on the kind of tillage.

Introduction

Soil compaction caused by the wheel traffic of agricultural farm machinery is an increasing concern throughout the United States. The extent of compaction caused during one growing season using common field management practices can be considerable (Voorhees et al., 1978). Soils in the northwestern Corn Belt are commonly moldboard plow in the autumn, and farmers generally assume that this tillage, plus freezing and thawing, ameliorates all compaction. However, field studies by Blake et al. (1976) demonstrated the limitations of natural weathering forces and cultural practices in alleviating a compacted plow pan. Field studies also show that tillage can produce both a loosening and compactive effect on soil depending on soil water content and soil texture (Allmaras et al., 1966) and kind of tillage operation (Voorhees et al., 1981).

Two current trends in farming practices require an evaluation of the relative effectiveness of tillage and natural forces in alleviating soil compaction. Firstly, is the trend towards larger and heavier farm tractors and machinery and its potential to increase both the intensity and depth of wheel-induced soil compaction. Secondly, increased use of no-till or minimum tillage systems puts more emphasis on natural forces to keep this compaction from persisting and accumulating to levels that are damaging for crop production. This paper describes the effectiveness of natural forces to alleviate soil compaction during the winter off-season in the presence and absence of autumn tillage.
Methods

Wheel traffic from all field operations on a series of plots 18.3 m wide x 47.3 m long was controlled to occur in the same path since 1973. The soil type was a Nicollet silty clay loam in southwestern Minnesota. Each year, a total of six field operations were performed with tractor weight ranging from 3,700 to 7,300 kg, depending on the operation being done. At the end of the growing season, bulk density and penetrometer resistance measurements were made to a depth of 60 cm to determine the amount of compaction at the end of the growing season.

Beginning in the autumn of 1977, each plot was divided into two parts. One part was either moldboard plowed, chisel plowed, or tandem disked. The other part did not receive any autumn tillage. The following spring, before any additional field operations were performed, bulk density and penetrometer resistance measurements were again taken to determine the amount of amelioration over winter. Soil water content was also measured in both the spring and autumn. Since penetrometer resistance is sensitive to soil water content, and because the soil water content did change between autumn and the following spring, the penetrometer data was adjusted to a common water content at each given depth. This was done from logarithmic relationships between penetrometer resistance and gravimetric water content for various classes of bulk density. The adjusted penetrometer resistance values are thus indicative of real changes in the physical nature of the soil. Bulk soil samples were also collected for determination of aggregate size and clod density. All of the above measurements were made in both the plot areas compacted by wheel traffic and the plot areas where there was no wheel traffic. While depth of frost was not measured on these plots, adjacent weather station measurements indicate annual frost penetration from 1 to 1.5 meters. Only the surface few cm go through more than one freeze-thaw cycle during the winter.

Results

The data for the winter of 1979-1980 is shown and is typical of the results from the other years. There was no difference between autumn chisel plowing and autumn diskling and therefore these two treatments were averaged together and are referred to as "reduced tillage." Bulk density values are shown in Table 1. The data in column (A) is the bulk density of the compacted wheel tracked soil before autumn tillage, October 1979. Column (B) is data taken the following spring (April 1980) and was taken in the autumn tilled portion of the compacted wheel tracked soil, and reflects the combined effects of natural amelioration and autumn tillage. Column (C) is data also taken the
Table 1. Bulk density as affected by natural weathering forces and autumn tillage, October 1979-April 1980.

<table>
<thead>
<tr>
<th>Depth, cm</th>
<th>October 1979</th>
<th>April 1980</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(A) wheel track</td>
<td>(B) tilled WT</td>
</tr>
<tr>
<td>0-7.5</td>
<td>1.63</td>
<td>1.23</td>
</tr>
<tr>
<td>7.5-15</td>
<td>1.63</td>
<td>1.31</td>
</tr>
<tr>
<td>15-22.5</td>
<td>1.57</td>
<td>1.37</td>
</tr>
<tr>
<td>22.5-30</td>
<td>1.57</td>
<td>1.61</td>
</tr>
<tr>
<td>30-45</td>
<td>1.56</td>
<td>1.61</td>
</tr>
<tr>
<td>45-60</td>
<td>1.58</td>
<td>1.63</td>
</tr>
</tbody>
</table>

Moldboard Plow

<table>
<thead>
<tr>
<th>Depth, cm</th>
<th>October 1979</th>
<th>April 1980</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(A) wheel track</td>
<td>(B) tilled WT</td>
</tr>
<tr>
<td>0-7.5</td>
<td>1.63</td>
<td>1.41</td>
</tr>
<tr>
<td>7.5-15</td>
<td>1.63</td>
<td>1.55</td>
</tr>
<tr>
<td>15-22.5</td>
<td>1.53</td>
<td>1.53</td>
</tr>
<tr>
<td>22.5-30</td>
<td>1.53</td>
<td>1.47</td>
</tr>
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<td>30-45</td>
<td>1.52</td>
<td>1.53</td>
</tr>
<tr>
<td>45-60</td>
<td>1.57</td>
<td>1.58</td>
</tr>
</tbody>
</table>

Reduced Tillage

<table>
<thead>
<tr>
<th>Depth, cm</th>
<th>October 1979</th>
<th>April 1980</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(A) wheel track</td>
<td>(B) tilled WT</td>
</tr>
<tr>
<td>0-7.5</td>
<td>1.63</td>
<td>1.41</td>
</tr>
<tr>
<td>7.5-15</td>
<td>1.63</td>
<td>1.55</td>
</tr>
<tr>
<td>15-22.5</td>
<td>1.53</td>
<td>1.53</td>
</tr>
<tr>
<td>22.5-30</td>
<td>1.53</td>
<td>1.47</td>
</tr>
<tr>
<td>30-45</td>
<td>1.52</td>
<td>1.53</td>
</tr>
<tr>
<td>45-60</td>
<td>1.57</td>
<td>1.58</td>
</tr>
</tbody>
</table>

*h.s.d. (honest significant difference, Steel and Torrie, 1960). The difference between treatment means must exceed the h.s.d. to be considered significantly different.

Following spring but where there was no autumn tillage of the compacted wheel tracked soil, and therefore represents just natural amelioration, mainly freezing and thawing. Curve (D) is the portion of the plot where there was no wheel traffic and represents the least compacted condition against which the other three treatments are compared. Results are shown for both moldboard plowing and reduced tillage.

Natural forces alone had little effect on reducing wheel track bulk density on either the moldboard plow or conservation tillage plots (compare columns "A" and "C"). The only real amelioration was limited to the surface 7.5 cm. Autumn moldboard plowing significantly ameliorated the compacted wheel track to the extent that its bulk density was lower than the nontracked and soil compare (columns "B" and "D"). This effect was limited to the depth of tillage, about 25 cm.

The ameliorative effects of conservation tillage were not as extensive as moldboard plowing, with bulk density reduction noted only in the surface 7.5 cm
of soil (columns "D" and "B"). Reduced tillage was only slightly more effective than natural weathering (compare columns "B" and "C" with "D").

Penetrometer resistance is shown in Table 2 and is in the same format as the bulk density data. Collectively, this data show that natural weathering alone reduced penetrometer resistance by roughly 50% (compare columns "A" and "C"). This contrast with bulk density data which showed little amelioration from weathering. Freezing and thawing, along with some wetting and drying, creates microfracture planes which would affect a fabric strength type of measurement, such as penetrometer resistance, more than a total porosity type of measurement such as bulk density.

Table 2. Penetrometer resistance as affected by natural weathering and autumn tillage, October 1979-April, 1980.

<table>
<thead>
<tr>
<th>Depth, cm</th>
<th>October 1979 (A) wheel track</th>
<th>April 1980 (B) tilled WT</th>
<th>(C) untilled WT</th>
<th>(D) tilled NWT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-7.5</td>
<td>3205</td>
<td>228</td>
<td>1369</td>
<td>251</td>
</tr>
<tr>
<td>Moldboard Plow</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.5-15</td>
<td>2100</td>
<td>367</td>
<td>594</td>
<td>364</td>
</tr>
<tr>
<td>22.5-30</td>
<td>1095</td>
<td>312</td>
<td>524</td>
<td>286</td>
</tr>
<tr>
<td>30-45</td>
<td>1383</td>
<td>384</td>
<td>698</td>
<td>493</td>
</tr>
<tr>
<td>45-60</td>
<td>1361</td>
<td>1051</td>
<td>833</td>
<td>959</td>
</tr>
<tr>
<td>Reduced Tillage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-7.5</td>
<td>2710</td>
<td>562</td>
<td>1129</td>
<td>177</td>
</tr>
<tr>
<td>7.5-15</td>
<td>2500</td>
<td>943</td>
<td>847</td>
<td>369</td>
</tr>
<tr>
<td>22.5-30</td>
<td>1655</td>
<td>1002</td>
<td>1018</td>
<td>711</td>
</tr>
<tr>
<td>30-45</td>
<td>1655</td>
<td>1039</td>
<td>1206</td>
<td>981</td>
</tr>
<tr>
<td>45-60</td>
<td>1589</td>
<td>1039</td>
<td>1118</td>
<td>902</td>
</tr>
</tbody>
</table>

Moldboard plowing essentially alleviated all compaction to a depth of about 25-30 cm (compare columns "A", "B" and "D"). Reduced forms of tillage were less effective and ameliorated compacted soil only slightly more than natural weathering (compare column "B" with column "C"). The reduced form of tillage was performed to a depth of about 20 cm, but was effective only in the surface 7.5 cm. It appears that the initial loosening expected in the autumn
with reduced tillage was not very stable due to perhaps raindrop impact and reconolized over the winter. Moldboard plowing results in larger structural units that apparently do not slake down as much over winter and resulted in a net loosening effect.

The above data show ameliorative effects of tillage and natural forces on the "bulk" compaction. Individual soil structural units are not so easily altered. Table 3 shows the density of individual soil clods about 5 cm in diameter. The density was measured in the spring after the soil had been autumn tilled and subjected to over-wintering. Clods from the wheel tracked area remained more dense than the noncompacted clods regardless of kind of tillage, or weathering.

Table 3. Clod density as affected by natural weathering, fall tillage, and wheel traffic, measured April 1978, before any spring tillage.

<table>
<thead>
<tr>
<th>Clod density, g/cm⁻³</th>
<th>Reduced tillage</th>
<th>Moldboard plow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheel track, no autumn tillage</td>
<td>1.67</td>
<td>1.65</td>
</tr>
<tr>
<td>Wheel track, autumn tillage</td>
<td>1.62</td>
<td>1.61</td>
</tr>
<tr>
<td>No wheel track, no autumn tillage</td>
<td>1.46</td>
<td>1.47</td>
</tr>
<tr>
<td>No wheel track, autumn tillage</td>
<td>1.43</td>
<td>1.48</td>
</tr>
</tbody>
</table>

h.s.d. at 5% = 0.04
h.s.d. at 1% = 0.06

Summary
1. Natural weathering forces alone reduced penetrometer resistance in the surface 30 cm by roughly 50%, but had little effect on bulk density.
2. Moldboard plowing in the autumn, in conjunction with natural weathering reduced both bulk density and penetrometer resistance to essentially the same level as the nontrafficked soil.
3. A reduced form of autumn tillage was less effective than moldboard plowing, and only slightly more effective than natural weathering alone.
4. Individual soil structure units remained dense and compacted in spite of weathering and tillage.

These conclusions have several important implications. In the United States, reduced tillage gives the benefit of erosion control and energy conservation in
much of the Corn Belt area. However, if natural weathering, especially freezing and thawing, are not very effective in ameliorating compacted soil, some of the conservation tillage practices may eventually lead to increased erosion. The data indicates that conservation tillage may not be a very effective way of ameliorating a compacted soil, but may be an effective way of maintaining a desired state of tilth if detrimental effects of wheel traffic are minimized or controlled.

Some effects of soil compaction may be subtle and not have any apparent serious practical consequences such as clod density. However, if clods remain dense for several seasons (as data suggests), or increase in number, eventually seedbed preparation problems may be encountered.

Ameliorative tillage, such as moldboard plowing to 30 cm, may become too expensive in terms of energy and soil erosion. This puts more emphasis on the need to avoid soil compaction in the first place.

**Literature Cited**


Research and experience with mechanical soil improvement in the Netherlands

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Abstract. Some statements are given derived from research and experience with soil improvement.

INTRODUCTION

A lot of experience from mechanical soil improvement has been obtained in the Netherlands. However, the yields per ha in the Netherlands belong to the largest in the world, many farmers are nevertheless not content about their soils. They consider their land too wet in wet periods and too dry in dry periods or even both. Since ages farmers have tried to improve soil conditions for plant growth, with more or less success, sometimes even negative success. The improved area was limited by the fact that most work had to be done by hand digging.

Powerful tractors opened far more possibilities in the last decades. Many soil improving machines were developed, to crash soil layers, to turn or to mix the soil profile or to loosen the soil.

These machines have been applied in practice both for private farmers and on state-owned land. A number of experimental fields were made with and without the improvement or with improving by different machines. From the results in practice and in research farmers and agricultural advisers learned what to do or not to and how to do. They also learned about the quantitative effect on yields of different crops and how this depends on the weather conditions.

Much of this experience has universal value but also much of it is confined in its applicability to the special conditions of soils and climate in the Netherlands. This paper deals with some general aspects; because these cover a fairly wide range of problems and the length is confined, some statements are given with a short explanation.
EXECUTION OF SOIL IMPROVEMENT

Although a complete review of machines used in soil improvement cannot be given in this paper, a short description of the machines in use cannot be missed. Basically there are two types of machines, loosening machines or rooters and profile turning machines or deep-plows. The first are used to increase water- and airpermeability and to decrease mechanical impedance for root growth. Deep-plows are used to change the soil profile, e.g. to replace a sandy top soil by a loamy one or a peat top soil by a sandy layer.

Both machine types developed into soil mixing machines in the last decades, because mixed soils appeared to have more stability than simply loosened soils and are a better root environment than layered profiles.

So the sharp rooter developed via the wide rooters into the mixing rooters. The turning plow developed into a tool which gives a rough mixture of the layers in the soil profile. At last machines were constructed which were intermediate between rooters and deep-plows. They can make conservative mixtures, where the majority of soil particles, originally lying in the top soil remain in the top soil. But they can also make revolutionary mixtures where the reverse holds. Also, proportional mixtures can be made by these machines.

The mixtures made by the rooter-plow machines are fairly rough; they consist of fairly big lumps of different soil layers scattered through the soil profile. Sometimes this is better than a fine mixture, which can be made by rotating machines.

Statement 1
Soil improvement to avoid or decrease drought damage is more effective than to avoid waterlogging.

In climates with a positive surplus of rainfall over evaporation in autumn and winter, a low surplus in spring and a negative surplus in summer, all crops can be affected by drought in summer. Only winter crops are affected by waterlogging.

Moreover, mostly waterlogging is caused by insufficient drainage. Very seldom a low water conductivity causes too wet conditions. By increasing permeability the amount of water which has to be discharged by sub surface drainage increases with the amount originally discharged by surface-run-off. From this the loosened soil is wetter in spring than the original soil which causes delay in seedbed preparation.

The results of a practical experiment to prove the validity of this statement for a soil improvement are given in table 1. Because of different opinions about the working of soil improvement in this place, a sprinkler irrigation ex-
experiment was made over the experimental field for soil improvement.

Table 1. Yield of winterwheat in kg grains per ha on a soil improvement experimental field at Borgercompagnie with and without sprinkling in 1964.

<table>
<thead>
<tr>
<th></th>
<th>Non irrigated</th>
<th>Irrigated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero treatment</td>
<td>4570</td>
<td>5280</td>
</tr>
<tr>
<td>Improved by deep-plowing</td>
<td>5220</td>
<td>5160</td>
</tr>
</tbody>
</table>

The wheat did apparently not react on soil improvement when enough moisture was available in summer. Nevertheless, the original soil contained a nearly impermeable peat layer.

Very seldom we have seen any positive effects of experiments to increase water permeability of soils.

Statement 2

Loosening of soil does not always cause lower bulk densities; it can even cause compaction if the conditions are unfavourable.

Every mechanical loosening of soil has a decrease of mean bulk density as immediate effect. This immediate effect is only temporary. It is followed by a subsidence sooner or later. After certain time, this stops and a new equilibrium has been reached. Ameliorationists hope that the bulk density then is lower than it was originally.

![Graph of change in bulk-density by sub-soiling](image)

**Fig. 1.** Change of bulk-density caused by rooting as related to the original bulk-density.
But this hope will only be fulfilled if the causes of the originally high bulk density are removed, or if the process of compaction lasts very long. If the high bulk density was caused by heavy farm traffic, the same compaction will return after loosening unless the traffic pressures are decreased.

By rooting, deep-plowing or mixing all large pores originating from plant- or animal action, are destroyed. The new bulk density and permeability can be worse than the original. Every soil has an equilibrium density, determined by its composition and environmental conditions as groundwater, climate and loads. A soil looser than this equilibrium should not be loosened, as is shown in fig. 1 from Boels and Havinga (1974).

Statement 3
If drainage is insufficient, loosening of soil can be disastrous.

In many places it has been observed that loosened land became wetter than it had been ever before. Mostly the farmer had his land loosened because it was too wet; he considered his land too dense, so a loosening should solve the problem. In the first winter it seemed that the loosening was the correct amelioration. The land is less wet than it has been in former winters. But in the second and following winters there is more ponding than before loosening and especially in spring it lasts very long before the land is workable for seedbed preparation.

The real cause of original wetness is not the density of the soil but a very poor drainage. By loosening the drainage is not improved, but the water storage capacity is increased in the loose soil. Therefore the land looks less wet in the first winter. In reality there is more moisture present than before loosening. A part of the unstable loose soil is fully saturated. This causes a subsidence. Falling solid material causes water to rise, which makes the soil wetter, which causes more subsidence.

This results in a situation in which the land is saturated to its surface. The amount of subsidence then equals the amount of drainage discharge. So even without rain the land remains wet. Only late in spring when evaporation removes much water the land becomes workable.

This lasts until the subsidence stops when the new equilibration bulk density has been reached, mostly after 3 to 4 years. In many cases the soil then is denser than before loosening.

If drainage is sufficient also some subsidence occurs but that is not amplified by very wet conditions.
Statement 4
Although yield increase by deeper rooting caused by soil improvement theoretically can be forecasted, the results in reality are often not in agreement with this theory.

The yields are nearly proportional to the actual evapotranspiration of the crops. If a soil after improvement contains more accessible moisture than before actual evapotranspiration can be increased by the improvement. This depends on the precipitation and potential evapotranspiration in the growing season. The yield increase should then be proportional to the increase in actual evapotranspiration.

This means that the effect of soil improvement differs each year, being sometimes even negative because of loss of fertility.

![Graph](image-url)

Fig. 2. Extra grain yield of oats obtained by deep plowing in 13 years in dependence of rainfall (P) and evaporation (Eo). Line calculated through the points (-----) and theoretically expected (------)

But even if this variance in weather is taken into account, the observed yields, and yield increases, differ from the expected ones. Fig. 2 and 3 give examples of this. In fig. 2 there is still a relation between extra yield of grains and the evaporation surplus, although it differs from the expected relation. In fig. 3 there seems to be no relation at all.

There can be many causes for this discrepancy, mostly related to the behaviour of soils and nitrogen. Weather and soil conditions in spring can be more or less good for rooting in the treated or control soil. Nitrogen can be leached by rain in winter or spring being only available for deep rooting crops. In dry summers the control soil can become so dry that the nitrogen which is
present is no longer available. The improved soil is getting less dry; nitrogen remains available and the extra yield is much higher than is expected. Also plant diseases can have influences which are not the same on the crops of treated and control soil.

Fig. 3. There is hardly any relation between summer-drought and the extra yields of potatoes and sugarbeets obtained by deepplowing.

Statement 5
Mechanical improvement of soils in which peat is present can have very good results; by decomposition of peat however, negative effects can occur.

Mostly the main effect of soil improvement is deeper rooting of the crops. Deeper rooting means more available moisture. The amount of extra accessible moisture depends on the properties of the soil. If this is sand the gain in moisture in only poor. But it can be very large if the high moisture contents of peat are made accessible for the roots. Therefore mechanical soil improvement of soils containing peat has often very good results.

Nevertheless the actual results can be disappointing because decomposition of peat can disturb the root environment. By increased pH and higher air contents a biochemical oxidation of the peat is started, which can decrease oxygen contents to zero. Moreover, the oxidation of oligotrophic moss peat needs supply of some nitrogen which is not available for the crop then.

In mixing acid peat with soil layers having a higher pH a coarse mixture is therefore preferable. In a coarse mixture there are less contact surfaces where pH is increased than in fine mixtures and hence there will be less decomposition of the peat. Table 2 gives an example of this in a long lasting field experiment.
Herein the yield increases are determined at the optimal level of nitrogen fertilizing, which was very high for the fine mixture in the first years.

Table 2. Average yield increase by mixing a profile consistent of 20 cm humous sand (pH-KCl 5.1) on 40 cm moss peat (pH 2.7) and 30 cm sand.

<table>
<thead>
<tr>
<th></th>
<th>Coarse mixture</th>
<th>Fine mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1964 - 1973</td>
<td>+ 15.5</td>
<td>- 4.5</td>
</tr>
<tr>
<td>1974 - 1981</td>
<td>-----</td>
<td>+ 16.2</td>
</tr>
</tbody>
</table>

In 1964 the C/N ratio was 71 in the fine mixture. In 1973 when the negative yield increases suddenly were replaced by positive ones, the C/N ratio had decreased to 25. Apparently the decomposition of peat had come to its end. But the loss of yield in the first 10 years did cost more than the execution of the mixing.

LITERATURE


2. REDUCED AND ZERO TILLAGE
A study was initiated in 1978 at the Ife (Nigeria) University Teaching and Research Farm on the effects of tillage and 2 seedbed configurations with and without mulch on soil physical properties and production of cassava (Manihot esculenta), cowpea (Vigna unguiculata L. Waep), and Maize (Zea mays L.) on an Oxic Paleustalf.

No-tillage treatment with crop residue mulch was superior in terms of more favourable soil temperature and bulk density, greater soil moisture reserve and more stable structure but inferior without surface mulch compared to ridge and mound cultivation. With the exception of cassava that had 13, 20 and 40% reductions in yield in subsequent years, no-tillage gave consistently higher crop yields. Maize was more responsive to tillage than cowpea which appears to be more preferentially susceptible to insect damage on the no-tillage plots. Ridge and mound cultivations were not significantly different with respect to soil and crop responses.
INTRODUCTION

The southwestern region of Nigeria lies approximately between longitudes 3 and 6° E and latitudes 6 and 8°N. Ife, the site of the experiment is in the lowland rainforest with an annual rainfall of over 1200mm that is bi-modally distributed in a way to give 2 cropping seasons annually. Alfisols formed from Pre-cambrian granite and gneiss are most predominant here and used extensively for arable cultivation.

Planting on ridges mounds and occasionally on flat cultivated land are used uncritically by farmers as standard procedures in annual crop husbandry. Information on the influence of tillage and seedbed preparation methods on soil and crops is limited. Comparisons of such studies (Ezedinma, 1964; Kowal and Stockinger, 1963; and Lal, 1973) have shown much variability from study to study. A farming system that permits minimal tillage operations however may be getting increasing concern considering the poor structural development and rapid deterioration (Aina, 1979) of the soils under cultivation. The objective of this study was to determine the effects of no-tillage, ridge and mound seedbed configurations on soil and responses of cassava, cowpea and maize.

MATERIALS AND METHODS

The study was conducted for 3 consecutive years (1978-1980) at the Ife University Teaching and Research Farm. Maize (Zea mays L. var. "FARZ 27"), cowpea (Vigna unguiculata L. Wasp. var. "Ife Brown) and cassava (Manihot esculenta var. "Isunikanikyan") were grown on experimental plots of 5m by 10m with and without mulch and the following treatments in a split-split plot design with 3 replications: (i) No-till with planting done in unplowed land, (ii) tillage with manually prepared ridges 40cm high and 45cm wide 1m row spacing and (iii) tillage with manually prepared mounds or hills, 40cm high, 45cm base width and 100- and 50- cm between- and within-row spacings, respectively. Mulched plots received 25kg crop residue each at planting.

The soil, classified as clayey skeletal, kaolinitic,
...isohyperthermic Oxic Paleustalf was freshly opened from a 15-year bush regrowth and on a land slope of 8%.

First and second cropping seasons plantings were done in April and September each year respectively, for maize and cowpea at 1m by 50cm spacing (reflecting spacings of mounds). Cassava was planted once a year in April at 1m by 1m spacing. Fertilizer was applied by side-dressing at rates of 120kg/ha N in 2 split applications, 26kg/ha P and 30kg/ha K for maize, 26kg/ha P and 30kg/ha K for cowpea and 20kg/ha P, 30kg/ha K for cassava at planting.

The following determinations described elsewhere (Aina, 1979) were made periodically on all plots: seedling emergence, plant growth rate and crop yields, soil particle size analysis, soil moisture content, bulk density, soil temperature at 0800, 1200 and 1500 hours, total and air-filled porosity, aggregation and p.i., organic carbon, Bray-P and exchangeable cations.

RESULTS AND DISCUSSIONS

Soil Properties

Particle Size Distribution - Changes in soil particle size distribution (Table 1) indicate that tillage decreased (P<0.05) contents of fine particles in the 0-7cm depth. Results vary depending on crop and mulching treatments, reflecting the relative exposure of soil to raindrop dispersive action.

Soil Structure - Stability of soil aggregates was generally low (Table 2). Aggregation and water stability decreased rapidly due to tillage; by about 2 folds in 3 years. Mulching slightly reduced the rate of deterioration in tilled plots.

Table 1-Particle size distribution of 0-7cm soil depth at the start and 36 months after initiating the experiment.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Sand %</th>
<th>Silt</th>
<th>Clay %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>64.9</td>
<td>17.1</td>
<td>17.5</td>
</tr>
<tr>
<td>No-tillage Mulched</td>
<td>66.7</td>
<td>16.8</td>
<td>16.6</td>
</tr>
<tr>
<td>Unmulched</td>
<td>71.6</td>
<td>15.3</td>
<td>13.1</td>
</tr>
<tr>
<td>Ridge     Mulched</td>
<td>69.6</td>
<td>15.8</td>
<td>14.6</td>
</tr>
<tr>
<td>Unmulched</td>
<td>73.6</td>
<td>12.4</td>
<td>12.0</td>
</tr>
<tr>
<td>Mound     Mulched</td>
<td>72.5</td>
<td>13.6</td>
<td>13.9</td>
</tr>
<tr>
<td>Unmulched</td>
<td>76.7</td>
<td>12.1</td>
<td>11.2</td>
</tr>
</tbody>
</table>
Bulk Density - Tillage resulted in soil compaction irrespective of whether soil was mulched or not (Table 3). Results suggest a significant influence of gravitational settling of loosened (due to tillage) soil particles upon wetting by rainfall as a major factor of compaction due to characteristically low structural stability of the soil.

Table 2 - Mean weight diameter of water stable aggregates (>2mm) of the 0-7cm layer at different times during the experiment. Values are averaged over cropping treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Time, months</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>No-tillage</td>
<td>Mulched</td>
<td>3.1</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>Unmulched</td>
<td>2.8</td>
<td>2.2</td>
</tr>
<tr>
<td>Ridge</td>
<td>Mulched</td>
<td>2.6</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>Unmulched</td>
<td>2.9</td>
<td>1.7</td>
</tr>
<tr>
<td>Mound</td>
<td>Mulched</td>
<td>2.9</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>Unmulched</td>
<td>2.6</td>
<td>1.5</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>ns</td>
<td>0.4</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 3 - Soil bulk density of the 0-7cm depth at different times during the experiment. Values averaged over cropping treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Time, months</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>No-tillage</td>
<td>Mulched</td>
<td>1.15</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>Unmulched</td>
<td>1.13</td>
<td>1.37</td>
</tr>
<tr>
<td>Ridge</td>
<td>Mulched</td>
<td>1.09</td>
<td>1.36</td>
</tr>
<tr>
<td></td>
<td>Unmulched</td>
<td>1.05</td>
<td>1.45</td>
</tr>
<tr>
<td>Mound</td>
<td>Mulched</td>
<td>1.05</td>
<td>1.38</td>
</tr>
<tr>
<td></td>
<td>Unmulched</td>
<td>1.07</td>
<td>1.44</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.06</td>
<td>0.08</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Porosity - Reduction in porosity due to tillage was at the expense of the air-filled porosity. Ridge or mound cultivation resulted in 75% and 25% less in air-filled and total porosity respectively, from initial corresponding values of 57% and 35%
compared to 15% and 5% less in air-filled and total porosity values, respectively under no-tillage over a 36-month period.

Soil Moisture Storage - Soil moisture contents were higher in no-tillage plots than in ridges and mounds particularly in the 0-15 cm depth. The difference between ridge and mound configurations was not significant. The differences due to tillage treatments were as high as 5% and more significant with maize and cassava than cowpea and without mulch during periods of low rainfall.

Soil Temperature - First cropping seasons had higher temperature amounts (averaging 38°C on bare soil) and amplitudes than the second seasons. Ridge and mound configurations showed no significant difference in soil temperature at 5 cm depth but had higher temperatures compared to no-tillage plots. Differences due to tillage were as high as 9°C for cassava, 7°C for maize and 4°C for cowpea 3 weeks after planting in the first season.

Chemical Properties - The chemical fertility of the soil generally declined with time but more rapidly with tillage than with no-tillage (Table 4). The most affected constituent was organic carbon which declined by over two-thirds and by less than one-fifth in plowed plots and no-tillage plots, respectively over a 36-month period. Tillage also resulted in significant losses of P. The higher P contents of no-tillage plots are due to fertilizer addition.

Table 4 - Changes in some chemical properties of the 0-10 cm soil depth at the start and 36 months after initiating the experiment. Values are averaged over cropping treatments.

<table>
<thead>
<tr>
<th>Soil property</th>
<th>Initial</th>
<th>No-tillage</th>
<th>Ridge</th>
<th>Mound</th>
<th>LSD (0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>NM</td>
<td></td>
<td>M</td>
</tr>
<tr>
<td>pH</td>
<td>6.0</td>
<td>6.2</td>
<td>5.8</td>
<td>5.8</td>
<td>5.7</td>
</tr>
<tr>
<td>Organic C %</td>
<td>2.16</td>
<td>1.9</td>
<td>1.2</td>
<td>1.6</td>
<td>0.8</td>
</tr>
<tr>
<td>Bray-1 P ppm</td>
<td>20</td>
<td>29</td>
<td>15</td>
<td>21</td>
<td>14</td>
</tr>
<tr>
<td>Exch. Ca me/100g</td>
<td>8.2</td>
<td>3.9</td>
<td>2.9</td>
<td>2.7</td>
<td>2.4</td>
</tr>
<tr>
<td>Mg</td>
<td>1.4</td>
<td>0.7</td>
<td>0.4</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td>K</td>
<td>0.8</td>
<td>0.4</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

"M" refers to mulched and "NM" refers to unmulched conditions of soil surface.
Crop Response

Seedling emergence was improved significantly with tillage only when not accompanied with surface mulch. Results suggest that seedling emergence or sprouting in cassava was more influenced by soil moisture and temperature conditions in the soil. There was no significant difference in emergence due to tillage treatments under mulch. Growth of maize and cassava was however more vigorous on no-tillage plots than on ridges and mounds which showed no significant differences. Tillage produced no significant effect on cowpea growth rate under mulched conditions.

The seemingly low crop yields presented in Table 5 reflect the wide spacings used. Maize consistently yielded more on no-tillage plots compared to ridges and mounds. There was on the average no significant effect on cowpea yield due to tillage after the first cropping year. Cassava yields, on the other hand, were higher on ridges and mounds by about 13, 20 and 40% in subsequent years compared to no-tillage plots. Increases in crop yields due to mulching were more significant with no-tillage than with ridge or mound cultivation. Response of individual crops to tillage was essentially the same for ridge and mound configurations.

Table 5 - Effects of tillage and mulching treatments on crop yields at different times during the experiment.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cassava</th>
<th>Cowpea</th>
<th>Maize</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time, years</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>No-tillage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NM</td>
<td>10.5</td>
<td>8.5</td>
<td>6.0</td>
</tr>
<tr>
<td>Ridge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NM</td>
<td>9.7</td>
<td>6.9</td>
<td>5.9</td>
</tr>
<tr>
<td>M</td>
<td>12.6</td>
<td>10.6</td>
<td>11.1</td>
</tr>
<tr>
<td>Mound</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NM</td>
<td>10.3</td>
<td>8.6</td>
<td>7.9</td>
</tr>
<tr>
<td>M</td>
<td>11.7</td>
<td>9.2</td>
<td>8.4</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>1.9</td>
<td>1.1</td>
<td>1.5</td>
</tr>
</tbody>
</table>

*M* refers to mulched and *NM* refers to unmulched conditions.

+ One crop per year for cassava and total of 2 crops per year for maize and cowpea each.
CONCLUSIONS

No-tillage accompanied with mulch was associated with more favourable soil conditions such as higher soil moisture storage, more favourable soil temperature regimes, higher levels of organic matter, phosphorus and exchangeable bases compared to ridge and mound cultivation. Continuous maize with no-tillage yielded higher than with tillage. Cowpea was less responsive to tillage provided it was grown with surface mulch. No-tillage cassava yielded considerably lower than from ridges and mounds; No-tillage farming is considered unsuitable for cassava production on this soil. No-tillage without mulch was generally inferior to ridges and mounds.

A no-tillage system is desirable for continuous maize and cowpea under the conditions of this study to limit soil deterioration and enhance crop yields.

REFERENCES

SOIL TILLAGE, STUBBLE CROP AND NITROGEN BALANCE.

H.C. Aslyng
Hydrotechnical Laboratory, The Royal Veterinary and Agricultural University, Copenhagen, Denmark.

Abstract
Many long term field experiments with stubble field tillage show that ploughing gives a more stable and a slightly larger grain yield than rotavating. Stubble crop as green manure or straw yield incorporated in the soil has minor influence on grain yield but reduces the nitrogen leaching. A nitrogen fertilized stubble crop should be used for fodder as incorporating in the soil results in an uneconomically large nitrogen loss owing to denitrification.

In Denmark 65% of the agricultural land is used for small grain production and of that area is 85% used for barley. The traditional stubble field tillage has been 6-8 cm shallow ploughing, several harrowings and 20 cm deep ploughing October/November. During the last decades the shallow ploughing has been replaced by stubble cultivating or rotavating. Investigations have been carried out on reduced tillage by omitting also the deep ploughing and on growing a stubble crop for green manure and also on incorporating straw in the soil. There is a combined interest in reduced tillage, soil structure, economic nitrogen use and crop yield.

Reduced tillage
During 6 years (1974-79) 66 tillage experiments with barley have been carried out on 11 state experimental fields with the following results (L. Hansen et al. 1980):

a. Stubble cultivating and 20-25 cm ploughing: 3.9 t ha⁻¹ grain
b. Stubble rotavating 6-8 cm : 3.8 t ha⁻¹ grain

Stubble rotavating gave in average almost the same yield but a yield more varying from year to year than with ploughing. The
reduced yield after rotavating occurred mainly on loamy soil and less on sandy soil. Ploughing should not be omitted continuously.

**Tillage and stubble crop**

During 6 years 36 field experiments with tillage and stubble crop for green manure as mustard (Sinapis alba) to barley have given the following results:

Table 1. Tillage and green manure for barley 1974-79. Yield of grain t ha⁻¹. (L. Hansen et al. 1980).

<table>
<thead>
<tr>
<th>Station</th>
<th>Ploughing, 20-25 cm No mustard</th>
<th>Mustard</th>
<th>Rotavating 5 cm Mustard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jyndevad, irrigated</td>
<td>4.1</td>
<td>4.4</td>
<td>3.9</td>
</tr>
<tr>
<td>Jyndevad (coarse sand)</td>
<td>2.4</td>
<td>2.6</td>
<td>2.3</td>
</tr>
<tr>
<td>Tylstrup (fine sand)</td>
<td>2.7</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td>Roskilde (loam)</td>
<td>4.4</td>
<td>4.3</td>
<td>4.3</td>
</tr>
<tr>
<td>Rønhave (loam)</td>
<td>5.1</td>
<td>5.1</td>
<td>4.8</td>
</tr>
<tr>
<td>Højer (loam)</td>
<td>5.0</td>
<td>5.1</td>
<td>5.2</td>
</tr>
</tbody>
</table>

On coarse sand (Jyndevad) mustard as green manure has increased the yield when ploughed, but not when rotavated into the soil. In all other cases there are no or minor differences due to green manure, ploughing or rotavating.

**Straw incorporation**

Cutting and incorporating in the soil of the 3-4 t barley straw per ha have in 24 experiments during 6 years given the following results:

Table 2. Incorporating of the barley straw 1974-79. Yield of barley grain t ha⁻¹. (L. Hansen et al. 1980).

<table>
<thead>
<tr>
<th>Station</th>
<th>No straw</th>
<th>Straw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jyndevad, irrigated</td>
<td>4.1</td>
<td>4.1</td>
</tr>
<tr>
<td>Askov</td>
<td>3.7</td>
<td>3.7</td>
</tr>
<tr>
<td>Rønhave</td>
<td>5.4</td>
<td>5.3</td>
</tr>
<tr>
<td>Højer</td>
<td>5.4</td>
<td>5.4</td>
</tr>
</tbody>
</table>

There has been no effect on yield of straw incorporating.
Stubble crop and nitrogen balance

A detailed investigation on green manure and nitrogen balance has been carried out on the farm Godthåb at Skanderborg by Hvelplund and Østergaard (1930). They have regularly sampled the soil in layers down to the depth of one meter for determining NO$_3$ and NH$_4$ and water content. They have also sampled and analysed the crop.

The clay (< 2 μm) contents in the soil were from 12% in the top layer to 22% in 80–100 cm depth and the organic matter contents were from 3 to 0.4%. After barley 1978 the stubble field treatments during the fall were:

a. Rotavating, August 14 and December 5 (also b and c)
b. Rotavating, mustard applied no N and rotavating
c. Rotavating, mustard applied 40 kg N ha$^{-1}$ and rotavating.

In this paper is given an interpretation of reported results of the investigations stated in Table 3–6. An annual average amount of nitrogen in precipitation is 15 kg. These are here simply divided into 5 kg in fall, in winter and in summer period, Table 3 and 5. In Table 3 denitrification and net mineralization during fall and winter are estimated from experimental results.

**Table 3. Change in nitrogen Aug. 1978 – April 1979, kg N ha$^{-1}$.**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a Stubble</td>
<td>0</td>
<td>- 5</td>
<td>40</td>
<td>0</td>
<td>2</td>
<td>37</td>
</tr>
<tr>
<td>b Stubb/Must. 0 N</td>
<td>0</td>
<td>- 5</td>
<td>3</td>
<td>44</td>
<td>0</td>
<td>42</td>
</tr>
<tr>
<td>c Stubb/Must. 40 N</td>
<td>- 35 1)</td>
<td>- 5</td>
<td>6</td>
<td>76</td>
<td>0</td>
<td>42</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>15. Dec. - 3. April</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a Fallow</td>
<td>0</td>
<td>- 5</td>
<td>-13</td>
<td>0</td>
<td>23</td>
<td>5</td>
</tr>
<tr>
<td>b Fallow</td>
<td>0</td>
<td>- 5</td>
<td>13</td>
<td>0</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>c Fallow</td>
<td>0</td>
<td>- 5</td>
<td>14</td>
<td>0</td>
<td>7</td>
<td>16</td>
</tr>
</tbody>
</table>

1) The 2 Mustard treatments have a difference in soil and crop N of 35 kg indicating denitrification of 5 of the fertilizer applied 40 kg N.

In Table 4 is estimated the increase in the soil of N in NO$_3$ and NH$_4$ under fallow April to August with zero or 100 kg N applied in fertilizer late in April. It is assumed that the profile increase in N is due to precipitation but mainly to net mineralization. The
soil water has been close to field capacity but no leaching of N has been detected. Assuming no denitrification with zero N applied the mineralization is found to be 49, 57 and 75 kg N for the 3 stubble treatments 1978. Where 100 kg N was applied there has been a loss of 50, 39 and 51 kg N ha\(^{-1}\) mainly as denitrification.

Table 4. Nitrogen balance under fallow 1979, kg N ha\(^{-1}\).

<table>
<thead>
<tr>
<th>Treatment 1978</th>
<th>Stubble 0</th>
<th>Stubb/Must. 0 N</th>
<th>Stubb/Must. 40 N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer 1979</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>3. April</td>
<td>47</td>
<td>36</td>
<td>40</td>
</tr>
<tr>
<td>15. May</td>
<td>(60)</td>
<td>(52)</td>
<td>(59)</td>
</tr>
<tr>
<td>1. July</td>
<td>91</td>
<td>87</td>
<td>101</td>
</tr>
<tr>
<td>20. August</td>
<td>101</td>
<td>98</td>
<td>120</td>
</tr>
</tbody>
</table>

| Increase      | 54        | 62              | 80              |
| Precipitation | 5         | 5               | 5               |
| Mineralization| 49        | 57              | 75              |

| Loss          | 50        | 39              | 51              |

Under barley the mineralization is assumed to be the same as under fallow for comparable treatments as the soil moisture under barley

Table 5. Nitrogen balance with barley, kg N ha\(^{-1}\) Apr.- Aug. 1979.

<table>
<thead>
<tr>
<th>Treatment 1978</th>
<th>Stubble</th>
<th>Stubb/Must. 0 N</th>
<th>Stubb/Must. 40 N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertil. + precip.</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Soil NO(_3) + NH(_4) 1)</td>
<td>34</td>
<td>29</td>
<td>33</td>
</tr>
<tr>
<td>Mineralization</td>
<td>49</td>
<td>57</td>
<td>75</td>
</tr>
<tr>
<td>Denitrification 3)</td>
<td>-1</td>
<td>-6</td>
<td>-18</td>
</tr>
</tbody>
</table>

| Sum total      | 87    | 85               | 95              |
| Harvested      | 65    | 64               | 71              |
| Roots 2)       | 22    | 21               | 24              |
| Grain, t ha\(^{-1}\) | 3.1  | 3.2              | 3.6             |

| DM | 4.8 | 4.8          | 4.7             |

1) Content April minus August.
2) Assumed 1/3 of harvested or 1/4 of total N in the crop.
3) Estimated as difference.
also was relatively high 1979. The nitrogen in barley root was not determined. A root content of 1/3 of the nitrogen in grain and straw or 1/4 of the total crop nitrogen is assumed on basis of other investigations, Ellen and Spiertz (1980).

From analysis reported and assumptions stated a nitrogen balance for barley is given in Table 5. The denitrification is estimated as difference and the uncertainty should be noted as due to the assumptions. If the mineralization is less than estimated, the denitrification will be equally lower. If the nitrogen in the root is higher as assumed, the denitrification will be equally lower.

In Table 6 are given net mineralization and losses for the whole year. With mustard as green manure the mineralization during the growth period of barley is 91 kg N ha\(^{-1}\) and increased to comprise about half the N content in the mustard. This is in agreement with Kolenbrander (1975) stating that about 80% decomposes the first year. The total loss is smallest with mustard 0 N and largest with mustard 40 N. The leaching of 25 kg N without mustard is in the order of quantities found by Hansen and Pedersen (1975). Considering the nitrogen balance and the crop yield a stubble crop for green manure should be unfertilized, but the there might be a weed problem due to less competition from the stubble crop. A fertilized stubble crop should be used as fodder and not as green manure.

Table 6. Nitrogen mineralization and loss during one year August 1978 - August 1979, kg N ha\(^{-1}\).
The shown nitrogen balance explains why a stubble crop as green manure does not increase the yield of the following crop. It also explains that no yield effect is observed from incorporating the straw in the soil. The mineralization during fall and winter is found to be 42 kg N ha\(^{-1}\) of which about 20 kg N is from the ploughed layer. The 20 kg plus 10 kg in precipitation is enough for immobilisation in microbes decomposing 3-4 t straw early incorporated and no nitrogen lack will be observed in the next crop. The leaching of nitrogen will be reduced by about 20 kg N ha\(^{-1}\).

Thus the green manure mustard 0 N and the straw incorporation can reduce the nitrogen leaching outside the growth period with about 20 kg N but have no influence on the yield. During longer periods there might be an improvement of the soil structure and thereby a positive effect on yield. However, the Danish loamy soils having a low clay content do not show much structure problems but that may occur in future due to increasing growing of grain.

References


LONG-TERM COMPARISONS OF DIRECT DRILLING, SHALLOW TILLAGE AND PLOUGHING ON CLAY AND SILT LOAM SOILS, WITH PARTICULAR REFERENCE TO STRAW DISPOSAL.

R.Q. Cannell, F.B. Ellis, D.G. Christian and B.T. Barnes

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Abstract

During 7 years direct drilling and shallow tillage gave similar or slightly heavier yields of winter cereals than after mouldboard ploughing on clay soils, even in seasons favouring heavy yields (c. 10 t ha⁻¹). These soils self-mulch in the surface few cm, and root elongation is aided by continuous macropores caused by cracking in summer and by earthworms. On a silt loam in the early years, direct drilling gave lighter yields than after ploughing, and shallow tillage the heaviest yields; recently yields from the three treatments have been about equal, associated with more organic matter and stable aggregates in the upper 2.5 cm with direct drilling and a zone of high mechanical resistance with repeated shallow tillage. In these experiments straw residues were burned after harvest.

Straw residues diminished yield of winter cereals, particularly after wet autumns, with direct drilling, but to a lesser extent with shallow tillage. The adverse effects can be diminished, but not eliminated, by incorporation of the straw residues into the soil immediately after harvest to lessen the potential for phytotoxin formation in winter, and by removal of straw during drilling and returning it immediately afterwards. Coating seed with calcium peroxide has not enabled more winter wheat plants to establish after direct drilling through straw.

Introduction

After favourable results with direct-drilled small-grained cereals on well-drained and structured soils (9,15,21), in 1974 we began three long-term experiments comparing different tillage treatments, two on clayey soils and one on a silt loam. There were several reasons for choosing these soil types: (i) clayey soils occupy 45% of the cereal growing area in England and Wales, (ii) these clayey soils are more suited to autumn sown cereals because in the spring they can be too wet for seeding, (iii) earlier experiments had shown improved surface soil conditions with repeated direct drilling (14) and this could aid crop establishment on weakly structured silt soils and avoid cloddy seedbeds on ploughed clayey soils, (iv) few tillage experiments have lasted long enough to assess the extent of macropore change with repeated direct drilling. In these experiments we adopted the recommended practice in Britain of burning straw before direct drilling or shallow tillage; because of the adverse effects that these
residues can have, especially in wet autumns (19). Preliminary results have been published (1,3,5,6,7,11,12,16).

In this paper we highlight results from the long-term experiments and from experiments examining potential means of alleviating the adverse effects of straw residues.

The long-term tillage experiments

The clayey soils, Vertic-epelic Gleysols, have poor natural drainage, and although they have been artificially drained, can be excessively wet in winter. The silt loam, an Orthic Luvisol, is well-drained, but has weakly structured topsoil and only 1.9% organic matter. More detail can be found elsewhere (5,12).

Autumn sown crops have been grown at each site, except for spring wheat on the silt loam in 1974. Winter wheat was grown in alternate years until 1980, and in 1981 on the clayey soils (with winter barley on the silt loam in that year). In other years until 1980 break crops of winter oats or oil-seed rape were grown to minimise the incidence of take-all (Gaeumannomyces graminis). Tillage treatments are mouldboard ploughing to 20 cm followed by appropriate secondary cultivation, shallow tine cultivation to 5-7 cm and direct drilling with a triple disc drill.

Table 1. Mean yields, 1974-81, of winter cereals and oil-seed rape after direct drilling and shallow tine cultivation, relative to ploughing, and grain yields when winter wheat was grown.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Shallow tillage</th>
<th>Direct drilling</th>
<th>Mean yield of winter wheat (t ha⁻¹)</th>
<th>1976</th>
<th>1978</th>
<th>1980</th>
<th>1981</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silt loam</td>
<td>103</td>
<td>98</td>
<td>4.4</td>
<td>8.8</td>
<td>9.0</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Clay loam</td>
<td>102</td>
<td>103</td>
<td>5.2</td>
<td>10.3</td>
<td>10.1</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>Clay not used</td>
<td>100</td>
<td></td>
<td>6.1</td>
<td>9.7</td>
<td>10.1</td>
<td>9.0</td>
<td></td>
</tr>
</tbody>
</table>

On average over the 7 years on the silt loam direct drilling has given slightly less yield than shallow tine cultivation or ploughing, whereas on the clayey soils direct drilling has at least equalled the yield after ploughing (Table 1), except after the wettest winters on the clay soil (5). Winter wheat is the crop of principal interest, and in the years that crop was grown the average yield after direct drilling has equalled that after other treatments (Table 2). Yields in 1978 and 1980 were heavy, especially on the clayey soils where the average was 10.0 t ha⁻¹ (Table 1).

In the early years of the silt loam experiment direct drilling yielded significantly less than after shallow tillage and ploughing, but in the last
4 years 3% more than ploughing (12). Possible reasons include a greater awareness of the most suitable soil moisture to direct drill on this soil, and the change in surface soil conditions during this experiment. By the fifth year, 1979, the organic matter content of the upper 2.5 cm in the direct-drilled treatment was 70% greater than in the ploughed land, associated with more stable aggregates (6), creating a better tilth for germination. The consistent good yield after shallow (5-7 cm) tine cultivation on this soil shows that the limitations for direct drilling are in the upper few cm. Nevertheless repeated shallow tillage gave greater penetrometer resistance at about 10 cm than after direct drilling or ploughing (12), an effect found in other soils (2,14,15); in 1980 this restricted the rate of root extension after shallow tillage, but yield was unaffected. It will be of interest to see if continuation of the treatment increases this effect. In a silt loam in Germany a plough sole restricted root growth compared with direct-drilled land (8).

Table 2. Mean yields of winter wheat after different methods of tillage in the years when this crop was grown at all 3 sites (t ha⁻¹).

<table>
<thead>
<tr>
<th></th>
<th>Ploughing</th>
<th>Shallow tillage</th>
<th>Direct drilling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976</td>
<td>5.2</td>
<td>5.0</td>
<td>5.2</td>
</tr>
<tr>
<td>1978</td>
<td>9.6</td>
<td>9.5</td>
<td>9.6</td>
</tr>
<tr>
<td>1980</td>
<td>9.8</td>
<td>9.6</td>
<td>9.7</td>
</tr>
<tr>
<td>Mean</td>
<td>8.2</td>
<td>8.0</td>
<td>8.2</td>
</tr>
</tbody>
</table>

On the clayey soils also there has been increased aggregate stability and organic matter in the upper 2.5 cm after direct drilling and shallow tillage (6), but these soils are naturally more strongly structured than the silt loam and self mulch in this layer. Although the bulk density on these soils is greatest after direct drilling (5), the continuity of macropores is improved by cracking in the summer, and by the greater earthworm activity after direct drilling (1,4,7). Root growth of winter cereals at the beginning of stem elongation in the spring has been greater after direct drilling than after ploughing, except on the heavier of the clayey soils in wet seasons; by anthesis root growth differences disappeared (11).

The effects of straw residues

Straw can impede the drill mechanism, particularly when it is wet, and keeps the top soil wetter (13); the decomposition of straw residues in close contact with developing seedlings under anaerobic soil conditions can
result in toxins being produced which are harmful to seedling establishment, and may lessen the yield of crops direct-drilled in the autumn (19). There may be other mechanisms also by which residues inhibit plant establishment. With greater amounts of straw the yield depressions after direct drilling are more obvious, on average about 25 per cent, but with greater effects in wet seedbeds (Table 3). This problem also occurs in the U.S.A. (10).

Several potential means of alleviating the adverse effects of straw residues have been examined:—
(i) Where the straw residues were rotovated into the topsoil about 3 weeks after harvest and about 3 weeks before drilling so that decomposition of the residues had already started, the effects on yield were less, but still important (Table 3).
(ii) Incorporation immediately after harvest may be more effective since straw retains the potential to produce phytotoxic concentrations of acetic acid, one of the principal toxins from anaerobically decomposing straw, only during the early stages of decomposition (17,19). Early incorporation of straw can minimise the potential for toxin production during winter (17). Nevertheless fewer plants emerged after chopped straw was incorporated within the top 7 cm immediately after harvest, and about 5 weeks before sowing, than when straw was burned before direct drilling (Table 4). Delayed sowing to avoid the peak of toxin formation is unacceptable, as the yield of direct-drilled crops is more affected by late sowing than with other tillage methods.
(iii) In the laboratory, coating cereal seeds with calcium peroxide diminished the effects of toxins from anaerobically decomposing straw (20), but in the field, seed coating with calcium peroxide has not prevented death of seedlings (Table 4); effects on yield have yet to be determined.
(iv) Where chopped straw was removed before drilling and returned afterwards there were more plants than where the seeds were direct-drilled through the straw in wet autumns, but not in dry seed-beds (Tables 4 and 5) and yield was heavier with the straw removal treatment in a wet autumn (Table 5). If on wider evaluation this treatment offers a means of diminishing the adverse effects of straw, it may be possible to devise drilling machinery to achieve this; however it is likely that other problems will remain, including a greater likelihood of slug damage, and herbicides may be less effective.

None of these procedures has eliminated the adverse effects of straw residues on the establishment and yield of winter cereals in simplified tillage systems, and in such systems burning is still the best way of coping with these residues in a cool temperate climate. Furthermore direct drilling
Table 3. Effect of different methods of disposing of crop residues on the yield of winter cereals on clay soils (expressed relative to yield after burning straw and direct drilling, = 100).

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetness of seedbed</td>
<td>dry</td>
<td>dry</td>
<td>wet</td>
<td>dry</td>
<td>wet</td>
<td>wet</td>
<td></td>
</tr>
<tr>
<td>Soil series/site</td>
<td>Denchworth CB</td>
<td>Denchworth CB</td>
<td>Lawford NF</td>
<td>Denchworth OF</td>
<td>Lawford NF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop</td>
<td>W.wheat</td>
<td>W.oats</td>
<td>W.wheat</td>
<td>W.wheat</td>
<td>W.wheat</td>
<td>W.oats</td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Straw</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Tillage</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burnt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotovated, 7 cm</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>105</td>
</tr>
<tr>
<td>Direct-drilled</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>105</td>
</tr>
<tr>
<td>Baled</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Rotovated, 7 cm</td>
<td>97</td>
<td>97</td>
<td>93</td>
<td>84</td>
<td>82</td>
<td>89</td>
<td>99</td>
</tr>
<tr>
<td>Direct-drilled</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>89</td>
</tr>
<tr>
<td>Chopped</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotovated, 7 cm</td>
<td>98</td>
<td>75</td>
<td>44</td>
<td>83</td>
<td>72</td>
<td>74</td>
<td>74</td>
</tr>
<tr>
<td>&amp; spread</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct-drilled</td>
<td>98</td>
<td>75</td>
<td>44</td>
<td>83</td>
<td>72</td>
<td>74</td>
<td>74</td>
</tr>
<tr>
<td>(weight of straw, t ha⁻¹)</td>
<td>Not</td>
<td>7.0</td>
<td>5.4</td>
<td>3.3(a)</td>
<td>2.4(a)</td>
<td>7.9</td>
<td></td>
</tr>
<tr>
<td>recorded</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean grain yield (t ha⁻¹)</td>
<td>5.9</td>
<td>6.8</td>
<td>5.6</td>
<td>4.7</td>
<td>8.1</td>
<td>7.3</td>
<td></td>
</tr>
</tbody>
</table>

(a) excludes chaff weight

Table 4. Effect of different methods of straw residue management and seed treatment on populations of direct-drilled winter wheat 6 weeks after sowing on a clay soil in a wet autumn, 1981. (Plants m⁻²)

<table>
<thead>
<tr>
<th>Straw burnt</th>
<th>321</th>
<th>Seed treated with organomercury fungicide and organochlorine insecticide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straw chopped and incorporated to 7 cm immediately after harvest</td>
<td>258</td>
<td>Seed coated with calcium peroxide</td>
</tr>
<tr>
<td>Straw chopped and removed for drilling</td>
<td>235</td>
<td>Seed treated with organomercury fungicide and coated organochlorine insecticide</td>
</tr>
<tr>
<td>Straw chopped and present for drilling</td>
<td>176</td>
<td>with calcium peroxide</td>
</tr>
</tbody>
</table>

LSD 42.0 LSD 26.5
and shallow tillage save fossil fuel energy, whereas incorporation and chopping of residues consume it.

Table 5. Effect of straw removal before direct drilling in dry and wet autumns on plant population and yield (t ha⁻¹) of winter wheat.

<table>
<thead>
<tr>
<th></th>
<th>Dry autumn, 1976</th>
<th>Wet autumn, 1980</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>plants m⁻² yield</td>
<td>plants m⁻² yield</td>
</tr>
<tr>
<td>Direct-drilled through chopped straw</td>
<td>199 5.9</td>
<td>249 5.0</td>
</tr>
<tr>
<td>Chopped straw removed, returned after drilling</td>
<td>175 6.1</td>
<td>344 6.5</td>
</tr>
<tr>
<td>Direct-drilled after burning straw</td>
<td>166 6.1</td>
<td>- -</td>
</tr>
</tbody>
</table>

References
ANTIEROSION AND AGROTECHNICAL EFFICIENCY OF ZERO AND SUBSURFACE BASIC TILLAGE OF DIFFERENT SOIL TYPES

A. Christov, N. Onoev, E. Tzvetkova
N. Poushkarov Institute of Soil Science and Yield Prediction, Sofia, Bulgaria
A. Momchev
Experimental Station of Erosion Control, Rousse, Bulgaria

ABSTRACT

Contrastive study of basic tillage has been conducted on three soil types and in three climatic subregions. The results indicate that it is immediately after their being carried out that moldboard ploughing and subsurface ploughing offer the best possibilities of erosion control. In spring and during vegetation these possibilities are not so great and with calcareous Chernozem water and soil losses are smallest in unploughed areas. With all soil types moldboard ploughing creates conditions for stable yields to be obtained. Calcareous Chernozem offers possibilities to employ subsurface and zero tillage as well.

About 50% of the arable land in this country is situated on slopes with a gradient of more than 3°. Incomplete data show that about 30% of this land is eroded (1). The National Long-Term Programme for Erosion Control in the People's Republic of Bulgaria attaches primary importance to the not capital agricultural measures. The present report discusses antierosion and economic efficiency of three ways of performing the basic tillage.

There were investigated moldboard ploughing to a depth of 25–30 cm, subsurface ploughing to a depth of 25–30 cm and zero tillage. These were tested at three fertilizer application levels both without mulching and as accompanied with mulching with 2500 kg/ha straw. With moldboard ploughing straw was used as vertical mulch. The studies were carried out on three soil types which differed
in a number of pedogenetical indices (Table 1).

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Depth</th>
<th>Silt</th>
<th>Clay</th>
<th>Index clayey minerals</th>
<th>Density at field capacity g/6m³</th>
<th>Field Humus</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcareous chernozem - Rousse</td>
<td>0-15</td>
<td>29.7</td>
<td>20.0</td>
<td>illite 1.24</td>
<td>28.0</td>
<td>2.56</td>
<td></td>
</tr>
<tr>
<td>Leached cinnamonic forest soil -</td>
<td>30-40</td>
<td>31.2</td>
<td>21.4</td>
<td>1.32</td>
<td>25.7</td>
<td>2.61</td>
<td></td>
</tr>
<tr>
<td>Topolovgrad</td>
<td>0-20</td>
<td>60.5</td>
<td>46.8</td>
<td>montmorillon 1.06</td>
<td>33.3</td>
<td>2.50</td>
<td></td>
</tr>
<tr>
<td>Leached chernozem - Smolnitza</td>
<td>29-39</td>
<td>63.5</td>
<td>48.1</td>
<td>morillon 1.12</td>
<td>31.0</td>
<td>1.89</td>
<td></td>
</tr>
</tbody>
</table>

On leached chernozem-smolnitz (Yambol) zero tillage was compared with some modifications of deep moldboard ploughing.

The present investigation covers three out of the four climatic sub-regions in which this country is situated: the town of Rousse and the village of Suhodol are in the temperate continental subregion, the town of Yambol - in the transitional continental subregion and the town of Topolovgrad - in the South Bulgaria subregion. These regions differ in a number of indices including seasonal rainfall distribution. The amount of liquid runoff and the amount of soil removed with it were measured over a period stretching from the completion of deep ploughing to the end of the vegetation in the following year. In the case of natural rainfall these were measured at long-standing runoff plots. Artificial sprinkling was carried out, the results of which, in order to be compared easier, were expressed in terms of units rainfall factor R calculated according to the formula

\[ R = \frac{P}{\sqrt{t}} \]

where P represents the amount of rainfall ≥9.5 mm with an intensity ≥0.180 mm/min. and t stands for the duration of rainfall.
The obtained results indicate (Table 2) that with different soils the runoff-reducing and erosion control efficiency of the studied ways of tillage is different. These differences are best manifested immediately after the completion of the tillage. With calcareous chernozem deep ploughing with or without a moldboard at that time completely prevents water from running off and protects soil from erosion. Some months after runoff occurs in these fields, too, but it is smaller than the runoff in unploughed fields. On leached cinnamonic forest soil runoff occurs as early as immediately after ploughing but water losses are some five times less as compared with those in unploughed fields. The amount of eroded soil is smaller, too. On leached chernozem-smolnitza complete prevention of water from running off and of soil from removal is achieved through ridge and furrow ploughing, the ridges and furrows having different depths and heights and being situated at different spaces apart.

In the fields ploughed with one of the moldboards shortened or removed the water retaining capacity of the resultant furrows is 600 m³/ha and 1500 m³/ha, respectively, which is absolutely sufficient to prevent runoff in autumn. During vegetation water runoff from unploughed fields on calcareous chernozem is about four times smaller than the runoff from moldboard-ploughed fields. In mulched fields to which subsurface and zero tillage have been applied no runoff whatsoever occurs in this period. The reason for this is probably the increased share of the clay fraction in the moldboard-ploughed soil and the lack of stubble residues. On leached cinnamonic forest soil the amount of water runoff during vegetation in ploughed fields equals that in unploughed fields. A similar phenomenon is observed with leached cinnamonic forest soil in Suhodol, Sofia District (2) and with smolnitzas. It is apparent that leached cinnamonic forest soil and chernozem-smolnitza are less erodible than calcareous chernozem. One very important reason for this is the presence of clay minerals with a mobile lattice in these soils while in calcareous chernozem micaceous minerals predominate.

Yield data show (Table 3) that moldboardless ploughing and zero tillage of calcareous chernozem are possible to be performed only if crops are well supplied with nutrients and there is good weed-control. With leached cinnamonic forest soil and chernozem-smolnitza the fields subject to zero tillage have an aeration porosity smaller and density and hardness greater than what
is considered most favourable for the majority of crops. Root system reaches lesser depth and plants cannot absorb water from the lower layers as a result of which yield remains lower. On these soils moldboard ploughing creates better conditions for the crop biological productivity to be realized and for intensification means to be effective. With ridge and furrow ploughing on leached chernozem—smolnitza higher yields are obtained in the years when rainfall during vegetation is lower than the average value for the respective climatic region.

REFERENCES


## TABLE 2

**LIQUID (m³/ha) AND SOLID (kg/ha) RUNOFF**

<table>
<thead>
<tr>
<th></th>
<th>Immediately after deep ploughing</th>
<th>Several months after</th>
<th>During vegetation</th>
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<tbody>
<tr>
<td></td>
<td>- mulch</td>
<td>+ mulch</td>
<td>- mulch</td>
</tr>
<tr>
<td></td>
<td>liquid</td>
<td>solid</td>
<td>liquid</td>
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<td></td>
<td>liquid</td>
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<td></td>
<td>liquid</td>
<td>solid</td>
<td>liquid</td>
</tr>
</tbody>
</table>

### 1. Calcareous chernozem - Rousse

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Along slope</td>
<td>16.0</td>
<td>1979</td>
<td>-</td>
<td>-</td>
<td>29.3</td>
<td>1050</td>
</tr>
<tr>
<td>Across slope</td>
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<td>0</td>
<td>1.0</td>
<td>38</td>
<td>5.5</td>
<td>242</td>
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<tr>
<td>Subsurface</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4.5</td>
<td>371</td>
</tr>
<tr>
<td>Zero</td>
<td>11.8</td>
<td>1063</td>
<td>10.6</td>
<td>962</td>
<td>12.5</td>
<td>145</td>
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</tbody>
</table>

### 2. Leached cinnamonic forest soil - Topolovgrad

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<table>
<thead>
<tr>
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<th></th>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Along slope</td>
<td>6.2</td>
<td>199</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.0</td>
</tr>
<tr>
<td>Across slope</td>
<td>3.9</td>
<td>61</td>
<td>1.9</td>
<td>28</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Subsurface</td>
<td>4.6</td>
<td>164</td>
<td>6.5</td>
<td>68</td>
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<td>-</td>
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<tr>
<td>Zero</td>
<td>22.3</td>
<td>292</td>
<td>26.2</td>
<td>116</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

### 3. Leached chernozem-smolnitsa - Yambol

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Across slope</td>
<td>4.6</td>
<td>119</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ridge and furrow:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One moldboard</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>shortened</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>One moldboard</td>
<td></td>
<td></td>
<td></td>
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</tr>
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<td>removed</td>
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<td>0</td>
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<td>-</td>
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</table>
### TABLE 3

**YIELD OF MAIZE GRAIN (14% MOISTURE CONTENT) – AVERAGES FOR THREE YEARS**

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Basic ploughing</th>
<th>Rate of fertilizer application (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcareous chernozem - Rousse</td>
<td>Moldboard</td>
<td>* 4850</td>
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<tr>
<td></td>
<td>Subsurface</td>
<td>95.9</td>
</tr>
<tr>
<td></td>
<td>Zero</td>
<td>81.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leached cinnamonic forest soil - Topolovgrad</td>
<td>Moldboard</td>
<td>* 3290</td>
</tr>
<tr>
<td></td>
<td>Subsurface</td>
<td>91.2</td>
</tr>
<tr>
<td></td>
<td>Zero</td>
<td>79.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leached cinnamonic forest soil - Suhodol</td>
<td>Moldboard</td>
<td>* 3108</td>
</tr>
<tr>
<td></td>
<td>Zero</td>
<td>52.4</td>
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<tr>
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<td></td>
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</tr>
<tr>
<td>Leached chernozem - Smolnitsa - Yambol</td>
<td>Moldboard</td>
<td>* 4230</td>
</tr>
<tr>
<td>Ridge and furrow:</td>
<td>Ridge</td>
<td>96.5</td>
</tr>
<tr>
<td>with one moldboard shortened</td>
<td>Furrow</td>
<td></td>
</tr>
<tr>
<td>with one moldboard removed</td>
<td></td>
<td>95.0</td>
</tr>
<tr>
<td>Zero</td>
<td></td>
<td>93.4</td>
</tr>
</tbody>
</table>

* Yield in the case of moldboard ploughing is given in kg/ha and in the cases of other treatments - as percentage toward it.
Experiences with ploughless tillage systems in the Federal Republic of Germany
Dr. Karlheinz Koeller
Chamber of Agriculture, Rhineland, Bonn, FRG

Abstract

Ploughless tillage is increasing steadily in significance. The most important advantages are protection from erosion and economy of work time, energy and costs. The success of ploughless tillage is largely dependent on the particular conditions on site (soil, climate, crop rotation).

In most farms of the FRG the conditions for a permanent and successful abandonment of all kinds of tillage (direct drilling) are lacking. As opposed to this ploughless tillage with chisel ploughs and p.t.o. driven rotary tillers make it possible for many farmers to lower their costs without loss of yield.

In many countries of the world ploughless tillage is already being practised to a great extent and its significance will continue to rise. It is estimated that by the year 2000 about 80% of the arable land in the USA and about 50% of that in the USSR will be tilled without the use of the plough (1). A similar development with us will hardly be to be seen as the necessary preconditions are missing. From a world wide point of view the abandonment of the plough is to be desired in order to combat soil erosion successfully. This point is of relatively secondary importance in the Federal Republic of Germany. Here economic considerations such as economizing on work time, energy and
costs are primary in the expansion of ploughless tillage.

What reasons can be given for abandoning the plough?

Both for ecological and for economic reasons it can be practical to abandon ploughing. In the first case the objective of such measures is first and foremost the reduction of the danger of erosion. Compared with the total area of arable land there are only a few sites which are endangered by erosion and which require special measures to be taken. In particular by abandoning ploughing one can succeed in reducing the danger of wind and water erosion. By the use of shallow working and mulching implements the larger part of the crop residues and plant remains stay as a protective cover on the soil surface. Such conservational tillage systems have been successfully employed by us (2, 3).

For most farms economic reasons are the decisive ones in choosing a system of cultivation. The abandonment of ploughing offers particular possibilities of economizing and reducing work time and energy expenditure. Whether and to what extent positive effects are to be observed depends on the particular conditions prevailing in the individual farm.

Preconditions for successful abandonment of ploughing.

Apart from the above mentioned sites which are endangered by erosion and in which the abandonment of ploughing is a necessity in order to engage in crop husbandry we do not observe corresponding exonomic compulsion in most farms or the local conditions make ploughing seem indispensable.

In this connection we can see that the abandonment of ploughing shows particularly clear advantages for those sites which are characterized by:
- heavy soil (clay content > 30 %)
- winter cereal cropping
- short cultivation periods (labour peaks)
- limited optimal sowing times
The necessity of renouncing time and cost intensive ploughing and the correspondingly expensive preparation of the furrows is clearly to be seen when all of the above conditions are met and when, if one maintains ploughing, no cultivation of winter cereal is possible. Such extreme conditions in connection with correspondingly difficult climatic conditions which, for example, make it impossible to sow winter wheat after the 31st. of October and which thus are to be recommended for a long-term abandonment of the plough are not to be found that frequently in the FRG.

The possibilities and limits of ploughless tillage

From the reasons and preconditions which have been listed so far result the greatest possibilities for the abandonment of ploughing as an economic necessity in sites which are endangered by erosion and in areas with "heavy" soils and unfavourable climatic conditions.

In most of our farms with relatively easily tilled sand and loam soils it is possible to abandon the plough but the economic advantages are less valued in comparison with the possible disadvantages.

The following reasons can be given in the context:
- On soils which require no further or only one pass for seedbed preparation there is hardly any occasion to abandon ploughing.
- Under favourable climatic conditions the ideal sowing date seems less fixed in time.
- In many cases sufficient efficiency is guaranteed with ploughing (whether or not this also means economic viability).
- In a wet autumn, as for example that of 1981, winter wheat sowing, for example, is frequently not possible after the sugar beet harvest without ploughing.

If at all then it only seems a consideration for most farms at the moment to alternate between using and not using the plough, that is to use both possibilities and not exclusively one or the order. In this connection one can mention in particular the cropping of winter wheat. Apart from the restrictions mentioned
above it seems to be possible from our experiences so far to cultivate the entire crop of winter wheat in the FRG without ploughing after the harvest of beet, maize, rape seed etc. without involving extra risks. It is also possible to engage in catch crop growing in this way. There are more difficulties however in ploughless cultivation of winter barley after winter wheat (straw incorporation, volunteer cereal, plant diseases, etc.). The local conditions and the experiences of the farmers are decisive, that is, in this case the plough can be successfully abandoned here also. For cultivation of sugar beet, potatoes, maize and summer cereal the disuse of the plough appears to be insignificant with the exception of those areas which are in danger of soil erosion. Even though for most farms at present it is only possible to till ploughlessly once or twice within a cycle of crop rotation the advantages connected with this should be exploited more. Many years of experiments and practical experience show that labour time, energy and costs can be economized on without a loss of yield (4). Only with consistent ploughless tillage, for which the preconditions are lacking in the FRG in most cases, do problems arise (for example, volunteer cereal, plant protection) which can however be solved as practical experience shows. Basically one can say that ploughless tillage is good but the conditions must be right as well the right attitude and ability of the farmer be present.

Chisel ploughs for primary tillage, p.t.o. driven rotary tillers for seedbed preparation

For ploughless soil tillage there are many possible machines but in general chisel ploughs and p.t.o. driven rotary tillers are employed. Such mechanization seems to be purposeful and economical as the machines mentioned are usually available on most arable farms anyway.

As under our conditions it is very difficult to avoid deep tracks, soil compaction and large amounts of crop residue after
harvest one can hardly renounce loosening and mixing effects, that is the prospects for abandoning all forms of tillage in the form of direct drilling is very slight. Under these aspects the use of the chisel plough is to be particularly recommended this being distinguished not only by good soil loosening and straw incorporation but also by its crumbling effect which reduces the effort required for the following seedbed preparation (4). These advantages lead especially on heavy soils to a significant saving of labour time and fuel when the chisel plough is used instead of the plough in one pass.

After the use of the chisel plough p.t.o. driven rotary tillers for seedbed preparation are to be recommended with increasing clay content of the soil. This is particularly so when there is still crop residue on the soil surface. But even there where it is not necessary from the point of view of labour method they have increased in significance as they can in combination with a seed drill do both the seedbed preparation and sowing in a single pass. One pass with the chisel and one pass with a p.t.o. driven rotary tiller with a mounted drill is a powerful procedure for ploughless cultivation of winter cereal and catch crops.

For simultaneous execution of both soil tilling and seedbed preparation in one pass the use of a chisel plough with two rows of tines is increasingly to be recommended when this can be combined with p.t.o. driven rotary tillers. With an additionally mounted drill the whole cycle of cultivation can be reduced to one single pass.

In summary one can say that the labour and fuel requirements with the use of chisel ploughs and p.t.o. driven rotary tillers (2 passes) as opposed to a comparable ploughing procedure on heavy soils is reduced by about 50%. If only one cycle is necessary for example with a rotary cultivating seeder (on its own or in combination with a chisel plough) then a reduction of total effort by about 70% is possible. On lighter soils the corresponding economy effect is about 30-40% or 50-60%. The possible
acreage increases twice or three times in comparison with ploughing procedure. As these advantages can be reached without loss of yield, and this is true particularly for ploughless cultivation of winter wheat after beet, maize, rape seed etc., they should be exploited more fully in practice.

Literature:


REDUCED TILLAGE - PRESENT STATE AND PROSPECTIVES OF USE IN VOJVODINA

Dr JORDAN KONSTANTINOVIC
RO "PODUNAVLJE"
BEZDAN

ABSTRACT

Experiment with reduced tillage are scarce in Yugoslavia. They do not keep continuity and beat no effects on the large-scale production. An experiment, which included five variants of soil tillage, was conducted in Bezdan in the period 1977 - 1981. The differences among the variants were small and statistically insignificant (the yield wheat and corn).

METHOD

The experiment, conducted after the method of Boguslawski in four replications, was established on calcareous chernozem soil which is prevalent in north-western Bačka. There were five variant of soil tillage: disk harrowing, plowing at 15,30 (standard), and 45 cm, and direct planting, applied in the crop rotation of wheat and corn. There were two variants of fertilization: medium dose (120 N: 80 P: 40 K) and high dose (140 N: 100 P: 60 K). The control variant was unfertilized. Soil cultivation was performed with the implements available at the estate which are suitable for conventional tillage. The variant of reduced tillage included disk-harrowing which was a serious shortcoming to the experiment.

The term "reduced tillage" implies a quality tillage of a shallow layer of 10 - 15 cm. The available disk harrows were incapable of meeting the requirement for quality, especially in the parts...
of the experimental plot exposed to compaction (turning points, trails for transportation vehicles) as well as during dry falls when the soil to be prepared for wheat planting had the moisture content below 16 % FWC. In such conditions, the harrows would slide, leaving unharrowed stretches, especially if the harrowing is performed in one passage as was the case in our experiment. It is our opinion that this variant would have rendered better results if appropriate implements had been available, or with crossing and diagonal disk harrowing.

The objective of our experiment was to determine differences in the yields obtained in the variants of soil tillage in conditions of Vojvodina. We also followed wheat growth and development per variants according to the stages of autogenesis (tillering, forking, heading, wax maturity). Finally, we observed physical properties of the soil (volumic weight, soil compaction and structure, etc.) and their changes in dependance of the system of tillage.

The climatic characteristics of the experimental period were: favorable conditions for wheat growing in 1977, medium in 1978, and poor in 1979. The years were generally favorable for corn growing.

Besides the exact trial with the basic plot size of 330 m² (22 x 15) we conducted simultaneously, in the same plot and at the same time, a production trial which included the same variants of soil tillage and only one level of fertilization (140 N: 100 P: 60 K). The basic plot size was 0,5 ha. In 1980 and 1981, the variant of disk harrowing was checked in large-scale production.

RESULTS

a) Analysis of wheat yields

Table 1 shows that all variants brought very high and uniform yields (5.8 - 8.4 t/ha) without fertilization (control) in the first year. In the second, the yields dropped considerably (2.5 - 3.5 t/ha), and in the third the reductions were drastic (0.9 - 1.7 t/ha) on account of the shortage in nutrients and unfavorable conditions of the year of growing.

The medium dose of fertilizers rendered high and uniform yields (8.2 - 6.6 t/ha) in the first and second year (1977 and 1978). The differences among the variants were very small and statistically insignificant. In 1979, which was most unfavorable

- 104 -
## WHEAT YIELDS IN PERIOD 1977 - 1979 y.

(Tabla 1)

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<tr>
<th>TILLAGE</th>
<th>FERTILIZATION</th>
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<th>1979</th>
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<th>LSD 1 %</th>
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A = TILLAGE   a=control unfertilization   A = B = C = AB = AC = BC
B = FERTILIZAT. b=medium dose fertilization LSD 5 % 281 168 169 377 377 292
C = YEARS c=high dose fertilization 1 % 286 222 222 495 496 384
for wheat growing because of a drought in spring (the total annual rainfall of only 470 mm) and a large-scale freezing of wheat plants (up to 40% of frozen plants; -22°C in February, without snow blanket), the yields were considerably lower but still uniform (2 - 5.2 t/ha). The difference between the variants of disk harrowing and deep tillage (45 cm) was only 0.2 t/ha (4.5 and 4.7 t/ha, respectively). The variant of direct planting brought a much lower yield (2 t/ha).

The high dose of fertilizers rendered high and stable yields (6.1 - 6.7 t/ha) in the first two years. Moreover, the variant of direct planting had the highest yields. In 1979, the yields were lower but still uniform, without significant differences among the variants of shallow and deep tillage (5.03 t/ha with disk harrowing, 4.9 t/ha with the tillage at 30 cm). Direct planting reduced the yields considerably (2.4 t/ha). It may be seen that the differences among the variants were small and insignificant on the three-year average, with the exception of the variant of direct planting.

Table 1 shows for factor B (fertilization) that there were highly significant differences between the medium (b) and high dose (c) on one side and control on the other. Fertilization had the highest effect on the yield in all three years.

Regarding factor C (year), there were highly significant differences between 1979 on one side and 1977 and 1978 on the other. These results indicate that the year of growing was also an important factor.

Regarding factor AB (interaction between tillage and fertilization), there were no significant differences among the variants of fertilization but the variants of tillage differed significantly within the control variant for fertilization. It means that all tillage systems depended on fertilization. Interactions were also found within factor AC (1977 : 1979).

Wheat yields realized within the production trial had similar tendencies. No significant differences could be found among the variants of tillage, with the exception of direct planting.
b) Analysis of corn yields

Table 2 shows that the control variant, without fertilization, brought high and stable yields, except direct planting, in the first year. The yields decreased and differences appeared in favor of deeper tillage in the second year. The yields were somewhat higher in the third than in the second year but the superiority of deeper tillage was again felt.

The medium and high doses of fertilizers rendered small differences among the variants of tillage. The only exception was the variant of direct planting. With the former dose, the three-year average yield in the variant of disk harrowing was 10.8 t/ha, in the variant of tillage at 30 cm 11.3 t/ha. The difference was 4.3%. With the latter dose, the yields were 11.4 and 11.6 t/ha, respectively. The difference was only 2%. The analysis of variance turned out significant differences between the variants of shallow tillage (disk harrowing and 15 cm) in relation to the variants of deep tillage (30 and 45 cm), as well as highly significant differences between all variants and direct planting which was considerably less productive. Regarding factor B (fertilization) there were highly significant differences between the control variant on one side and the medium and high dose of fertilizers on the other. Regarding factor C (year), significant differences were found in favor of climatically favorable years. Interactions were also found for factor AB (tillage and fertilization).

* * *

Corn yields realized in the production trial differed from those in the exact trial, i.e., they were more uniform, without significant differences, with the exception of the variant of direct planting which brought 9.6, 9.7, and 9.6 t/ha in the variants of disk harrowing, 30, and 45 cm, respectively.

* * *

In the large-scale production (200-300 ha), the variant of disk harrowing brought higher wheat yields in 1980 (5.850 kg/ha) and 1981 (5.150 kg/ha) than the conventional tillage.

* * *

Besides in Bezdan reduced tillage is successfully used in Kikinda (on 3.000 ha) and Vršac (on 1.000 ha) of heavy soils (hidromorphic black soil). The obtained wheat yields are on the level of those obtained with conventional tillage.

* * *

We followed the development of wheat plants in all tillage variants but failed to find reliable differences at all stages of
## Corn Yields in Period 1977 - 1979 (kg/ha)

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<tr>
<th></th>
<th>A TILLAGE</th>
<th>B FERTILIZATION</th>
<th>C YEARS 1977</th>
<th>C YEARS 1978</th>
<th>C YEARS 1979</th>
<th>AB TILLAGE FERTILIZATION</th>
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**A**=TILLAGE
- a = control unfertilization
- b = medium dose fertilization
- c = high dose

**B**=FERTILIZATION
- b = medium dose fertilization 5%
- A B C AB AC BC L S D  

**C**=YEARS
- c = high dose
development and for all characters (dry matter gain, number of plants, plant height, number of leaves, leaf area).

There were no significant changes in the physical status of the soil in dependence of tillage system. Volumic weight increased, especially in the third year, as the depth of tillage was reduced. Soil compaction, measured by a penetrometer, was higher with the shallower variants - 46.47, 44.27, and 58.55 kg/cm³ in the variants of disk harrowing, 45 cm, and direct planting, respectively.

Water physical properties of the soil were not affected by tillage system. The differences obtained were small, but it should be mentioned at this point that the methodology used was not adjusted to the needs of the experiment.

CONCLUSIONS

The following conclusions may be drawn on the basis of the results of the three-year exact and production trial:

1. The differences in wheat and corn yields among the examined variants of tillage were small and mostly non-significant, except for the variant of direct planting. It means that in conditions of Vojvodina, wheat and corn may be grown safely for 1-2 years in the system of reduced tillage on chernozem soil.

2. All tillage variants were highly dependant on fertilization. The differences between the control on one side and the medium and high dose of fertilizers were significant whereas the differences between the two doses of fertilizers were usually small and non-significant.

3. The differences among the variants of tillage were small in climatically favorable years. In unfavorable ones, the yield increased with the increases in the depth of tillage. The unfavorable effects of bad years were mitigated to a large extent with the high dose of fertilizers.

4. Reduced tillage may be used from time to time in combination with conventional tillage within a cropping system. The time of its application depends on the crop, preceding crop, condition of soil, and other factors.

5. Reduced tillage as a permanent system of soil cultivation is out of question. Still we should continue to study the possibilities of its limited application and its effects on crop yields and soil.

6. New trials with reduced tillage have been established at 24 locations around Vojvodina. The crops included in the trials are wheat, sunflower, and soybean. A shortcoming of these trials is that special machines for reduced tilling have not been used.
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ABSTRACT

Effects of continuous no-tillage and conventional plowing on maize yield and on properties of an Alfisol in Southern Nigeria are reported for 21 consecutive crops of maize from 1971 to 1981. After 10 years, the surface 0-10cm layer of no-till plots had 1.70% organic carbon compared with 1.21% in the plowed soil. The casting activity of earthworms was 29 and 12 casts/m²/day in no-till and plowed plots, respectively. The mean bulk density of the surface layer of no-till plots was 1.27g/cm³ compared with 1.34g/cm³ in the plowed treatments. The equilibrium infiltration rate after 21 consecutive seasons were 23.8 and 8.2 cm/hr for the no-till and plowed treatment, respectively. The mean grain yield over the 21 consecutive seasons was 3.0 and 2.6 t/ha/season in the no-till and plowed plots, respectively.

Introduction

During the past decade, food production in tropical Africa has not kept pace with the ever increasing demand. And yet, there is a tremendous potential for bringing about substantial increases in food production from these soils. Introduction of improved varieties and use of fertilizers has been shown to increase crop yields even with the traditional systems of management (Greenland, 1977). Bringing new land into production is another aspect that merits consideration, because hardly 25% of the arable land in Africa is currently under cultivation (Hopper, 1976). Consequently vast areas of land are being cleared annually with the hope to increase food production. Productivity from these soils can be sustained if soil physical and chemical properties can be maintained, and the degradation due to accelerated soil erosion can be prevented.

In this connection, the no-till system of seedbed preparation has proven to be an effective soil conservation measure (Lal, 1976a). In this method, the weeds killed by appropriate herbicides and the previous crop residue used as mulch prevent the raindrop impact and minimise crust. The soil loss by water is completely eliminated, and the soil physical and chemical properties are better maintained than with the mechanical method of seedbed preparation.

This report describes the effects of a long term on-going experiment initiated since 1971 at the IITA, Ibadan, Nigeria to investigate the effects of tillage methods on soil properties and crop yield. In this region of Alfisols with bimodal rainfall distribution, two crops of maize can be grown. The results reported earlier have indicated that whereas the no-till system maintained high yields and more favourable soil physical and chemical properties over a short period of time (Lal, 1974; Lal, 1976b), the long term effects on soil and crop response were yet to be seen. An attempt is made in
this report to compile the results of the effects of 10 years of cultivation of an Alfisol by no-tillage and the conventional tillage methods on soil properties and maize yield. The methodology adopted and field layout have been described in earlier reports (Lal, 1976b).

Results And Discussion

1. Grain Yield

Two maize crops have been grown every year since 1971 with the no-till and conventional methods of seedbed preparation (Fig. 1). The fluctuations in grain yield from season to season are attributed to the variations in rainfall and other related biological factors. Over and above the seasonal effects, maize yield with the no-till system was superior to the plowed plots. This was particularly so in those seasons that experienced short duration droughts. However, since 1979 for the last six consecutive seasons, maize yield in no-till system is definitely superior to that from plowed plots. The degradation in soil physical and chemical properties caused by plowing could not be completely compensated by the supplementary doses of chemical fertilizers. The total yield obtained over the 21 seasons from no-till and plowed plots was 63.3 and 54.5 t/ha corresponding with an average yield of 3.0 and 2.6 t/ha/crop respectively. This implies that with the maize-maize crop rotation, high yields can be sustained with the no-till system without causing serious soil degradation provided soil compaction is kept minimum.

![Graph showing seasonal fluctuations in maize grain yield affected by two tillage systems](image-url)
However, the no-till system may have higher N requirements than the conventionally plowed plots for the first one or two seasons (Lal, 1974; Kang et al., 1980). This may be particularly the case if the crop residue mulch has a wide C:N ratio and the soil is initially compacted. With the continuous use of no-till system, the efficiency of N is even better on no-till than on plowed plots (Lal, 1979).

The results presented in Fig. 1 do not indicate yield decline with the no-till system, although the yield from the plowed plots lagged behind for the last six seasons from 1979 to 1981. However, in another study conducted with the mechanised operations of planting, spraying, and harvesting, the observed decrease in maize yield with the no-till system was attributed to severe soil compaction (Couper et al., 1979). In this study with the manual operations, soil compaction was not a problem even after 21 consecutive crops of maize.

2. Soil Chemical Properties:

The initial organic carbon content of 2.33% in the surface 0-10cm layer in 1971 decreased to 1.70 and 1.21% in 1980 in the no-till and plowed plots, respectively (Fig. 2). The mean rate of decline over this ten year period was 0.063 and 0.112 percent per year for the no-till and plowing methods of seedbed preparation, respectively. Since 1977, however, the organic matter content has stabilised in both systems of seedbed preparation. The total soil nitrogen also observed the trend that was similar to that of organic matter content (Fig. 2). In 1980, the total nitrogen in the surface 0-10cm layer of the no-till plots was about 1.5 times more than plowed treatments.

![Graph showing changes in soil carbon and nitrogen content over time](image-url)
Similar to the organic carbon, the exchangeable cations, mainly calcium and potassium, were also more in the surface 0-10cm layer of the no-till than plowed plots (Fig. 3). Results reported earlier (Juo and Lal, 1977) also indicated that nutrients in the no-till system are concentrated in the surface about 20cm layer whereas they are somewhat better mixed in the plowed layer in the mechanically tilled treatments.

![Graph showing exchangeable potassium and calcium in no-till and plowed plots]

3. Earthworm Activity:

Crop residue mulch and the elimination of the mechanical soil disturbance maintain high biological activity of earthworm in no-till than plowed soil (Lal, 1976; Lal and De Vleeschauwer, 1981). Even after 10 years, the casting activity of Hyperodrilus Africanus in no-till plots was about twice than in plowed plots (Table 1). These earthworm casts contain more organic matter, more silt and clay, and more nutrients than the uncontaminated surface soil. In addition, these earthworm casts are structurally stable to raindrop impact and have significantly high mean weight diameter of structural aggregates than the surface soil.
Table 1. Rate of cast production of Hyperodrilus Africanus after 11 years of adopting two tillage systems

<table>
<thead>
<tr>
<th>Casting Activity</th>
<th>No-Tillage</th>
<th>Conventional Tillage</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) Casts (m² day⁻¹)</td>
<td>29.4</td>
<td>11.5</td>
</tr>
<tr>
<td>(ii) Equivalent weight (gm² day⁻¹)</td>
<td>97.4</td>
<td>49.2</td>
</tr>
</tbody>
</table>

LSD (.05)
(i) Weight 50.5
(ii) Rate 8.9

4. Soil Physical Properties:

The equilibrium infiltration rate and the accumulative infiltration are higher in no-tillage than in plowed treatments (Fig. 4). For example, the equilibrium infiltration rate in the no-till plots was 23.8 cm/hr compared with 8.2 cm/hr in the plowed plots. This high infiltration rate in the no-till plots is attributed partly to high earthworm activity and also to the lack of crust formation due to the preventive effect of crop residue mulch (Lal, 1976b)

![Figure 4: Accumulative water infiltration as affected by two tillage methods.](image-url)
The mean gravel content in the surface 0-10 cm layer of the no-till plot in 1980 was 9.5 percent compared with 20.9 percent in the plowed treatments. The preferential removal of the fine soil particles in water runoff and turning over of the soil by a plow may be responsible for the concentration of the gravel in the plowed plots. The gravel content, being an inert material, also influences the "capacity factor" of the soil for nutrient and water retention and their availability to plants. Since the chemical properties are determined on the soil fraction less than 2 mm, the actual nutrient and organic matter content in the soil from plowed plots is even less than that reported in Figs. 1 to 3. Furthermore, high gravel content is also known to inhibit root growth and development (Babalola and Lal, 1977).

The bulk density of the surface layer of no-till plots at harvest is also less than in plowed treatments. The mean bulk density of the 0-5 cm layer measured at the end of the second season in 1980 was 1.27 and 1.34 g/cm³ for the no-till and plowed treatments, respectively.

The soil moisture retention characteristics also indicate more available water retention capacity in the surface 0-20 cm layer of the no-till than plowed treatments. Consequently, maize was observed to suffer from drought loss in no-tillage than plowed plots (Lal et al., 1978).

Conclusions

The maize grain yield in no-till plots is maintained for the last 21 consecutive seasons, whereas the yield in the plowed plots began its downward trend since 1979. This high yield in the no-till system is associated with more soil organic matter contents, nutrient status, and the available water holding capacity than the plowed soil. High biological activity of earthworms in no-till plots keeps the soil porous, improves its infiltration rate, and minimizes runoff and erosion. With annual operations of planting, spraying, and harvesting, soil compaction in the no-till system has not been observed even after 21 consecutive crops of maize.

References


Effect of zero-tillage on soil characteristics and crop yields.

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Abstract:
In zero-tillage cropping on different soil types with various crops, the problems were greater on sandy soil than on clay soil. On sandy soil the growing of root crops on zero-tillage fields was hardly possible after 5 years. On clay soil zero-tillage caused less problems, but generally produced lower yields of the root crops. Other crops, for instance, spring barley, wheat and peas produced the same or even higher yields on the zero-tillage soil than on the tilled soil; only under Dutch conditions is the risk of failure greater on the no-tillage soil. The distribution of organic matter and nitrogen in the profile of the zero-tillage fields was characterized by an increase in the organic matter and nitrogen in the topsoil layer and a decrease in deeper layers. The zero-tillage treatments after a rainy period remained wetter in the topsoil layer than the tilled soil. The sub-soil was drier in the zero-tillage treatments.

In the Netherlands zero-tillage growing is only profitable, for instance, on erosion-sensitive soils or to save time when sowing silage maize after Italian ryegrass crop or to limit soil tillage when sowing winter cereals.

1. Introduction
The soil is tilled to improve the soil structure, to obtain a good seed or plantbed and to control or plough under volunteer plants, green manure crops and weeds. With respect to weed control, soil tillage has for a long time been the most important measure. However when effective herbicides became available
undesirable plant growth could be controlled without soil tillage. In principle this opened the possibility to reduce the input of labour, energy and farm machines, at the same time decreasing the number of passages with heavy farm machines. Thus, at the former Institute for Biological and Chemical Research on Field Crops and Herbage (IBS) in 1962 a long-term study was started on the effects of zero-tillage on soil properties (structure, fertility and fauna), weed coverage, crop growth and yield of agricultural crops. Permanent experimental fields were set out on different soil types and the growth of various crops on conventionally tilled soil was compared to that on zero-tillage soil. (Bakermans and De Wit, 1970; Baeumer and Bakermans 1973)

2. Soil compaction with growing of arable crops on no-tillage soil

After some years of zero-tillage the soil compacted distinctly in the layer 5 to 30 cm below the surface, which was measured with a penetrometer. In sandy soil high penetrometer values (3 to even 4 MPa) were measured. For optimum root growth penetrometer resistance should not be above 2 MPa. Because of the great mechanical resistance, rooting in the compacted layer was distinctly less. For cereals this compaction usually did not give lower yields. In growing root crops, as sugar beets, carrots and chicory the compacted layer caused serious malformations and branching which made them difficult to harvest and unmarketable. Moreover decreased rooting sometimes caused heavier drought damage on the zero-tillage plots.

On clay soil compaction also gave higher penetrometer resistance, but with sufficient moisture the soil usually remained plastic so that the roots could penetrate. In general root growth in the compacted layer was distinctly retarded, but in the end the roots penetrated to the same depth as in the tilled soil.

On clay soil compaction decreased the pore volume to such an extent that during heavy rainfall the rain water drained slowly. This caused insufficient aeration and with it the dying of roots. Often only the top layer collapsed, which caused puddling; with it anaeroby and because of this roots or germinating seeds died. The process of compaction was somewhat retarded by growing green-manure crops which also decreased the collapse of the top layer of clay soil. On sandy soil decreased activity of earthworms was also observed. The larger deeply penetrating species, such as Lumbricus terrestris, Allolobophora caliginosus rarely occur on sandy soil, the smaller species are of little
effect in loosening the zero-tillage soil. The compacted profiles on sandy soil could only be improved by soil tillage. On clay soil, especially in periods of drought (cracking down to 150 cm below the surface) and probably also during periods in which frost and thaw alternate, the structure of the soil was more or less improved in a natural way.

3. Distribution of organic matter, nitrogen and moisture in the profile of tilled and zero-tillage soil.

Because the soil in zero-tillage was not loosened, but heavy harvesters passed over it, the topsoil was distinctly more compacted when compared with the ploughed soil. All inorganic (fertilizers) and organic (plant remains, green-manure crops) dressings were spread or left on the soil. The top layer of 5-10 cm of the zero-tillage soil contained more organic matter, nitrogen and other nutrients than the original top layer.

The distribution of organic matter and nitrogen in the profile is shown in Fig. 1. The top layer of the zero-tillage soil contained distinctly more nutrients. Below this layer less organic matter and nitrogen were present, because the topsoil and subsoil layers were not mixed by ploughing and moreover less organic matter was removed to the subsoil.

![Fig. 1. Distribution of organic matter (left) and nitrogen (right) in the profile (50 cm) in kg organic matter are$^{-1}$ cm$^{-1}$ and kg N are$^{-1}$ cm$^{-1}$. ——— = tilled, ——— = zero-tillage soil.](image-url)
The moisture content in the soil, expressed as an A-value is shown in Fig. 2. The reaction of the different treatments is distinct to the dry period (3 through 18 April) and to periods of rainfall (14 mm on 20 April).

![Fig. 2. Moisture content - A value - in the profile (30 cm) on tilled (A) and no-tillage (B) soil on different dates: x — x = 3 April; 0—-0 = 11 April; □ — □ = 18 April; △ — △ = 24 April 1979.](image)

The topsoil of the zero-tillage treatment dries more slowly in spring than the rough surface of the ploughed soil. After a shower the top layer of the zero-tillage soil remains distinctly wetter than that of the tilled soil. Drainage on the zero-tillage soil is probably slower than that on tilled soil. A difference in the pore volume might be the cause. The subsoil of both treatments shows little differences in moisture characteristic (Fig. 2). The subsoil of the zero-tillage treatments is somewhat drier than that of the tilled soil.

4. Yields of the various crops
The crop rotation system on the long-term experimental fields was not fixed. In some cases another crop had to be chosen because of weed problems on the zero-tillage treatments. For this reason a cleaner crop was preferred, for instance, maize instead of sugar beets or peas.

Fig. 3. shows the yield of silage maize, spring barley, winter wheat and peas on tilled and no-tilled soil plotted against the nitrogen dressing. The yields are averages of 2 on clay and 9 on sand; 12 on sand and 10 on clay; 10 on clay; 12 on clay, respectively. Silage maize on the zero-tillage treatments was distinctly retarded, but the differences were similar with all the nitrogen levels. Silage maize did, however, show a distinct nitrogen effect.
Fig. 3. Yields of silage maize in 10^3 kg ha^{-1}; spring barley, winter wheat and peas in 10^2 kg ha^{-1}. = tilled; x—x = zero-tillage soil.

Spring barley on the zero-tillage treatment at a low nitrogen level produced a higher yield, but the increase was lower with more nitrogen on the zero-tillage treatment. At the highest nitrogen level the difference was negligible only 60 kg per ha.

Winter wheat on the tilled and no-tilled treatments produced almost the same yields. The lower yields with 190 kg N per ha were caused by lodging.

The zero-tillage soil was favourable for the yield level of peas.

Table 1 shows that the lower yields of the zero-tillage treatments could be partly compensated by a higher nitrogen dressing.

Table 1.

<table>
<thead>
<tr>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29</td>
</tr>
<tr>
<td>2</td>
<td>39</td>
</tr>
<tr>
<td>3</td>
<td>43</td>
</tr>
<tr>
<td>4</td>
<td>29</td>
</tr>
</tbody>
</table>

Fig. 4 shows all the yields of the various crops and nitrogen levels on the tilled and non-tilled soil. Fig. 4 shows that about 65% of the yields of tilled soil treatments were higher than those of the no-tilled treatments but that the yield difference usually was between 0 and 10% (the interrupted line shows the 15% differences).
Sugar beets and other root crops have not been included in the figure, since these crops produced lower yields on the zero-tillage treatments, especially on sandy soil. Table 2 shows the sugar yields of beets grown on clay soil.

Table 2. Yields of sugar beets (kg sugar per ha), averages of 2 experimental fields on clay soil in 3 years

<table>
<thead>
<tr>
<th></th>
<th>50</th>
<th>150</th>
<th>250</th>
<th>350</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tilled soil</td>
<td>8500</td>
<td>8600</td>
<td>8900</td>
<td>8500 kg sugar ha⁻¹</td>
</tr>
<tr>
<td>No-tilled soil</td>
<td>7250</td>
<td>7700</td>
<td>7550</td>
<td>7500 kg sugar ha⁻¹</td>
</tr>
</tbody>
</table>

The yields of the zero-tillage treatments are distinctly lower. These are partly caused by the usually less even germination in the rough and sometimes compacted seedbed on the zero-tilled soil. In addition beet growth was often retarded on the no-tilled soil.

Potatoes are not suitable in a zero-tillage system because of the intensive soil tilling with both planting and lifting.
Conclusion.
Many crops adjust surprisingly well to the less favourable conditions in the no-tillage treatments of the long term experiments. The yield decreases did not suggest an increase or disappearance in the course of the years. However, the risks of failure or lower yields were greater than with conventional soil tillage. The no-tillage system is unsuitable for root crops.

In the Netherlands the zero-tillage system is not generally used, because of the high percentage of root crop in the rotation programme. Incidentally, sowing in no-tilled soil may be profitable, for instance, in erosion-sensitive soils and saving of time when sowing silage maize in spring after the harvest of an Italian ryegrass crop.

In future a change to less soil tillage could be profitable for some crops, with a view to energy costs, for instance, less soil tillage when sowing winter cereals after a root crop.

Literature

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ABSTRACT

Research results and experiences show that the normal autumn ploughing (20–25 cm) can be replaced with shallower tillage using a disc-tiller or a cultivator, or both in combination, to depths of ca. 10–12 cm provided that soil compaction is not too severe, that the quantity of crop residues does not cause problems, and that the amount of weeds is not too large. Tillage costs are normally reduced, most at autumn sowing on clay soils during dry conditions. Of the crops studied, oats has reacted most positively to ploughless tillage. Suitable soil types were silt loam, silt clay loam and heavy clay.

INTRODUCTION

About 125 years ago mouldboard ploughs of the type used today started to be made and sold in Sweden. Attempts to replace the expensive work of ploughing with some form of shallower tillage have, however, occurred to minor extents from time to time, largely since the early 1940’s, without being used to any particular extent in practice.

In the early 1970’s, however, a rapid development of implements for stubble cultivation took place. In addition, many different forms of using alternatives to the mouldboard plough began to become popular in many places throughout the world, mainly in areas with low precipitation and in areas with water- or wind erosion. In 1973-1974 the prices of energy increased strongly. Many Swedish farmers asked themselves whether it was always essential to plough, as in some cases, following a couple of stubble cultivations plus subsequent harrowing, the sowing could be done without problems.
Taking this in consideration long- and short-term trials were started where normal autumn ploughing to depths of 20-25 cm was replaced with shallower tillage alone in the autumn. The shallower tillage implies 2-3 stubble cultivations with a disc-tiller or a cultivator, or with both in combination, down to ca. 10-12 cm.

The results and experiences of 171 harvest-years from 73 different trial localities where this form of ploughless tillage is compared with conventional ploughing are presented in this report. The experimental work was done during the years 1976-1981. The experiments were spread over the whole of Sweden, most of them, however, in southern and central Sweden. At present there are 25 long-term experiments. The soil was a clayey till in 28 trials, sandy loam in 7, silt loam or silt clay in 10, clay in 26 and organic soil in 2 trials.

RESULTS AND EXPERIENCES

Crop. Table 1 shows that ploughless tillage generally decreased the yield, except in oats and spring oilseeds (rape and turnip rape). Table 1 also shows that the results for winter wheat, barley and winter oilseeds (rape and turnip rape) vary due to the preceding crop and the amount and treatment of the crop residues. The experiments in winter wheat and winter oilseeds have been divided into two groups, 1 and 2, in order as far as possible to illustrate the effects of excess crop residues. In group 2 the trash did not cause any problems and the differences between yields in ploughed and unploughed plots were negligible in this group. As problems seldom occur with crop residues during spring tillage, the division in the case of barley is instead made so that the negative effects of a preceding crop susceptible to root and foot rot diseases are eliminated in group 2. The result indicates that barley in unploughed plots is more easily attacked by diseases resulting from the rotation, as the effect of a non-susceptible crop was greater in unploughed plots than in ploughed. Ploughless tillage in the case of sugarbeet did not give satisfactory results. Although the average results were not much lower, the variation was greater in unploughed plots at the same time as the beets on these plots were also more forked.
Table 1. Field experiments with ploughless tillage, 1976-1981. Crop yield kg/ha:

<table>
<thead>
<tr>
<th>Crop</th>
<th>Number of harvest-years</th>
<th>Conventional tillage kg/ha</th>
<th>Ploughless tillage kg/ha</th>
<th>rel. yield</th>
<th>Sign.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter wheat</td>
<td>53</td>
<td>5120</td>
<td>5010</td>
<td>98</td>
<td></td>
</tr>
<tr>
<td>1. After cereals</td>
<td>26</td>
<td>4430</td>
<td>4230</td>
<td>96</td>
<td>*</td>
</tr>
<tr>
<td>2. After other crops</td>
<td>27</td>
<td>5780</td>
<td>5750</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Spring barley</td>
<td>54</td>
<td>4030</td>
<td>3940</td>
<td>98</td>
<td></td>
</tr>
<tr>
<td>1. After susceptible crops</td>
<td>33</td>
<td>3850</td>
<td>3680</td>
<td>96</td>
<td>**</td>
</tr>
<tr>
<td>2. After other crops</td>
<td>21</td>
<td>4310</td>
<td>4350</td>
<td>101</td>
<td>n.s.</td>
</tr>
<tr>
<td>Oats</td>
<td>28</td>
<td>4760</td>
<td>4840</td>
<td>102</td>
<td>n.s.</td>
</tr>
<tr>
<td>Winter oilseeds</td>
<td>20</td>
<td>2890</td>
<td>2630</td>
<td>91</td>
<td>**</td>
</tr>
<tr>
<td>1. Residues incorporated</td>
<td>13</td>
<td>2880</td>
<td>2520</td>
<td>87</td>
<td>**</td>
</tr>
<tr>
<td>2. Residues removed</td>
<td>7</td>
<td>2960</td>
<td>2870</td>
<td>97</td>
<td>*</td>
</tr>
<tr>
<td>Spring oilseeds</td>
<td>8</td>
<td>2030</td>
<td>2030</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Sugar-beets, t/ha</td>
<td>8</td>
<td>43.7</td>
<td>42.4</td>
<td>97</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

1) Crops with small amounts of residues
2) Susceptible to root and foot rot diseases

**Soil compaction.** Bulk density measurements have throughout shown increased values in the central and lower parts of the topsoil when ploughing was not carried out. The increase of the bulk density does not necessarily imply a deterioration of the root environment, in some situations this may even be improved, but the results still indicate that the risk of yield reductions caused by too high bulk densities are greater with ploughless tillage than with conventional tillage.

Despite the increased risk of compaction damage, ploughless tillage allows the natural processes of structure formation to work more undisturbed. If compaction is not too severe there will be a more favourable structural development that is very similar to the one occurring in a long ley. Soil physical investigations aimed at studying structural development and its effects have, for example, shown that air permeability (measuring method according to Andersson, 1969) in the bottom of the plough layer is markedly improved when
using ploughless tillage. Furthermore, preliminary results indicate that the improved structure of the topsoil obtained in ploughless tillage in comparison with conventional tillage, provides better protection against evaporation during dry conditions. This primarily concerns well-structured soils.

_Crop residues_. Only conventional implements have been used in the experiments. Among these, primarily the seed drills, with 12-13 cm row spacing, and the harrows have been sensitive to the trash on the surface. It must be possible to carry out seedbed preparation and sowing without problems caused by excess quantities of crop residues. We have found that if large quantities of residues occur they should always be removed from the field before autumn sowing but even if only normal quantities occur they should be removed if the period between harvest and sowing is short. Before spring sowing, it is often sufficient that crop residues are chopped and well incorporated during the autumn. As regards both autumn and spring sowing, however, the larger the quantity of crop residues left in the field the larger the number of stubble cultivations that will be needed to obtain acceptable degree of incorporation, and with the increased number of passes there will be an increased risk of compaction damage.

_Weeds_. Extra herbicide applications have generally not been done in unploughed treatments. In some of the experiments root-propagated weeds caused severe yield reductions in unploughed treatments. The root-propagated weeds in the treatments without ploughing were especially difficult to control on organic soils.

_Soil type_. Figure 1 shows how the relative yields of cereals in ploughless tillage vary with soil type. In this respect there was no difference between oats, barley or winter wheat. Good results were obtained on sites where the clay content was 15-30 % and particularly in conjunction with high silt content. Relatively good results were also obtained on heavy clays with stable structure. It was surprising that the results for the clayey-tills, that are relatively unsusceptible to compaction, were not better. The somewhat lower yields in places with medium clay can probably be ascribed to the susceptibility of these soils to compaction. The clay content is not sufficiently high to guarantee a stable aggregate structure (Heinonen, 1975). No trends were noticed on sandy loams.
Annual variations. The results of ploughless tillage also varied from year to year. Fig. 2 illustrates the yield results for barley and winter wheat for a number of years. In particular, 1978 was an unfavourable year for ploughless tillage. An explanation might be that the last stubble tillage operations during the autumn of 1977 in unploughed treatments in many cases were done under conditions that were too wet, with compaction and puddling as a result. Similarly, the climate during the growing period was relatively wet, which favoured certain diseases. These may have damaged the crop in unploughed treatments more than that in ploughed.

Fig. 1. Relative yield in ploughless tillage on different soils, with a 95% confidence interval. Mean values for oats, barley and winter wheat.

Fig. 2. Winter wheat and barley experiments with ploughless tillage, 1976-1981. Harvest results.

Tillage costs. Comparison of tillage costs (costs of implements, labour and fuel) between conventional tillage and ploughless tillage show that the greatest saving with ploughless tillage is in autumn sowing on clay soils.
In dry conditions, where ploughing and seedbed preparation are difficult. In some cases as much as 400 SEK/ha will be saved, which corresponds in Sweden to a market value of 350 kg of winter wheat (5.25 SEK = 1$). When conventional tillage worked well the cost-saving was considerably less and sometimes non-existent (Rydberg, 1980).

CONCLUSIONS

The results and experiences discussed indicate that ploughless tillage in Sweden can only be successful if the following three requirements are fulfilled.

1. Soil compaction must not be too severe. No field traffic under wet conditions.
2. Crop residues should either be removed or well disintegrated. The requirement for a good seedbed must always be met.
3. The weeds must be satisfactorily controlled with shallow cultivations and herbicides. Weeds propagated vegetatively should not be present.

The situation in which one should primarily consider ploughless tillage in Sweden is in autumn sowing under dry conditions. The risk of compaction damage is then small at the same time as ploughing and subsequent seedbed preparation are often demanding as regards time and energy.

Also in other cases where ploughing is difficult, e.g., in fields of uneven shape, it is recommended that ploughless tillage is used in both spring- and autumn sowing. The continued experiments will demonstrate whether there are cases when ploughless tillage throughout gives higher yields than conventional tillage. For example, whether the positive effect obtained in oats is permanent, or whether soils with high silt contents in conjunction with clay contents of 15-30% are particularly suited to ploughless tillage.

REFERENCES


- 130 -

SWELLING POTENTIAL OF SOIL AS A CRITERIUM OF PERMANENT DIRECT DRILLING SUITABILITY.

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Abstract.

Shrinkage and pF curves of 17 soil samples having clay contents of 11 to 65 % were determined. Using these results, shrink-swell magnitudes were calculated for different pF ranges. The rank of different soil materials as established with respect to swelling potential wasn't modified when changing the pF range. The described swelling potential test can be considered as suitable to compare cracking ability of soils and used as a direct drilling suitability criterium, provided soils have the same water regime.

In a direct drilling long term experiment, swelling appeared to be lower in the direct-drilled soil than in the ploughed one. Continuous direct drilling may consequently decrease cracking magnitude.

INTRODUCTION.

Division of soil mass by wetting and drying is one of the major processes of structure evolution in no-tilled soil. In cultivated soils under zero-tillage technique the conservation and regeneration of a convenient structure for agronomic purposes depend largely on it. This is the reason why cracking ability has to be considered as one of the main criteria of permanent direct-drilling suitability of the topsoil layer (STENGEL et al., 1982).

Cracking ability depends on shrink-swell properties of soil. However, information about structure evolution (fissures volume and shapes, size of structural units) is not sufficient to quantitatively assess the effect of water content changes, according to their number and magnitude, in different soil-types. Generally, cracking ability is only evaluated indirectly by using shrink-swell potential tests, i.e. measuring volume changes of soil samples between the dry and a low pF states. Classifying swelling behaviour of different soil material on this basis is possible. It is gene-
rally admitted, and broadly confirmed by field observations, that swelling classification is also valuable with respect to cracking ability.

This hypothesis has to be assumed. But since a potential for shrinkage and swelling is more or less completely realised, depending on pF variations in the field (REEVE et al., 1980), it is necessary at least to verify that swelling potential tests are suitable to compare field expression of shrinkage and swelling in different soil-types. Water regime influence on shrink–swell behaviour is likely to be a function of shrinkage curve feature.

For the assessment of direct-drilling suitability, eventual influence of tillage suppression upon swelling and cracking properties of soil must be known. Such an influence could modify a suitability classification established on a tilled soil properties basis.

MATERIAL and METHODS.

Soils :
Seventeen samples were taken from topsoil (12 samples) and subsoil layers. They were chosen to provide a range of clay contents in order to get contrasting shrink–swell behaviours. Extremes of clay content C were 11 and 65%.

Methods :
Samples were air dried and sieved between 3.15 mm and 2 mm meshes. Further measurements were made on aggregates obtained by sieving. This kind of aggregates generally have a massive structure on a macroscopic scale, and their porosity in the dry state evidences little variation when they are taken at different times in a given soil layer. Working with these aggregates allows to eliminate soil structure variations effects on shrinkage curve. Consequently the shrinkage curve can be considered as stable for one soil material under a given crop system and taken as a characteristic of its behaviour (STENGEL, 1979). This cannot be assumed with clods of different size in tilled layers, because of structure and porosity variations of clods.

Initially, air dried aggregates were placed on water-saturated porous plates, with a 3 mbar water suction (pF = 0.5). Duration of wetting was at least four days. Swelling had not any limitation due to mechanical stresses. Such conditions are only representative for aggregates if loca-
ted precisely at the soil surface. It is likely that they can be extrapolated within the tilled layer, when the pore volume between aggregates or clods is sufficient for them to swell quite freely in it.

Increasing air-pressure were then applied to porous plates up to \( pF = 4.2 \). Duration of anyone of the eight successive equilibria was 48h as a minimum. For upper \( pF \) values suctions were fixed by vapour equilibrium with sulfuric acid solutions. At any step of drying, measurements of water content and aggregates density were made. Techniques are described in FIES and STENGEL (1981).

RESULTS and DISCUSSION.

Shrinkage curves.

\[ e \quad \text{vs} \quad \frac{v}{v_{\text{solid}}} \]

- - - C = 11%  
- - - C = 29%  
- - - - C = 65% (values, up to \( e = 1.51 \) could not take place)

\( pF_{AE} = 2.1 \)
\( pF_{AE} = 2.3 \)
\( pF_{AE} = 4.5 \)

saturation line

Fig. 1 - Shrinkage curves of aggregates for different clay contents.

Three shrinkage curves are shown (Fig. 1) as example of variation in the curve type with clay content, which had previously been described
with smectitic clay-silt mixtures (STENGEL, 1982). At the lowest clay content (C = 11%), shrinkage magnitude was low, and only normal (saturated) shrinkage occurred in a low pF range. For C = 29%, shrinkage was mostly residual (non-saturated). Air entry point (AE) and shrinkage limit (SL) appeared distinctly with pF<sub>SL</sub> = 4.8. When different of pF<sub>AE</sub>, pF<sub>SL</sub> had a high value in all soils and varied from 4.2 to 5.5.

For C = 65%, essentially normal shrinkage was observed. Aggregates stayed saturated to pF<sub>AE</sub> = 4.5. The following regression equation obtained on these samples suggests this result is common to clay soils:

\[ pF_{AE} = 0.049 C + 1.19 \]

\[ r = 0.90^{**} \]

\[ n = 17 \]

Because of these important differences in shrinkage behaviour deviation between shrink-swell potential, measured between air dry state and pF = 0.5, and shrinkage or swelling corresponding to narrower pF ranges in the field must depend on soil type.

**Swelling in relation to pF range.**

Swelling index was defined as follows:

\[ S = \frac{e_{pF_1} - e_{pF_2}}{\Delta V (pF_1 + pF_2)} \]

where \( e \) is the void ratio and \( V \) the massic volume, corresponding to indicated values of pF.

Particular values of \( S \) were calculated corresponding to pF ranges which are typical of water regime in soil. They are:

\[ s_{0.5} = \frac{e_{0.5} - e_d}{e_d + 1} \]

\[ s_1 = \frac{e_{0.5} - e_{4.2}}{e_{4.2} + 1} \]

\[ s_2 = \frac{e_{FC} - e_d}{e_d + 1} \]

\[ s_3 = \frac{e_{FC} - e_{4.2}}{e_{4.2} + 1} \]

\( e_{0.5} \) = void ratio at pF = 0.5, rewetting of aggregates

\( e_{4.2} \) = void ratio at whilting point

\( e_{FC} \) = void ratio at field capacity. pF of FC was chosen between pF 2 and 3 according to soil granulometry.

\( s_1, s_2 \) and \( s_3 \) are closely correlated to \( s_p \) (swelling potential) as shown in table 1. It can be concluded from it that swelling potential test appears to be adequate to compare shrink-swell behaviour of different soil-materials if they have in the field similar water regime, i.e. similar climate, crop system and drainage conditions. When this hypothesis has to be discarded comparison of shrink-swell behaviour in the field may be different from the comparison on \( s_p \) basis, as indicated by differences between
$S_p$ and $S_3$ for example. Shrinkage and pF curves, and an adequate knowledge of pF variations are necessary to get some kind of assessment in this case.

Table 1: Regression equations between different swelling indexes and swelling potential.

<table>
<thead>
<tr>
<th>Index</th>
<th>Equation</th>
<th>r</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_1$</td>
<td>$0.540 S_p + 0.081$</td>
<td>0.98***</td>
<td>17</td>
</tr>
<tr>
<td>$S_2$</td>
<td>$0.835 S_p - 0.086$</td>
<td>0.96***</td>
<td>17</td>
</tr>
<tr>
<td>$S_3$</td>
<td>$0.458 S_p - 0.030$</td>
<td>0.92***</td>
<td></td>
</tr>
</tbody>
</table>

Regression equations and shrinkage curves description lead to the same conclusion. The influence of a change in pF range on swelling magnitude varies with soil materials, resulting in significative values of the intercept of the regression line. For a soil with $S_p < 0.15$, when the upper hydration limit is drawn from pF:0.5 to FC, swelling becomes zero. This can explain TRI and MONNIER's finding (1973) showing that granular structure under granaceous meadows develops only if $S_p > 0.15$.

Swelling as influenced by direct-drilling.

There is no evidence of a difference in the shape of the shrinkage curve in a direct-drilled or ploughed soil, when organic matter content is the same (STENGELE, 1979). But direct-drilling seems to change hydraulic properties of previously ploughed soils (GOSS et al., 1978). An eventual change in swelling ability could be due to variation in water retention properties.

In order to determine whether this occurs, aggregates were sampled in the ploughed and direct-drilled treatments of a tillage experiment in a silty-clay-loam, at 10 cm depth. Air-dried aggregates were rewetted on porous plates, successively at decreasing pF values. Equilibria duration was at least 10 days.

Results in figure 3 indicate that the nine years direct-drilled soil retained less water than the ploughed one between pF = 3 and pF = 0.7. In situ measurements of FC agreed with this conclusion. FC was 22.1 % of dry mass in ploughed soil and 20.2 % in direct-drilled one. Such a decrease in FC, when converted in variation of $S_2$ using shrinkage curves of the respective soils, reduced $S_2$ from 0.14 to 0.11. As a consequence of it, non tilled soils can lose part of their cracking ability.
Fig. 2- Effect of tillage technique on water retention.

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EFFECT OF CONVENTIONAL AND MINIMUM TILLAGE ON SOME PHYSICAL PROPERTIES AND ON SOIL ORGANIC MATTER OF TWO SOIL TYPES IN BULGARIA

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ABSTRACT

Minimum tillage has a considerable negative effect on the physical properties of smolnitza (Pallic Vertisol) whereas it almost does not affect the physical properties of grey forest soil (Chromic Luvisol). Growing of pea as a forecrop to maize raises organic matter content in both soils. Similar is the effect of minimum tillage. Qualitative composition of humus in smolnitza is strongly influenced by the system of soil tillage and crops grown. With grey forest soil no such influence is observed.

To study the effect of different systems of soil tillage and of maize residues on some physical properties, on quantitative and qualitative composition of soil organic matter and on the yield of maize grown as a single crop and in combination with a second crop (winter field pea) with wheat and lucerne as forecrops, in the period 1972-1980 field experiments were carried out on grey forest soil in the experimental field near Belogradchik, Vidin District, and on leached smolnitza in the experimental field in the village of Budechte, Stara Zagora District.

The grey forest soil is located at an altitude of 450 m above sea level. In terms of mechanical composition it is loamy and contains about 10-14% clay in the arable horizon. The sandy fractions (particle size 1-0.25 mm) predominate throughout the profile. Considerable is also the amount of large particle-size silt (0.05-0.01 mm particle size). The humus horizon has a depth of 30-40 cm and the humus content is very low: 0.7-1.4%
in the arable layer and less than 0.5% in the layers beneath. The supplies of N and P are low and the reaction of the humus horizon is acid.

The Smolnitsa investigated is located in South Bulgaria, in a hilly plain at an altitude of 160 m above sea level. The soil is moderately thick with a high content of clay (50-56%). The humus horizon is 70 to 80 cm thick. The humus content in the arable layer is 2.7 - 3.3% and in the underlying layers - 1.1 - 2.2%.

Meteorological conditions of the two fields during the period of experimentation are characterized by the following data:

<table>
<thead>
<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Belogradchik (Grey Forest Soil - Chromic Luvisol)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation (mm)</td>
<td>961.5</td>
<td>750.7</td>
<td>1105.6</td>
<td>806.8</td>
<td>738.6</td>
<td>653.8</td>
<td>838.5</td>
<td>848.9</td>
</tr>
<tr>
<td>Mean annual temperature (°C)</td>
<td>9.0</td>
<td>9.3</td>
<td>9.7</td>
<td>8.2</td>
<td>10.0</td>
<td>8.9</td>
<td>9.6</td>
<td>8.7</td>
</tr>
<tr>
<td>Budeshte (Smolnitsa - Pallic Vertisol)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation (mm)</td>
<td>680.0</td>
<td>578.9</td>
<td>628.4</td>
<td>585.2</td>
<td>568.6</td>
<td>658.2</td>
<td>702.2</td>
<td>601.2</td>
</tr>
<tr>
<td>Mean annual temperature (°C)</td>
<td>11.6</td>
<td>12.3</td>
<td>12.8</td>
<td>11.8</td>
<td>12.9</td>
<td>12.1</td>
<td>12.5</td>
<td>11.5</td>
</tr>
</tbody>
</table>

The field experiments were carried out according to one and the same scheme and included the following treatments:

A. Tillage treatments
1. After maize harvest stems are cut and incorporated 20-22 cm deep into soil, pea is sown which is harvested in spring, pre-sowing discing is done and maize is sown.
2. The operations are the same but maize residue incorporation is not performed.
3. Conventional tillage of maize grown as a single crop: ploughing 26-28 cm deep in autumn, spring cultivation 7-8 cm deep and sowing of maize.
4. Minimum soil tillage: discing 7-8 cm deep in autumn, herbicide application and pre-sowing discing in spring.
5. Mulch tillage of soil: maize stems are cut into pieces and spread over soil, then 7-8 cm deep discing follows, in spring herbicides are applied
and presowing discing is performed.

B. Fertilizer application treatments:

<table>
<thead>
<tr>
<th></th>
<th>F₁</th>
<th>F₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td>N₁6 P₅₄ K₂₀</td>
<td>N₂⁷ P₉₀ K₃₀</td>
</tr>
<tr>
<td>Leached chernozem-smolnitzya</td>
<td>N₁₆ P₅₄ K₂₀</td>
<td>N₂₄ P₉₀ K₃₀</td>
</tr>
</tbody>
</table>

P and K fertilizers were applied every four years whereas N fertilizers were applied annually.

The basic herbicides used were atrazine and alachlor and during the vegetation period - 2,4-D. The experimental field in Budeshte was sown under the K 21602 maize hybrid and that in Belogradchik - under the BC 66-25 hybrid. The two experimental fields were also sown under field pea of a Pleven improved variety.

During the vegetation period the basic physical indices of the arable layer and of the underlying layers were studied in relation to the main tillage treatments, as follows:

- moisture content - by measuring weight;
- density and porosity - using the cylinder method
- strength - with a strength-meter with a falling weight (of our construction).

RESULTS AND DISCUSSION

The data obtained for the soil moisture content in leached chernozem-smolnitzas involved in a multiple cropping system during the vegetation period (Tabl.2) indicate the following:

In the event of even distribution of rainfall deep ploughing is instrumental in retaining more water in the arable layer within 25 cm of the surface. Before its harvest, in spring, winter pea takes up considerable quantities of water for transpiration but shading of soil surface reduces the amount of water evaporated and that is why in most cases there are no significant differences between the second crop treatments and no second crop treatments in terms of moisture content. The minimum tillage treatments do not differ considerably from the conventional tillage treatments in soil moisture content.

During vegetation in most cases soil density is lower with the deep ploughing in autumn treatments. After a long-term minimum tillage soil becomes compact and only within 5 cm of the surface where considerable amounts of semi-
decomposed plant mass accumulates it remains loose. Since ploughing for the second crop (pea) is usually shallow, below 15 cm of the surface soil is very dense.

Soil strength varies within an extensive range depending on soil density and moisture content. At soil moisture content which is optimal for crop growth soil strength does not exceed 20–30 kg/cm² and does not seriously impede maize root penetration deep into soil. When soil dries up, however, strength may reach values of the order of 100 kg/cm² which is far beyond the admissible limits. On the average (for four years), soil density within 25 cm of the surface is 0.5 to 2.2 times higher with the surface tillage treatments as compared with the annual ploughing treatments.

### TABLE 2

Average Moisture Content, Density and Strength of Leached Chernozem–Smolnitza during the Vegetation of Maize (for Four Years)

<table>
<thead>
<tr>
<th>Treatment No.</th>
<th>Moisture content in different layers (%)</th>
<th>Density in different layers (g/cm²)</th>
<th>Strength at different depths (kg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>21.4 22.8 19.9</td>
<td>0.98 1.27 1.37</td>
<td>9.2 17.1 26.9 34.8 34.8</td>
</tr>
<tr>
<td>3</td>
<td>22.1 21.9 24.5</td>
<td>1.02 0.98 1.29</td>
<td>7.4 12.9 17.9 18.8 21.9</td>
</tr>
<tr>
<td>4</td>
<td>20.9 24.4 20.8</td>
<td>0.97 1.22 1.37</td>
<td>9.8 21.7 26.3 31.2 30.7</td>
</tr>
<tr>
<td>5</td>
<td>21.6 23.3 20.9</td>
<td>0.94 1.23 1.39</td>
<td>11.7 27.0 32.6 43.6 32.8</td>
</tr>
</tbody>
</table>

### TABLE 3

Average Moisture Content, Density and Strength of Grey Forest Soil during the Vegetation of Maize (for Three Years)

<table>
<thead>
<tr>
<th>Treatment No.</th>
<th>Moisture content in different layers (%)</th>
<th>Density in different layers (g/cm²)</th>
<th>Strength at different depths (kg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>13.6 17.4 18.1</td>
<td>1.22 1.42 1.49</td>
<td>17.6 25.4 31.3 32.3 36.7</td>
</tr>
<tr>
<td>3</td>
<td>16.6 17.3 17.8</td>
<td>1.30 1.52 1.58</td>
<td>19.7 41.6 52.4 52.2 51.4</td>
</tr>
<tr>
<td>4</td>
<td>14.8 17.5 16.6</td>
<td>1.22 1.52 1.55</td>
<td>13.3 38.2 56.8 57.6 55.5</td>
</tr>
<tr>
<td>5</td>
<td>16.2 17.9 17.4</td>
<td>1.24 1.55 1.59</td>
<td>10.2 26.3 44.0 46.8 46.1</td>
</tr>
</tbody>
</table>
Physical indices for the arable layer of grey forest soil do not vary significantly with different treatments (Table 3). The effect of loosening of soil through ploughing in autumn is completely lost in winter and during maize vegetation soil density becomes more or less the same with all treatments. As soil moisture content decreases during the vegetation period soil strength increases far more in the case of ploughing treatment than it does with other treatments. In the surface layer the lowest soil strength values are recorded after mulching while in the underlying layers soil strength is lowest where a second crop is grown because then the loosening effect of roots and of spring tillage of maize lasts longer.

The results from the study of soil organic matter are given in Tabl.4.

**TABLE 4**

<table>
<thead>
<tr>
<th></th>
<th>Total C (g%)</th>
<th>Ch/Cf</th>
<th>Treatments</th>
<th>Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td>1 2 3</td>
<td>4 5</td>
<td></td>
</tr>
<tr>
<td>Grey forest</td>
<td>0.76 0.70 0.67 0.76 0.85 0.68 0.76 0.70 0.63 1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smolnitzo</td>
<td>1.74 1.64 1.50 1.63 1.72 3.00 3.31 2.27 2.11 1.70</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All treatments have advantage over the standard (conventional tillage (treatment 3) in terms of raising humus content. On both soils favourable conditions for humus formation are created in the event of growing of pea as a second crop and maize residues incorporation. This fully agrees with the hypotheses of humus formation (Flaig, Kononova). Considerable is the effect of minimum tillage, too (treatment 4). In this case leaving mulch in the field does not increase humus content. The ratio of $C_h$ to $C_f$ varies in an interesting manner which can be attributed to the humus quality. On smolnitzo pea sowing strongly increases the amount of humic acids whereas minimum tillage increases the relative share of fulvic acids. This fact is probably due to some deterioration of soil physical properties which occurs in the event of minimum tillage and regular waterlogging of smolnitzo. In grey forest soil the changes in humus composition are so small that they can be considered insignificant which completely agrees with the stated above, i.e. that no significant differences between the physical indices for the investigated treatments on this soil have been noted. From here it logically follows that humus content state or humus quality are strongly dependent on soil physical conditions.

THE LIMITATIONS OF GROWING CEREALS UNDER ZERO TILLAGE IN CZECHOSLOVAKIA

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ABSTRACT
The paper summarizes the main limiting factors of growing cereals under zero tillage in Czechoslovakia. Soil as well as climate conditions have been designated as conservative limitations which specify, in general, the extent of cereals grown under zero tillage technology. From cultivating factors the following ones proved the main importance: crop structure on the arable land; precrops; weed infestation. Material as well as technical limitations have a conditional character only.

INTRODUCTION
In the last 10-15 years the Czechoslovak research on soil tillage has been concentrated mainly to "minimum tillage", especially to investigating conditions for growing cereals under zero tillage. Firstly, the causal dependences between physical soil characteristics and cereal growth under various soil tillage systems were studied /ČERNÝ, 1979/. On the basis of an extended series of model experiments a dependence of winter wheat and spring barley on the soil density was derived by STRAŇÁK /1968/.

This essential research became basis for numerous experiments in which the dependence between soil tillage and other cultivation elements as precrop, fertilizing etc. was studied. The main interest was concerned to possibilities of growing cereals under zero tillage /STRAŇÁK, 1971 a, b, NOVÁČEK, 1973/. In parallel with mentioned experiments ŠIMON /1976/ established model field experiments to reveal the possibilities of growing other crops, namely silage maize, horse bean, mustard, sugar beet, sunflower and peas under zero tillage.
Along with this, the theoretical problems of growing cereals under zero tillage were studied, in particular the relations to mineral fertilizing, dynamics of chemical soil characters, microbial processes in the soil, decomposition of post-harvest residues and their phytotoxicity, soil humidity etc.

The further important phase of the research concerned various cultivation systems, namely crop rotations and agroecological conditions/cultivation zones/. The experiments by NOVÁČEK /1976/, SUŠKEVIČ /1976, 1978/, ŠIMON /1979/ and others established in the cropping areas of maize and sugar beet, were to compare growing of cereals under zero tillage and traditional tillage in conditions of different proportion of crops in the rotation.

The experimental results of the period 1970-1975 have represented a complete theoretical knowledge on the chemical, physical and biological processes in the soil which can be exploited in exact as well as farm field experiments.

On the basis of experimental results of minimum tillage and completed research on soil classification the farming systems for individual soil-ecological units are being elaborated. Within the framework of soil tillage research also parameters and essential limitations for growing cereals under zero tillage are being determined.

LOCALITY LIMITATIONS

Soil limitations

Some indicators of soils suitable for minimum tillage and growing cereals under zero tillage were defined on the basis of land classification in Czechoslovakia/SUŠKEVIČ ET AL., 1979/, tillage methods, farming measures, mechanization /especially drilling machine 20-SeX 80-150/ and practical experience, as well.

Under conditions of Czechoslovakia following soil types are considered suitable for growing cereals under zero tillage: chernozem; browngrey podzolic soil; illimerized soil; rendzina. In connection with studies on suitability of mentioned soil types for growing cereals under zero tillage following soil indicators were investigated: a) granulation - 25-45 % proportion of clay-particles of 0,01 mm; b) depth of the arable layer - depth of the arable profile over 30 cm; c) skeleton particles - isolated particles over 10 mm only; d) moisture content - neither temporal
wetting of ground; e) water permeability - good water infiltration; f) pH - over 5.6; g) humus content - over 2.5 % in the arable layer; h) absorption capacity - well or fully saturated soils; i) biological activity - good; j) warming-up capacity - e.g. cold soils /clayed/ are unsuitable.

The soil classification performed according to listed indicators showed that suitable soil conditions for minimum soil tillage and zero tillage exist in 49 and 36 % of the arable land in the Czech Socialist Republic, respectively. In the Slovak Socialist Republic the respective per cents are 39 and 33.

Climate limitation

Definition of suitable conditions for drilling cereals under zero tillage has been derived from climatic regions as established according to data of the new climatogeographical regionalization of the Czechoslovak Socialist Republic /based on fifty years averages/. As main climatic characteristics the following ones were chosen: a) the sum of daily temperatures over 10°C; b) the average yearly air temperature /°C/; c) the average yearly rainfall /mm/.

It was ascertained that the application of minimum soil tillage has been limited by climate conditions only weakly. Minimum soil tillage can be applied on all suitable soils with the following limitations: elevation up to 500 m s.s.l.; average yearly air temperature over 7°C; the sum of temperatures over 10°C greater than 2500 °C; rainfall up to 700 mm.

The extent of growing cereals under zero tillage, however, has been much more conditioned by climate conditions. This concerns namely the safety of the zero tillage application, i.e., the minimum application risks. When grown under zero tillage, spring cereals are more susceptible to climate conditions than winter cereals.

The sufficient safety of the systems of growing cereals under zero tillage can be achieved in climate regions as defined: elevation 350 m above sea level; average yearly air temperature 8°C; rainfall up to 600 mm. The influence of climate conditions on the possibility of growing cereals under zero tillage in the Czech and Slovak Socialist Republics is demonstrated in maps 1 and 2. The influence of the climate on cereals grown under zero
tillage has been manifested by weather conditions of the year, in particular by weather course at the times of precrop harvest and cereals drilling.

Locality limitations have a character of directive values, i.e. criteria which have not been specified into classification score scales for individual localities as it was performed by CANNEL, DAVIES, MACKMEY, PIDGEON /1978/ and PIDGEON, RAGG /1979/ for conditions of Great Britain and Scotland. Our case concerns general criteria which are to be specified for individual farms according to concrete soil and climate, eventually weather conditions.

FARMING LIMITATIONS

The proportion of crops on the land has been considered the decisive farming limitation for growing cereals under zero tillage. The extent of applying the zero tillage system has been limited by unsuitable crop proportion, e.g. by a high proportion of cereals in crop rotation.

The maximum extent of growing cereals under zero tillage has been dependent particularly on appropriate precrops, i.e. appropriate crop rotation. In Czechoslovakia, drilling winter wheat under zero tillage can be recommended after following precrops: legumes; silage and grain maize; potatoes; early harvested sugar beet; and some vegetables. Spring barley under zero tillage can be grown only after sugar beet, grain maize and exceptionally also after potatoes.

Weed enfestation proves a very important factor which limits growing cereals under zero tillage. Provided only broad-leaved weeds are present that are easy to be controlled by common herbicides, no important danger of weed infestation takes place for cereals grown under zero tillage. In no case, however, cereals are to be grown under zero tillage if land is infested by perennial weeds, particularly by doggrass or by some broad-leaved weeds which are resistant to common herbicides. In such conditions the zero tillage technology represents risk of yield reduction due to weed infestation or proves inprofitable due to necessity of applying expensive special herbicides.

MATERIAL, TECHNIQUE ORGANIZATION LIMITATIONS

These limitations of growing cereals under zero tillage represent a conditional character only. The application of the sys-
stem requires particularly a perfect technical equipment of the farm, i.e., appropriate and efficient drilling machines, efficient herbicides, eventually other agrochemicals inclusive of increased amounts of fertilizers.

Organization measures represent also an important prerequisite. They consist in establishing appropriate tillage system/inclusive of zero tillage/, adapted system of both fertilizing and manuring/storage fertilizing/, weed control in crop-interphases, and establishing further prerequisites for growing crops under zero tillage as reducing soil acidity, increasing the content of organic matter in the soil, biological softening of the soil and subsoil etc.

Also experienced personal is of great importance; this concerns not only the organizing but also the efficient personal applying the system of growing cereals under zero tillage. Unsuccessful experience may result in unsuccessful zero tillage technology.

REFERENCES

STUDY OF MINIMUM SOIL TILLAGE IN DRY FARMING AND IRRIGATION CONDITIONS ON CHERNOZEM TYPE OF SOIL

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Abstract

During 1979 and 1980, we investigated the effect of three methods of soil tillage and stubble removal in conditions of dry farming and irrigation on soil water balance and maize grain yield on chernozem type of soil.

Results showed that the dynamics of the moisture level in the soil layer 0-40 cm (soil water balance) was considerably more favourable in conditions of irrigation than dry farming. This was particularly expressed in 1980, when it was found, in all investigated factors, that the water in the soil was above the limit of prewettering moisture. In 1979, several times the moisture content dropped below this limit in irrigation conditions. However, this lasted only a short time.

In conditions of dry farming, the moisture content in the soil was for a considerably long period of time below the limit of prewettering moisture, but not below the limit of nonaccessible water, which affected to a certain degree the maize yield.

The yield of maize grain was by 12.68% higher in irrigation conditions than in dry farming. Plant remains, when left on the plot in dry farming conditions, increased maize yield. The investigated methods of soil tillage showed that it is possible to grow maize on chernozem type of soil without tillage, and, yet, not significantly reduce maize yield.

Introduction

The intensification of maize production during the last decade both in the world and Yugoslavia, required a constant improvement of soil tillage methods. The task was to study the justification of eliminating certain procedures and developing new methods for soil tillage, as well as to critically review some methods of tillage which were so far accepted as necessary.
One of the latest methods is minimum soil tillage, or planting the crop without tillage, to save energy, reduce soil erosion, timely conduct cropping practices, eliminate the negative effect of mechanization on the soil and achieve many other effects.

Minimum tillage was investigated in this work combined with different methods of removing plant residues. At the same time, an attempt was made to determine the effect of investigated factors on the dynamics of soil moisture and maize yield in conditions of dry farming and irrigation.

The Yugoslav scientific and professional public is well acquainted with the possibilities in growing crops without tillage. Milić (8) and (9) in 1963 and 1964, respectively, reported the first experiment results. Ćorić (10) and (11) followed, and also studied this problem. Advantages of minimum tillage and removal of plant residues were reported by Van Doren and Triplett (13), Triplett (12), Kahn (3), Marissiov (10), Kovacev and Penčev (16) and many others. Many of them showed that superior yields are obtained using minimum tillage compared to conventional soil tillage.

There are no reports in Yugoslav literature which treat minimum soil tillage in irrigation conditions. There are basically reports treating different methods and depths of soil tillage in conditions of irrigation and dry farming. Such findings were reported by Kišić et al. (4), Dragović et al. (1) and Vučić (14).

A considerably greater attention is paid to minimum tillage in the world with many interesting reports such as Kraus (7), Simikaja (11), Weatherl et al. (14) and others.

The aim of this study was to determine the degree and characteristics of the effect of investigated factors on the dynamics of soil moisture and maize yield and at the same time investigate the possibility of growing maize on chernozem soil without soil tillage.

Material and Method

This study was conducted in 1979 and 1980 in Zemun Polje on chernozem type of soil. The cultivated layer of this soil contained 0.14 - 0.19% N, 3.72 - 6.15 mg P$_2$O$_5$ and 19.2 - 22.3 mg K$_2$O per 100 g of soil. The trial was set up as a three-factorial trial using the split-split plot design in four replications. In each year of investigation the preceding crop was wheat. The following factors were investigated:

I. Water $V_1$ - dry farming and $V_2$ - irrigation;

II. Method of removing plant remains: $S_1$ - burned straw; $S_2$ - removed straw and $S_3$ - straw left on the field;

III. Soil tillage: $O_1$ - minimum tillage - planting without tillage; $O_2$ - tillage with rotary hoe and $O_3$ - standard-conventional tillage.

Irrigation was conducted with artificial rain using "Savica" type of sprayers. The time of irrigation was determined on the basis of moisture content in the soil layer 0-40 cm. Prewatering mo-
Isture (P.M.) was 50% of the total accessible water (25.8%) of this soil layer or 70 mm of accessible water. In 1979, there were three waterings 20, 40 and 50 mm, respectively, giving a total norm of 110 mm. In 1980, the irrigation norm was 120 mm, distributed in three waterings each 40 mm. In 1979, waterings were performed May 25, June 5 and August 1, and in 1980, July 8 and 18, and August 5.

Plant residues were burned on the plot (S1) removed after harvesting chopped on the plot (S2). In treatment O1, planting was performed with a planter without preceding tillage of the soil. In the treatment O2, tillage was performed with a rotary hoe in the fall to a depth of 10-12 cm, and planting with a planter. Conventional tillage consisted of the following: chaff ploughing under of the stubble field to approximately 15 cm immediately after harvesting wheat, primary tillage in the fall to a depth of 25 cm, seedbed preparation in the sowing with RAU-combi and planting with planter.

The following amounts of fertilizers were applied, in the fall: 150 kg/ha N, 105 kg/ha P2O5 and 75 kg/ha K2O. After planting the hybrid ZP SC 1A with a plant population of 40,800 plants/ha, the plot was treated with the herbicide Lasso-Atrazin in the amount 6 l/ha. During the growing season, one inter-row cultivation was performed. Every 15 days determinations were made of the soil moisture content by drying soil samples at a temperature of 105°C. The yield was analysed using the factorial analysis of variance.

### Basic Climatic Characteristics

Basic meteorologic data for the growing season 1979 and 1980 are given in Table 1. Table 1 shows that the average air temperature in 1980 (16.9°C) was lower compared to 1979 (17.7°C) when the rainfall was somewhat lower 332.9 mm, too. In 1980, there was 358.7 mm of rainfall. In the studied years, the conditions for maize growing were favourable, so that good yields were obtained.

<table>
<thead>
<tr>
<th>Climatic factors</th>
<th>Year</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
<th>X/</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature °C</strong></td>
<td>1979</td>
<td>10.5</td>
<td>17.2</td>
<td>21.8</td>
<td>19.6</td>
<td>19.9</td>
<td>17.0</td>
<td>17.7</td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td>9.1</td>
<td>14.6</td>
<td>19.9</td>
<td>20.8</td>
<td>20.5</td>
<td>16.8</td>
<td>16.9</td>
</tr>
<tr>
<td><strong>Rainfall mm</strong></td>
<td>1979</td>
<td>45.5</td>
<td>60.6</td>
<td>94.5</td>
<td>48.4</td>
<td>66.2</td>
<td>17.7</td>
<td>332.9</td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td>38.8</td>
<td>116.6</td>
<td>88.8</td>
<td>42.6</td>
<td>46.5</td>
<td>25.2</td>
<td>358.7</td>
</tr>
</tbody>
</table>

### Results and Discussion

1. Soil moisture content

The dynamics of moisture content in the soil layer 0-40 cm is show graphically in absolute indices (volumetric %) for the maize growing season according to investigated treatments and years (Graph 1 and 2).
The rainfall sum for the maize growing period in both investigated years was almost the same 332.9 mm in 1979 and 358.7 mm in 1980, but the distribution was not uniform. This affected to a certain degree the dynamics of soil moisture content. In 1980, the water balance of the studied soil layer was somewhat more favourable both in conditions of irrigation and dry farming. This was partially due to a greater reserve of soil moisture retained during the winter period (Graph 2).

Graph 1 and 2 show that there were no significant differences and deviations in the accumulation of moisture and the development of a more favourable water balance of the studied soil layer depending on the investigated methods of tillage. It was observed in some cases that the accumulation of moisture in the soil was lower when using the conventional method of soil tillage, i.e. the water balance was less favourable than in the other tillage treatments. This shows that minimum tillage is not inferior in providing a certain moisture content level compared to conventional tillage or tillage with rotary hoe.

The investigated methods of removing plant remains did not significantly affect the soil moisture content, although, it was observed, that, when plant remains were left on, the plot, the moisture content was higher. It was found that this was more expressed in conditions of dry farming.

2. Effect of investigated factors on maize yield

Table 2 shows average yields for 1979 and 1980.

Results show that the investigated factors did have a certain effect on the yield of maize grain. The average yield under irrigation conditions was by 1.21 t/ha or 12.68% higher compared to dry farming. This is statistically highly significant. Similar results on the effect of irrigation on maize yield was reported by many other authors.

Plant remains affected the yield to a certain degree. The highest yield was obtained in treatments where plant remains were left on the plot both in conditions of irrigation and dry farming. Therefore, plant remains increase the yield when left on the plot. The highest effect of plant remains on yield was observed in dry farming with treatment (O1) minimum tillage. The yield was 8.58 t/ha when the straw was burned and 9.63 t/ha when it was left on the plot. Similar results on the positive effect of plant remains on yield were reported by Van Doreen and Triplett (13), Triplett (12) and many others.

Table 2 - Effect of irrigation, different methods of soil tillage and plant remains on the yield of maize grain (average for 1979 and 1980 in t/ha)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>O1</th>
<th>O2</th>
<th>O3</th>
<th>Average</th>
<th>Relative</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>8.58</td>
<td>8.57</td>
<td>9.68</td>
<td>8.94</td>
<td></td>
</tr>
<tr>
<td>V1</td>
<td>9.33</td>
<td>9.50</td>
<td>10.31</td>
<td>9.71</td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>9.63</td>
<td>10.08</td>
<td>10.17</td>
<td>9.96</td>
<td></td>
</tr>
</tbody>
</table>

- 151 -
Differences were found among investigated methods of soil tillage. However, differences were significant only in conditions of dry farming between minimum and conventional tillage. This means, that irrigation secures a higher yield even in the case without soil tillage. It is significant to mention that these results were obtained on chernozem type of soil of good physical and chemical properties, which in this case is very important. Results of Milojic (9), Drezgic (2), Kovačev and Pencev (6) also confirm that with minimum or reduced tillage higher yields can be obtained compared to conventional soil tillage on soil types with favorable physical and chemical properties.

Reference


Fig. 2. Changes dynamic of the amount of water in the part of soil up to 40 cm depth in irrigation conditions in 1979 and 1980.
Fig. 1. Changes dynamic of the amount of water in the part of soil up to 40 cm depth in dry farming conditions in 1979 and 1980.
Effect of Reduced Tillage Systems on Soil Physical Properties and Maize Grain Yield in Ontario.
Departments of Land Resource Science* and Crop Science, University of Guelph, Guelph, Ontario, Canada. N1G 2W1.

Abstract
Maize plant performance on loam and silt loam soils in Southern Ontario appears to be more closely associated with the proportion of fine aggregates in the seedbed zone than with soil bulk density or mechanical impedance in the upper 20 cm of soil. Results of tillage experiments conducted on these soils have indicated that a substantial reduction in volume of seedbed preparation appears feasible with no reduction in maize productivity. Indeed, the data suggest that there is no requirement to till these soils deeper than 5 to 10 cm. However, complete elimination of tillage (i.e. zero tillage) has resulted in unacceptable reductions in maize yield.

Introduction
In 60 tillage experiments conducted during the past two decades in Southern Ontario, maize planted without tillage (zero tillage) has averaged approximately 14% lower grain yield than maize planted following conventional tillage (fall moldboard plowing plus spring secondary tillage). This yield reduction with zero tillage has occurred on all soils except coarse sands and gravelly loams where yield differences owing to tillage have been much smaller. Where maize has followed sod crops rather than maize in rotation, zero tillage has resulted in maize yields within 4% of those obtained with conventional tillage (Vyn et al., 1979).

Since 1975, experiments have been conducted on five soils with a wide range in texture to study various minimum tillage systems for maize production. The maize yield response to any particular tillage system has varied with soil texture and year. In this paper we will present summaries
of soil physical properties, maize yields, and their inter-relationships, for various tillage treatments on both a loam and a silt loam soil. In addition, we will outline the results of two experiments which examined the effects of reductions in depth and/or width of seedbed preparation for row-crop maize production. All experiments involved plot land which had been seeded continuously to maize since 1968.

Results and Discussion

I. Relationship of Yield to Soil Physical Properties

Although there were nine tillage treatments in each experiment, grain yield results are presented for the six tillage systems which were common to both soil types (Table 1).

On loam soil the combinations of fall chisel plowing plus spring secondary tillage, spring off-set discing plus harrowing, or spring plow-planting have resulted in maize yields similar to those achieved after conventional tillage. Zero tillage has resulted in an average yield reduction of 10%.

<table>
<thead>
<tr>
<th>Tillage Treatment</th>
<th>Soil Texture (years)</th>
<th>Grain Yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall moldboard plow; spring disc, harrow</td>
<td>6.62</td>
<td>6.34</td>
</tr>
<tr>
<td>Fall chisel plow; spring disc, harrow</td>
<td>6.60</td>
<td>5.92</td>
</tr>
<tr>
<td>Spring moldboard plow only</td>
<td>6.61</td>
<td>5.63</td>
</tr>
<tr>
<td>Spring moldboard plow, disc and harrow</td>
<td>6.36</td>
<td>6.13</td>
</tr>
<tr>
<td>Spring off-set disc, harrow</td>
<td>6.49</td>
<td>5.94</td>
</tr>
<tr>
<td>Zero tillage</td>
<td>5.94</td>
<td>5.33</td>
</tr>
<tr>
<td></td>
<td>0.17</td>
<td>0.14</td>
</tr>
</tbody>
</table>

* Yield in t/ha at 15.5% moisture.

On silt loam soils, alternatives to conventional tillage such as fall chisel plowing and spring moldboard plowing followed by secondary tillage have resulted in a 3 to 7% yield reduction. Zero tillage has resulted in an average yield reduction of 16%.

Various measurements of soil physical properties on all tillage treatments were taken following planting in an attempt to understand their
possible contribution to differences in the growth and development of maize. Tillage treatments on silt loam soil had a significant impact on the proportion of fine aggregates in the seedbed zone (upper 7 cm), bulk density and mechanical impedance as measured with a penetrometer (Table 2).

### TABLE 2. Effect of various tillage practices on soil physical properties of a silt loam soil (average of 1976-1981)

<table>
<thead>
<tr>
<th>Tillage Treatment*</th>
<th>Aggregates &lt; 5 mm in Diameter+</th>
<th>Bulk Density (g/cc)</th>
<th>Penetrometer Resistance (N/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall moldboard &amp; 2°</td>
<td>47,2</td>
<td>1.21 1.35</td>
<td>50 109</td>
</tr>
<tr>
<td>Fall chisel &amp; 2°</td>
<td>47.0</td>
<td>1.20 1.42</td>
<td>49 125</td>
</tr>
<tr>
<td>Spring moldboard only</td>
<td>35.3</td>
<td>1.27 1.33</td>
<td>45 74</td>
</tr>
<tr>
<td>Spring moldboard &amp; 2°</td>
<td>47.0</td>
<td>1.23 1.37</td>
<td>48 92</td>
</tr>
<tr>
<td>Spring off-set disc</td>
<td>45,5</td>
<td>1.17 1.42</td>
<td>57 144</td>
</tr>
<tr>
<td>Zero tillage</td>
<td>24.2</td>
<td>1.41 1.48</td>
<td>157 178</td>
</tr>
<tr>
<td>S</td>
<td>2.53</td>
<td>0.025</td>
<td>9.1 10.5</td>
</tr>
</tbody>
</table>

* 2° refers to spring secondary tillage with tandem disc and harrow.
+ Proportion (by weight) of air-dried aggregates which were sieved through screens with 5 mm openings; average of 1977-1981.
++ Average of 1978-1981 only.

### TABLE 3. Correlation coefficients between maize grain yields and various soil physical properties, determined across nine tillage systems on a silt loam soil for the years 1976-81

<table>
<thead>
<tr>
<th>Soil Parameter</th>
<th>Aggregates &lt; 5 mm in diameter</th>
<th>Bulk density (5 - 10 cm)</th>
<th>Bulk density (15 - 20 cm)</th>
<th>Penetrometer resistance (5 cm)</th>
<th>Penetrometer resistance (15 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1976 1977 1978 1979 1980 1981</td>
<td>-0.64 -0.40 -0.28 -0.14</td>
<td>-0.11 -0.39 -0.26 -0.26</td>
<td>-0.54 -0.53 -0.42 -0.41 -0.26 -0.75*</td>
<td>-0.18 -0.67* -0.09 -0.34 -0.22 -0.30</td>
</tr>
</tbody>
</table>
| Aggregates     | * Statistically significant at P = 0.05 | ** Statistically significant at P = 0.01

Linear correlation coefficients across the nine tillage treatments between various soil parameters and maize grain yields are summarized in Table 3. In four of six years, maize yields were significantly related (positively) to the proportion of fine aggregates in the seedbed layer. Grain yields were correlated less consistently with bulk density or penetrometer resistance values, particularly for those values recorded at
the deeper depth. Similar trends were observed on the loam soil. Correlation analysis on both soil types suggested that the soil parameter most closely associated with maize plant performance was the relative fineness of soil aggregates in the surface layer. Furthermore, the analysis suggested that maize yields were generally unaffected by differences amongst tillage treatments in soil density or strength below the 10 cm depth.

II. Relationship of Yield to Volume of Prepared Seedbed

Additional experiments were established on the same two soils to define more precisely the minimum depth and width of the seedbed in need of preparation to maximize maize yields. Previous research in Ontario had shown that there was no maize yield advantage from moldboard plowing a clay soil deeper that 10 cm (Bolton et al., 1977). Our experiments will be discussed individually.

The first experiment investigated the effects of depth of spring tillage with either an off-set disc or a chisel plow on maize development and yield on loam soil from 1977 to 1979. Measurements of various soil physical properties were taken during the month following planting. Penetrometer resistance and bulk density values indicated significant differences amongst treatments at two depths of measurement (Table 4). Both soil measurements differentiated between tilled and untilled soils. At the shallow depth, both penetrometer resistance and bulk density values were greatest with zero tillage. At the second depth, penetrometer resistance and bulk density were lower for those treatments which were tilled more deeply than the plane or zone of measurement.

<table>
<thead>
<tr>
<th>Tillage Treatment*</th>
<th>Penetrometer Resistance (N/cm²)</th>
<th>Bulk Density (g/cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 cm</td>
<td>15 cm</td>
</tr>
<tr>
<td>Off-set disc to 5 cm</td>
<td>51</td>
<td>171</td>
</tr>
<tr>
<td>Off-set disc to 9 cm</td>
<td>63</td>
<td>156</td>
</tr>
<tr>
<td>Off-set disc to 18 cm</td>
<td>41</td>
<td>118</td>
</tr>
<tr>
<td>Chisel plow to 18 cm</td>
<td>41</td>
<td>97</td>
</tr>
<tr>
<td>Chisel plow to 30 cm</td>
<td>45</td>
<td>91</td>
</tr>
<tr>
<td>Zero tillage</td>
<td>115</td>
<td>189</td>
</tr>
<tr>
<td>S</td>
<td>13.2</td>
<td>14.5</td>
</tr>
</tbody>
</table>

* All treatments were performed in spring. Chisel plow treatments were followed by light tandem discing.
Corn growth and development rates were similar amongst the tilled treatments, but significantly lower for the zero tillage treatment (Table 5). Grain yields were also lower for the zero tillage treatment. The tilled treatments all achieved similar yields, with the exception of the shallow chisel plow treatment. We are unable to adequately explain the slight yield depression with the latter treatment. This experiment demonstrated that, although complete elimination of tillage resulted in reduced maize performance, maximum rates of maize growth and yield could be achieved with very shallow tillage.

TABLE 5. Effect of tillage depth on maize development and yield on a loam soil (average of 1977-79)

<table>
<thead>
<tr>
<th>Tillage Treatment</th>
<th>Plant Height (cm)</th>
<th>Leaf Number</th>
<th>Silk Emergence (days to 50%)</th>
<th>Grain Yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-set disc to 5 cm</td>
<td>38.3</td>
<td>8.3</td>
<td>68.6</td>
<td>5.95</td>
</tr>
<tr>
<td>Off-set disc to 9 cm</td>
<td>38.3</td>
<td>8.4</td>
<td>68.1</td>
<td>5.96</td>
</tr>
<tr>
<td>Off-set disc to 18 cm</td>
<td>37.7</td>
<td>8.2</td>
<td>68.3</td>
<td>5.82</td>
</tr>
<tr>
<td>Chisel plow to 18 cm</td>
<td>35.6</td>
<td>8.0</td>
<td>69.6</td>
<td>5.50</td>
</tr>
<tr>
<td>Chisel plow to 30 cm</td>
<td>34.9</td>
<td>8.1</td>
<td>68.4</td>
<td>5.91</td>
</tr>
<tr>
<td>Zero tillage</td>
<td>29.5</td>
<td>6.7</td>
<td>72.4</td>
<td>5.11</td>
</tr>
<tr>
<td>S</td>
<td>1.31</td>
<td>0.19</td>
<td>0.76</td>
<td>0.27</td>
</tr>
</tbody>
</table>

The second experiment investigated the effect of various widths and two depths of spring tillage on performance of maize planted in 76-cm row widths on a silt loam soil. The experiment included nine treatments, namely: spring moldboard plowing with secondary cultivation either 8 or 15 cm deep; rototilling the entire plot either 8 or 15 cm deep; rototilling bands 38 or 13 cm wide (centered on a row) either 8 or 15 cm deep and zero tillage. Measurements of bulk density and penetrometer resistance (not shown here) again resulted in values which could be differentiated into two categories - tilled and untilled soil.

Measurements of the rate of maize growth and development indicated that there were generally no significant differences resulting from either width or depth of spring tillage (Table 6). Although grain yields for the zero tillage treatment were consistently lower, grain yield differences among the other eight treatments were not significant in each of the three years of the experiment.
TABLE 6. Effect of width and depth of spring tillage on maize development and yield on a silt loam soil (average of 1979-1981)

<table>
<thead>
<tr>
<th>Tillage Treatment</th>
<th>Plant Height (cm)</th>
<th>Leaf Number</th>
<th>Silk Emergence (days to 50%)</th>
<th>Grain Yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moldboard plowing</td>
<td>29.7</td>
<td>7.3</td>
<td>76.0</td>
<td>5.51</td>
</tr>
<tr>
<td>76 cm rototilling</td>
<td>29.7</td>
<td>7.2</td>
<td>76.0</td>
<td>5.47</td>
</tr>
<tr>
<td>38 cm rototilling</td>
<td>30.3</td>
<td>7.2</td>
<td>75.8</td>
<td>5.46</td>
</tr>
<tr>
<td>13 cm rototilling</td>
<td>29.4</td>
<td>7.1</td>
<td>76.9</td>
<td>5.49</td>
</tr>
<tr>
<td>Zero tillage</td>
<td>29.2</td>
<td>6.9</td>
<td>76.6</td>
<td>5.15</td>
</tr>
</tbody>
</table>

S_d

Average of above tilled treatments at:
- a) 8 cm depth
  - 30.4 7.3 76.1 5.51
- b) 15 cm depth
  - 29.2 7.1 76.2 5.44

* Plant height and leaf number measurements taken 5 weeks after planting.

The results of this experiment tend to reinforce the conclusions reached in the previous experiment on loam soil, namely, that (a) spring tillage at depths greater than 8 cm did not increase the rate of maize growth or the resultant yield and (b) zero tillage resulted in substantial yield reductions. Furthermore, the width of the tilled band could be reduced to 13 cm with no significant effect on rates of maize growth and development or grain yield.

LITERATURE CITED


Soil tillage is mainly based on traditions and experiences of the farmers, so it is difficult to change tillage systems. But today research and farmers are challenged to look for alternatives in plant production — especially in soil tillage because of the high energy input and soil erosion, which is increased also in Middle Europe. New soil tillage concepts have to be proved as to the question, how far stable yields can be ensured (2).

Conventional tillage includes operations — such as plowing, disk ing, and harrowing — that control weeds and prepare the seedbed. Sometimes the tillage intensity is too high. Too much tillage destroys the soil clods and pulverizes the topsoil. In this case wind and water erode the soil. In the spring of 1980 there was enormous wind erosion on the sandy soils of Northern Germany and in the spring of 1981 water erosion produced large damages in sugar beet and corn fields.

CONSERVATION TILLAGE is not a new concept in farming in the USA (1) because keeping a protective cover of plant residues on the soil surface or mulching these residues together with soil in the top layer (about 8 cm) are the simplest
and surest possibilities to control both wind and water erosion (3).

Farmers know that plant residues are also a source of nutrients and widespread removal of residues increase mineral fertilizer use. Last but not least the retention of crop residues conserves soil moisture.

In applying CONSERVATION TILLAGE one problem is to find the best set of tillage equipment which makes the best use of this concept and save energy by reducing mechanical tillage.

In 1978 field experiments were started in order to investigate the problems and advantages of CONSERVATION TILLAGE under the conditions of Northern Germany. Only rotary harrow was used on a sandy loam for primary and secondary tillage in autumn and springtime, respectively. The results indicate some problems with barley in the first years but positive effects on sugar beet yields, Fig. 1.

<table>
<thead>
<tr>
<th>Year</th>
<th>Sugar Beet Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>100 104 101</td>
</tr>
<tr>
<td>1980</td>
<td>100 99 104</td>
</tr>
<tr>
<td>1981</td>
<td>100 99 103</td>
</tr>
</tbody>
</table>

Fig. 1: Sugar beet yields 1979 - 1981 on a sandy loam (4)

\( \uparrow \) conservation tillage, SE: rotary harrow ¹)

\( \uparrow \uparrow \) conservation tillage, F: rotary tiller ¹)

\( \uparrow \uparrow \uparrow \) conventional tillage, P: Plow

¹) with straw mulch
The experiences show that the following questions must be solved:

- which amount of residues may be incorporated into the soil?
- which is the best drill-technique?
- what about the weed, insect and diseases control?
- which amount of energy, labor, and fertilizer is necessary in comparison with conventional systems?
- at which time is a deeper tillage necessary also in the concept of CONSERVATION TILLAGE?
- how much erosion is occurring?
- are the yields as good as - or better than - those of conventional systems?

Literature


Tillage without ploughing

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Summary

According to experiences made, tillage without ploughing is strongly recommended for most of the outdoor croppings. Particularly though, where due to the kind or texture of soil (heavy and humid soils), the ploughing is not recommended or even impossible. As the substitute for the plough, one can work with commuting rotary spading machines and with chisel with rigid tines. The cultivator tillage - without plough as well - is indicated especially for catch croppings and for wheat growing after root crops and maize.

The development and yields of the plants are not affected by tillage without ploughing, but to the contrary, they are rather implemented. Generally, the effective weed control does not require any supplementary costs for spraying solutions or for mechanical measures, with an exception however in the case of root-weeds.

Seen from the point of view of labour input, costs and consumption of fuel, the tillage without ploughing is even more favourable than the traditional preparation with plough.

Introduction

Using the plough, one usually complains about soil compaction as well as a limited mixing of the soil surface, but also an insufficient labour productivity with important tractor output requirements. Especially with
heavy and humid soils, the plough shares and the mould boards as well as the tractor's wheels could create some soil compactions which again would lead to structural damages. Research has been therefore undertaken with a view to supplant the plough by using other implements.

With the development of the rotary spading machine, the chisel and the rotary cultivator, a useful solution has been found and the tillage without ploughing was realized.

Taking into account the already existing results of experiences in practical research during the period of 1975 until 1981, the following can be reported on the tillage without ploughing:

**Implements and cultivation methodology**

Among the existing spading machines, the commuting ones have proved to be especially good. The soil is being cut stabwise without a particular compaction layer and then thrown towards a wing and reduced into quite small texture. The operating speed however cannot exceed the limit of 2,5 km/hour; otherwise the "biting length" would be too large and the tillage insufficient. The chopped harvest- and other plant residues, are being mulched to 70 - 80 %.

When using the chisel as substitute for the plough, the soil is being thoroughly tilled with two transit, crosswise and diagonal, and with an operating speed of 6 - 8 km/hour. The harvest residues are mulched by 60 - 70 %; the soil structure shows a medium till rough clodiness. The abovementioned quality of work is being achieved with a cultivator equipped with rigid tines, a crescent space of 30 cm and the shares were showing a width of 8 - 15 cm, having a feeding angle of 25 - 30°. These types of chisels are proper for the stubble ploughing and deep cultivation.

The chisels, equipped with flat shares, are less recommendable as substitute for the plough, their mulching effect or their ploughing depth is too little. The use of too large shares (more than 15 cm) is not recommendable neither; they need more traction power and do develop a lubricating layer as do the ploughs.

For the 20 - 40 % harvest residues, which have not been mulched and are still on the soil surface, one should use blockage-resistant implements.
Contrary to the procedure with rotary spading machines or field cultivators through which the tillage is still accomplished in three working phases, the use of a combined rotary cultivator plus a mounted sower enables to accomplish the tillage in one working phase. In only one transit, the field, which has not been ploughed is ready for sowing and sown; that is why this system is called "minimum tillage". If there are small chopped and regular harvest residues they can be mulched during the same transit. In case of heavy and humid loamy soils, the pre-cultivating is appropriate, as a measure against formation of lubricating layers; for other kind of soils, the pre-cultivation is only recommended in case of soil compactions or deep wheel traces. The depth of sowing is irregular when using the rotary cultivator, therefore the rising will be less important than with the drilling. It is hence recommended to increase the seed rate by approx. 10%.

Aspects from the plant cultivation point of view

The experiments which were undertaken by FAT, in different locations and without ploughing, have shown that the plant growth has been rather more favourable than disadvantaged. One must however count with rising disorders and blank spaces due to the insufficiently mulched harvest residues. There is also a risk of a re-sprouting of the superficial weeds. As for the weed control, it is mostly possible to control the one-year-old weeds with the usual rates of spraying liquids and other intercultivation measures. When turning meadow soil or with root-weeds, special herbicides, (i.e.: roundup etc.) plus additional mechanical steps must be taken.

According to the results of the trials, the yields of the plants have been influenced positively, by most of the plant varieties, when using rotary spading machines or chisels.

Table 1: Plant yields in relation to the system of tillage

(average figure from trial results between 1975 - 1981)

<table>
<thead>
<tr>
<th>System of tillage</th>
<th>wheat (7)</th>
<th>winter barley (1)</th>
<th>winter colza (3)</th>
<th>spring wheat (3)</th>
<th>corn naize (1)</th>
<th>sugar beets (1)</th>
<th>potatoes (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dt/ha</td>
<td>%</td>
<td>dt/ha</td>
<td>%</td>
<td>dt/ha</td>
<td>%</td>
<td>dt/ha</td>
</tr>
<tr>
<td>1. Plough</td>
<td>53,9</td>
<td>100</td>
<td>52,7</td>
<td>100</td>
<td>25,7</td>
<td>100</td>
<td>47,5</td>
</tr>
<tr>
<td>2. Rotary spading</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>machine</td>
<td>55,3</td>
<td>103</td>
<td>62,8</td>
<td>119</td>
<td>44,1</td>
<td>93</td>
<td>93,0</td>
</tr>
<tr>
<td>3. Chisel</td>
<td>57,3</td>
<td>106</td>
<td>64,2</td>
<td>121</td>
<td>47,1</td>
<td>99</td>
<td>92,2</td>
</tr>
</tbody>
</table>

* between (): number of comparative trials
In the case of combined rotary cultivator plus sower, which is recommended especially for catch fodder crops and for wheat coming after root crops and maize, the tendencies were similar.

Table 2: Wheat yields (preparation with plough furrows and combined rotary cultivator)
(average figures from trial results between 1975 and 1980)

<table>
<thead>
<tr>
<th>System of tillage:</th>
<th>winter wheat (3)*</th>
<th>spring wheat (1)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Plough</td>
<td>45.8</td>
<td>59.6</td>
</tr>
<tr>
<td>Combined rotary cultivator with pre-cultivating</td>
<td>45.9</td>
<td>59.7</td>
</tr>
<tr>
<td>Combined rotary cultivator without pre-cultivating</td>
<td>45.8</td>
<td>62.1</td>
</tr>
</tbody>
</table>

* between (): number of comparative trials in A: heavy soil
B: medium soil

Labour input, costs and consumption of energy

Parallel to the cultivation advantages, the system of tillage without ploughing is also more advantageous from the point of view of labour input and costs. Additionally, this system allows a number of important fuel savings. This factor merits special attention in a time where warnings of energy crises are up-to-date.

Table 3: Fuel consumption, working time and costs of various systems of tillage, including sowing of a winter wheat variety with a tractor of 48 kW (65 HP)

<table>
<thead>
<tr>
<th>System of tillage:</th>
<th>Input</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>fuel 1/ha</td>
</tr>
<tr>
<td>Plough</td>
<td>47</td>
</tr>
<tr>
<td>Combined rotary cultivator with pre-cultivating</td>
<td>41</td>
</tr>
<tr>
<td>Chisel with rigid tines</td>
<td>32</td>
</tr>
<tr>
<td>Combined rotary cultivator without pre-cultivating</td>
<td>24</td>
</tr>
<tr>
<td>Combined rotary cultivator without pre-cultivating</td>
<td>14</td>
</tr>
</tbody>
</table>
Literatur

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Vez A. : Dix ans d'expérience de cultures sans labour.

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Zumbach W. : FAT-Blätter für Landtechnik Nr. 66, 93, 118 und 137.

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Tänikon, 1st February 1982
3. ANTROPOGENIC SOIL COMPACTION
Soil compaction of arable soils due to recultivation of loam pits.

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Abstract
On areas of recultivated loam pits in Southern Bavaria soil workability and crop yields are reduced. Bulk densities, pore size distributions, and saturated hydraulic conductivities of recultivated and nonrecultivated loess-derived, partly pseudogleyed grey-brown podzolics were determined. The recultivated soils have high bulk densities of up to 1.63<g/cm³> and small percentages (about 3<%)> of larges pores (>10<μm>) in the top layer, and kₚ-values as low as 2.0x10⁻⁶<cm/sec> in the recultivated subsoils whereas the undisturbed soils have mean values of 1.45<g/cm³>, 10<%>, and 1.0x10⁻³<cm/sec>, respectively. These unfavourable properties of the recultivated soils, which lead to visible anaerobic conditions in parts of the profiles, are due to strong soil compaction produced during clearing away and grading of the former solum, and also by traffic of heavy machines for mining and transporting of loam. Neither the weather during recultivation actions nor the time elapsed since recultivation influence these properties. Lighter machines used in earlier years for grading, however, did not produce such unfavourable soil conditions. It is recommended to shift the soil in a special manner and to subsoil the recultivated areas prior to agricultural re-use in order to overcome the high compaction hazard.

Introduction
In Bavaria surface mining of loam is carried out for the production of tiles. Here, as in other countries, solum is cleared away at appropriate sites proceeding mining. After finishing surface mining, soil material is again graded for readjustment. The productivity of the arable layers is, however, usually reduced, and soil workability is always complicated. Because of this farmers are reluctant to make agreements with manufacturers of tiles concern-
ing surface mining of loam on their fields. To find causes for the reduction in productivity of soils following readjustment, disturbed and adjacent undisturbed soil profiles were studied. The results of this study is reported here.

Materials and Methods

The studied area is situated in the loess-covered landscape in western Lower Bavaria. This area, 65 ha in size, contains readjusted and undisturbed soils. The undisturbed soils are mostly grey-brown podzolics, more or less eroded and pseudogleyed. These profiles still have a C-horizon containing calcareous younger loess (most grey-brown podzolics) or are underlain by older loess, which is dense and contains Fe- and Mn-concretions, but no carbonates. For the areas readjusted since 1969 soil surveying showed soils similar to brownwars with some carbonate in the profile, higher clay contents, and a high soil strength. Some few of these profiles have blue-grey colours due to anaerobic conditions. Soil survey in late April 1981 showed the readjusted areas to have a more or less intense cracking under relatively dry conditions in contrast to the undisturbed area.

For subsequent soil sampling representative sites were selected on the undisturbed area as well as on parts of the area being readjusted in 1969, 1970, 1972, 1976, and 1979, together with a site shortly before being graded. From two to four representative horizons of each profile disturbed samples were taken for texture and chemical analyses using routine procedures (SCHLICHTING u. BLUME 1966), and undisturbed soil core samples for determinations of pore size distributions and bulk densities (HARTGE 1965) and saturated hydraulic conductivities (HARTGE 1966).

Results

Chemical and textural analyses showed the disturbed soils in most cases to have higher pH-values and clay contents, especially in the upper horizons (Table 1), as compared to undisturbed profiles. The soil physical characteristics gave much more pronounced changes, namely decreases of pore volumes, proportions of large pores (>10 μm), and k₅-values; and increases of bulk densities and proportions of small pores (<0.2 μm) (Table 1). There is only some decrease in proportions of medium pores (10-0.2 μm). From Table 1 it can be seen that changes to unfavourable conditions are mostly restricted to sites readjusted since 1970. Moreover, in some cases the arable layer (R₅) has undergone more damage than the next soil layer (R₄). Most unfavourable condi-
tions were observed in the bottom layers ($R_2$) of those soils readjusted in 1972 and 1976 and in the soil material taken shortly before being spread by grading. In some of the undisturbed soil profiles the arable layer ($A_p$) and the $C$-horizons also have some unfavourable conditions. These, however, are not so pronounced as in the disturbed profiles and are due to tillage of wet soils, or to sedimentation conditions and weathering ($C$-horizons), respectively.

**Discussion**

The unfavourable soil physical conditions are due to heavy soil compaction during clearing away and - some years later - grading of the solum which is necessary for surface mining of loam and readjustment of areas just mined. For surface mining the solum is removed and heaped up to more than 5$m$ by bulldozers, thus mixing and compacting the soil for a first time, as shown by the $k_S$-values for 1981 in Table 1. Mining and transporting of loam compact the bottom layer of the pit not only by weight and vibration of the heavy machines, but also by kneading this soil layer, especially under wet weather conditions. To make things worse, oven-dried tiles are spread on the floor of the pit for re-use after being mixed with water and soil during routine mining operations. This results in a very high compaction as demonstrated by bulk densities as high as 1.77$g/cm^3$, $k_S$-values as low as 0.1$cm/d$, and pore volumes as low as 35$%$ for a clay loam in the $R_2$-horizons. In these horizons only a very small proportion of large pores exists; rounding off produces the value '0' in Table 1. After finishing surface mining the heaps are graded, and traffic and working layers (mostly without being subsoiled) are covered by soil material of the heaps, thereby being mixed for a second time and once more compacted. Not only mining and transporting, but also removing and grading the solum is done under moist to wet weather conditions, thereby also increasing soil compaction. All soil mixing, incorporating also the clay-rich $B_t$- and 'older loess' $B$-horizons and calcareous $C$-horizons, leads to a more or less homogenized soil material with higher clay and carbonate contents, the latter demonstrated by pH-values $>7$ (Table 1) as compared to undisturbed profiles. The higher clay content favours structure formation as well as soil compaction, but carbonates do not seem to do so.

The effects of soil compaction seem to be less pronounced for soils readjusted prior to 1970. This may, however, be due to the fact that lighter machines were used up to 1969 for all operations. For later readjustments no influence either of time elapsed nor of weather before, during or after read-
justment could be observed. The soils are often compacted additionally due to farmers cultivating the fields immediately after soil readjustment, often under weather conditions unsuitable for tillage, and without sowing special crops suitable for soil amelioration.

Field observations on the profiles demonstrated two important facts. Firstly, due to soil compaction, especially of the top layer, soil aeration is strongly reduced, causing anaerobic conditions especially in the $R_1$-horizons, visible as large blue-grey spots. This becomes more pronounced under moist to wet soil conditions, when the cracks are closed due to swelling of the clayey soil. Secondly, soil compaction hinders biological activity, even in the top layer. This is demonstrated by the persistance of thin, intact silt strata, which must have been deposited during a period before the last tillage two years prior to the survey. This means aeration status and compaction of the soil prevent earthworms and other soil fauna to live, to decompose organic matter and to transport soil material within and between horizons. This low biological activity impedes root growth below 50 cm.

On the basis of soil analyses, field observations, technique of surface mining and readjustment, and subsequent tillage practice the following recommendations are given to overcome strong soil compaction:

1. to clear away the solum using light shovel dredgers and band conveyors and heaping the soil material to piles 3 m wide, 2 m high and of limited length;
2. to plant the piles with alfalfa or other deep rooting plants in order to keep these relatively dry;
3. to subsoil all floors under relatively dry conditions prior to readjustment;
4. to spread the soil also using light shovel dredgers and band conveyors;
5. to grade the soil using a small or light bulldozer;
6. to recultivate the readjusted area with alfalfa to promote organic matter and biological activity in top and subsoil layers;
7. to subsoil these areas in the next year under dry conditions prior to returning the fields to farmers;
8. to advise the farmers to till the fields only under favourable soil and weather conditions thus preventing recompaction of the soil.

If all, or at least most of these measures are carried out soil compaction hazard will be avoided.
References:

Acknowledgement
I greatly acknowledge Dr. E. Murad for revising the manuscript.
Table 1: Soil physical characteristics of readjusted and not readjusted soil profiles derived from loess

<table>
<thead>
<tr>
<th>Hor. Depth</th>
<th>PV</th>
<th>LP</th>
<th>MP</th>
<th>FP</th>
<th>f_b</th>
<th>k_s</th>
<th>clay</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>readjusted 1969</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RA_p 0-25</td>
<td>44</td>
<td>9</td>
<td>9</td>
<td>26</td>
<td>1.493</td>
<td>1728</td>
<td>7.2</td>
<td></td>
</tr>
<tr>
<td>RA_p 35-55</td>
<td>39</td>
<td>5</td>
<td>8</td>
<td>27</td>
<td>1.622</td>
<td>54</td>
<td>6.9</td>
<td></td>
</tr>
</tbody>
</table>

readjusted 1969

| RA_p 0-30  | 44 | 9  | 11 | 24 | 1.471 | 3404 |      |    |
| RA_p 50-100 | 41 | 8  | 7  | 26 | 1.595 | 985  |      |    |

readjusted 1970

| RA_p 0-25  | 41 | 1  | 15 | 25 | 1.589 | 497  | 30   | 7.4 |
| RA_p 25-50 | 40 | 3  | 11 | 26 | 1.623 | 145  | 24   | 7.7 |
| RA_p 50-90 | 45 | 9  | 12 | 24 | 1.479 | 364  | 31   | 7.4 |

readjusted 1972

| RA_p 0-22  | 40 | 2  | 12 | 26 | 1.583 | 5    | 31   | 7.0 |
| RA_p 22-50 | 44 | 7  | 13 | 24 | 1.493 | 32   | 32   | 7.1 |
| RA_p 50-60 | 35 | 0  | 7  | 28 | 1.772 | 0.3  | 38   | 7.5 |

readjusted 1976

| RA_p 0-20  | 38 | 2  | 12 | 24 | 1.634 | 40   | 31   | 7.4 |
| RA_p 20-55 | 41 | 4  | 11 | 26 | 1.578 | 1711 | 30   | 7.7 |
| RA_p 55-75 | 35 | 0  | 9  | 28 | 1.757 | 0.1  | 36   | 7.4 |

readjusted 1979

| RA_p 0-20  | 44 | 11 | 12 | 21 | 1.475 | 154  | 28   |    |
| RA_p 20-60 | 41 | 6  | 11 | 24 | 1.565 | 2    | 29   |    |

1981, prior to grading

RR 250 45 3 16 27 1.473 0.7 35 6.4

-- grey-brown podzolic

A_1 12-30 49 19 18 12 1.340 254 19 3.5
B_1 30-50 46 9 12 25 1.448 11 32 3.8
C_1 78-110 43 9 20 14 1.550 16 17 7.6

-- grey-brown podzolic, weakly pseudogleyed and shortened due to erosion

A_g 0-22 42 7 13 22 1.508 1132 30 6.5
B_g 22-45 47 12 8 28 1.419 1555 42 6.6
C_g 45-75 42 9 15 18 1.566 28 7.5
D_g 75-115 39 5 11 23 1.665 33 7.4

-- grey-brown podzolic, pseudogleyed and shortened due to erosion

A_p 0-20 45 13 14 18 1.451 1477 27 6.0
B_p 20-45 46 9 10 26 1.468 117 40 6.3
C_p 45-55 47 12 11 24 1.416 63 37 6.4
D_p 55-90 42 7 20 15 1.586 188 23 7.7

-- colluvial brownearth

A 0-30 49 14 21 14 1.344 1607
B 30-80 47 15 19 13 1.416 2151
The paper describes the accurate electronic recording penetrometer developed by CEMAGREF and its particular use in evaluating tillage implement impact and soil compaction effects in agricultural soils. Several examples are presented to illustrate the interest of such a method which proposes a new process of soil macro-structure analysis through the study of graphical representations.

1 Introduction

ASAE standard S 313.1 describes a soil cone penetrometer recommended as a measuring device to characterize the penetration resistance of soils. In the above mentioned standard the following point is specified: "Area profiles in any plane may be graphically constructed by connecting points of equal penetration resistance for specific areas of interest". Such a use is not very frequent. More commonly penetrometers provide, for a studied soil, an index of general mechanical conditions.

As we frequently use the S. HENIN's observation method of "profil cultural", to study soil structural variations under tillage implement and wheel impact, we decided to operate with a penetrometer to add numerical non subjective data to qualitative descriptions. New methodological perspectives can thus be derived from that approach.

2 Material and method

We use a special electronic recording penetrometer designed and developed at CEMAGREF.

It consists of three parts:
- The 50 cm rod "1" which is vertically pushed into the soil, is equipped with a 90° circular cone of which the cross-sectional area at the base is 0.25 cm². The cone shape selected allows to point out the smallest penetration resistance changes.
- A strain-gauged force sensing transducer "2" (of 0 to 10 daN) is fixed on the top of the rod. We push the terminal cone regularly revolving a crank "3" which
Fig. 1:
The CEMAGREF soil penetrometer

acts on a rack "4".

- A paper recorder "5" writes the penetration resistance changes. The paper is moved by the crank.

This measuring device - mounted on a carriage "6" - is moved horizontally on a 1 m rail. So a series of vertical penetration resistance curves can be plotted at regular intervals. Observations done on silty loam soil at field capacity moisture, show that the cone lateral influence does not extend to more than a radius on both sides of the vertical penetration hole; so we commonly have adopted a 2 cm interval.

A small rechargeable battery "7" allows a 6 hour continuous operation in the field.

Fig. 2:

Each penetration resistance versus depth curve (Fig. 2) presents a reference depth level "1" giving calibration data "2", a straight part "3" (zero resistance) the cone still being in the air, a heterogeneous part "5"
corresponding to the cone way into the soil. The surface level is clearly indicated when the resistance ceases to be zero "4].

From this series of curves, a precise survey of the soil surface level and the penetration resistance of the different soil layers, is then manually or semi-automatically drawn up on the very vertical plane which bears the cone-made holes. Different graphical representations may be used: we may connect points of equal pressure, form isobar lines and areas so defined are darkened as pressure increases (see Fig. 5), or drawn according to a chosen depth step (1 cm or 0.5 cm) a conventional symbol as high as that step and as wide the interval between two close penetrations of the cone. The higher the penetration resistance is the darker will be the chosen graphic symbol. So we have a "scanner" type graphical representation (see Fig. 3, 4).

3 Use of graphical representation

When we want to study the soil macro-structure in a test field, we dig a trench and observe the walls after we have revealed such macro-structure with a knife; then we can analyse it. Such an analysis which requires highly qualified observers is often too long and sometimes considered as a subjective method, so research workers are now codifying it. To be aware of different types of representative structures in a test field and to have an idea of their frequency, it'll be necessary to make many trenches in the soil, a too long and destructive method. Using our penetrometer we work quickly (half an hour for a 1 m wide soil profile), we don't destroy neither soil structure nor crops and experts are required only for result interpretation and for some complementary trench observations of peculiar places considered as typical and interesting taking the penetrometer data into account. Some trench observation have to be necessarily made to complete numeric penetrometer data by qualitative informations such as: root implantation, presence of polished zones and of asphyxiating areas. Meanwhile in some soils, structure differences are barely visible, even by a qualified observer, when the penetrometer shows heterogeneities furthermore confirmed by density measurements. For these reasons we have used that technique for the last years to carry out different soil studies.

**Analysis of tillage implement effect**

We compare penetrometer graphical data before and after one pass of the implement under study. Fig. 3 (a and b) shows to what extent we can use this method for studying the global action of a p.t.o. driven harrow on a ploughed soil.
Fig. 3: Ploughed soil (cross section) before (a) and after (b) one pass of a p.t.o. driven harrow.

We clearly see the general ploughed soil structure and the bottom level on the two drawings. After the tillage work of the harrow we notice a leveling of the soil surface, a crumble of the superficial layer, and a general settling down of the lowerpart of the ploughed soil caused by the weight of the implement and above all by vibrations.

Analysis of soil compaction

When we try to study in the field the action of different types of tyres on soil compaction, we can see that soil heterogeneity influence on compaction is important (Fig. 4 a). However, the peculiar effect of wheel types may be shown,

Fig. 4: Sugar beet seed bed preparation with tractor large tyres (a) and dual wheel arrangement (b, right), two passes in each case. No pass on b left part.

mainly the shallow compaction caused by tractor wheels during the seed bed preparation "1" compared to deeper compaction due to spraying machine "2".

It should be enticing to read penetration resistance variations directly as soil porosity changes: more the soil is resistant, lesser is the porosity and more important is the compaction. There is a close connection between
penetration resistance and soil compaction but moisture plays an important part. So when we study compaction variations with a penetrometer homogeneous moisture conditions are required. As far as theoretical studies on compaction are concerned we try to work on a homogeneous medium: a deep loosen clay sand with a low moisture content. Fig. 5, cross section of the rut made by a large tyre shows the dissymetrical action of the lugs.

Fig. 5:
Cross section of a rut in a homogeneous medium

4 Limits of the method and other developments

Such a method is convenient for sandy, silty clay soils mainly found in France. On the other hand, very plastic clay soils are not well suited to such a penetrometer use. The cone progression is strongly braked by clay adhesivity, and frequent cleaning of the rod are necessary. Therefore the soil macrostructure representation is completely blurred. In soils with high stone content too, the use of a penetrometer raises major problems. With big stones it is quite impossible. Small stones are plushed aside by the cone with an indetermined amount of friction on the rod. Numerical data are subsequently affected. But areas touched by compaction for instance are shown and can be numerically characterized by complementary density measurements.

The complete graphical representation immediately available in the field would be very interesting as an analysis element and to decide whether new measurements are required in other places or not. So we are now studying a new implement giving immediately a drawing representation and recording data on a magnetic support for a further processing: statistic computations (giving characteristics of horizontal layers and homogeneous soil areas), automatically programmable graphical representation according to specific studies.
Conclusions

1°) An accurate penetrometer may be used to objectively show structure heterogeneity of a soil area, using graphical data of numerous regularly spaced penetration resistance profiles.

2°) With such an aim, precautions should be taken to carry out measurements in good conditions: homogeneity of soil moisture, neither stony nor adhesive clay soil.

3°) The graphical representation obtained may be helpful to explain general and particular action of tillage implements upon the soil, and make known the relative intensity and extension of soil compaction.

4°) This quick, non-destructive method is a valuable one much appreciated by those who carry out comparisons of tillage techniques on plots.

5°) On-field automatic analyzing and recording on magnetic tape for further drawing and calculation will increase the interest of the method and related equipment.

References:

S. HENIN et al., Le profil cultural - MASSON ÉDITEURS 1969
ASAE R 313.1 Soil cone penetrometer - Agricultural Engineers Yearbook 1978
INFLUENCE OF WHEEL-TRAFFIC ON PROPERTIES OF SANDY SOIL AND CROP YIELDS

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Institute of Agrophysics, Polish Academy of Sciences
Krakowskie Przedmieście 39, 20-076 Lublin, Poland

ABSTRACT

Differences in the physical state of soil induced by tractor wheel passes were reflected by the values of soil hydraulic conductivity and soil strength. The range of these differences depend upon the number of passes and the period of measurements.

INTRODUCTION

The increased use of agricultural machinery causes its physical properties, which, in turn, influences the development and yield of plants. Therefore, a proper evaluation of the variation of soil physical state, caused by wheel traffic is of great importance. Besides the changes of soil density this evaluation should also include other physical parameters of soil which allow us to do more precise description of the compaction effects /3,4,5,6/. The experiments carried out on clay soil have shown that the soil strength appeared to be more sensitive in the indicator of soil compaction than its density /6/.

The aim of this study was to examine the effect of tractor wheel traffic on the changes of the hydraulic conductivity and strength of sandy soil.

MATERIALS AND METHODS

A field experiment was carried out on sandy soil of the following texture; sand - 86%, silt - 9%, clay - 5% and 1.21% of organic matter.

Wheel traffic was imposed with a 2,500 kg tractor three days after sowing oats. The total experimental field /0.5 ha/ was subdivided into five equal sized areas used for the following treatments: 1 - no compaction /control/, 2 - one pass, 3 - two passes, 4 - four passes, 5 - five passes. Various number of passes were made over the entire plot area.
at soil water content about 0.1 kg/kg.

The following measurements were performed: saturated hydraulic conductivity \( k_s \) and unsaturated hydraulic conductivity up to soil moisture tension 30 mbar was carried out in the steel infiltrometer of 28 cm in diameter on the surface layer of 0 - 10 cm with the method described by Bouma /1/. In the soil moisture tension with range above 30 mbar hydraulic conductivity was calculated according to the program by Luxmoore /2/. Soil strength was determined by laboratory soil penetrometer 3.8 mm in diameter and 30° cone point/ in cylinders taken from the depths 0-10, 10-20 and 20-30 cm.

These properties were measured twice during the growing season: first - directly after wheel passes and second - before harvesting.

RESULTS

Hydraulic conductivity

In the first period of measurements mean value of the saturated hydraulic conductivity \( k_{sat} \) on control plot was 586 cm/day and one, two, four and five tractor wheel passes caused its decrease by 33, 78, 86 and 88%, respectively /fig.1a/. Thus, the results indicate that after one and two passes the \( k_{sat} \) mostly decreased. The degree of reduction in \( k \) upon increasing soil moisture tension to 30 mbar was higher in control and one wheel pass plots. It indicates that the highest value of \( k_{sat} \) was due to presence of macropores, as these pores mainly determine saturated conductivity.

At the soil moisture tension range above 30 mbar calculated \( k \) values on the five-fold trafficked plot exceeded generally those of the two and four trafficked plots, and the highest value was on the controlled plot and the lowest after the four wheel passes /fig. 1a/.

In the second period of measurements \( k_{sat} \) increased almost three times on the plot with two wheel passes and about twice on four and five trafficked plots compared to the first term /fig.1b/. Nevertheless, \( k_{sat} \) values on the plots with four and five wheel passes maintained significantly lower compared to remaining combinations in which \( k_{sat} \) closed together.
Hydraulic conductivity as a function of soil moisture tension before and after compaction.
Unsaturated $k$ values were the highest on the plot with two wheel passes and lowest on control plot /fig. 1b/.

Increase of hydraulic conductivity in the above mentioned plots in the second period of measurements can reflect a loosing effect of the plant roots.

**Soil strength**

Directly after compaction the soil strength on the top layer was increased after the number of passes i.e. on plots with one, two and four wheel passes, however five wheel passes produced little change as compared to four passes /fig. 2a/.

Before harvesting the soil strength in all combinations and layers increased as a result of moisture content decrease and was almost equal in plots with two, four and five wheel passes /fig. 2b/.

In the layer 20-30cm, irrespective of the period of measurements, the differences in the soil strength were much lower /fig. 2a and 2b/.

Comparison of the soil strength data in both period, shows that the soil strength is negatively correlated with soil water content. This relationship masked the trend of the changes in soil structure taking place during the growing season in different combinations.

The trend, however, was indicated by hydraulic conductivity, saturated and unsaturated in low soil moisture tension as a parameter strongly depended on the pore-size distribution.
Grain yield of oat was higher in plots with one and two tractor wheel passes compared to the control and combinations with four and five passes /fig. 3/

CONCLUSIONS

Directly after compaction /first period/ saturated hydraulic conductivity $k$ in plots with one, two, four and five tractor wheel passes was decreased by: 33, 78, 86 and 88% as compared to the control. However before harvesting /second period/ $k_{sat}$ increased almost three times on the plot with two wheel passes and about twice on four and five trafficked plots compared to the first period. Nevertheless, $k_{sat}$ value on the plots with four and five passes still maintained significantly lower compared to the remaining combinations.

Unsaturated $k$ in the first period was higher in the control plots, however in the second, it was lower compared to remaining combinations.

Soil strength, in the first period, increased successively in plots with one, two and four passes, but in the second period it was increased as a result of water content decrease in all combinations, and was higher and almost equal in combinations with two, four and five passes, This relationship masked the influence of soil structure on soil strength in different combinations.

The grain yield of oat was higher in the plots with one and two passes. The data indicates that one and two wheel passes after sowing, it created more favourable physical conditions for yielding of oat compared to the remaining combinations.

LITERATURE CITED


CONTROLLED TRAFFIC ON A SANDY CLAY LOAM UNDER WINTER BARLEY IN SCOTLAND

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Scottish Institute of Agricultural Engineering, Bush Estate, Penicuik, Midlothian, EH26 0PH, Scotland, U.K.

Introduction

Recently there has been widespread interest in the methods and advantages of controlling traffic in crop production (Perdok, 1979; Chamen et al., 1980; Taylor, 1981; Soane et al., 1982). Following earlier work at the Scottish Institute of Agricultural Engineering on controlled traffic in the potato crop in which Soane (1975) showed that zero traffic could result in increased tuber yield and fewer clods in the ridge than normal traffic, the programme was extended to include cereals. Suitable machinery was assembled to allow winter barley to be grown and harvested in 2.8 m wide plots following six levels of seedbed traffic including zero traffic, but with no subsequent traffic. This paper reports the preliminary results of the first year of the experiment which was undertaken in the 1980-81 crop season.

Experimental Details

The site is in Midlothian where the annual rainfall is 866 mm, the altitude 200 m and the aspect southeast. The sandy clay loam topsoil overlies a poorly drained clay loam and has been classified as unsuitable for the direct drilling of both winter and spring cereals.

There are three replications of six levels of traffic on two cultivation treatments giving a total of 36 plots, each 30 m x 2.8 m. In this, the first year of the experiment, all plots were ploughed to 270 mm and secondary cultivated to 150 mm, but it is intended that half the plots will be direct drilled in future years.

Before sowing, the traffic treatments were applied
uniformly over the whole plot area with a 41 kW Leyland 255 tractor weighing 2.9 t fitted with 13.6/12-36 rear tyres. Zero, one, two, four and six pass treatments were used. In addition, there was a single pass treatment in which the minimum recommended tractor tyre pressures (front 2.2 bar; rear 0.9 bar) were reduced (front 1.0 bar; rear 0.4 bar). The seedbeds were not cultivated before sowing.

The crop was sown on the 10th of October and difficulty was experienced in maintaining adequate drill penetration on the plots which had received more than one wheel pass. Between one and two months after sowing the rainfall was close to the long-term average, but the daily rainfall exceeded 10 mm on five occasions. Soil and crop responses were measured at intervals during the growing season.

Results of soil and crop measurements

The mean results of soil and crop measurements made between one and two months after sowing the crop are in Table 1.

Table 1
Mean soil and crop measurements in the seedbed

<table>
<thead>
<tr>
<th>Number of wheel passes</th>
<th>Sowing depth, mm</th>
<th>Plants per m²</th>
<th>Cone resistance, kPa</th>
<th>Dry bulk density, kg m⁻³</th>
<th>Air-filled porosity, % w/w</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero</td>
<td>47.5</td>
<td>315</td>
<td>95</td>
<td>960</td>
<td>34.5</td>
</tr>
<tr>
<td>One R⁺</td>
<td>41.4</td>
<td>189</td>
<td>213</td>
<td>1181</td>
<td>16.1</td>
</tr>
<tr>
<td>One</td>
<td>39.3</td>
<td>131</td>
<td>206</td>
<td>1180</td>
<td>14.7</td>
</tr>
<tr>
<td>Two</td>
<td>30.1</td>
<td>75</td>
<td>379</td>
<td>1254</td>
<td>11.4</td>
</tr>
<tr>
<td>Four</td>
<td>24.0</td>
<td>36</td>
<td>587</td>
<td>1321</td>
<td>5.8</td>
</tr>
<tr>
<td>Six</td>
<td>21.7</td>
<td>9</td>
<td>637</td>
<td>1319</td>
<td>4.6</td>
</tr>
<tr>
<td>S.E.</td>
<td>3.67</td>
<td>26.7</td>
<td>66.2</td>
<td>49.2</td>
<td>3.60</td>
</tr>
</tbody>
</table>

+ R = reduced tyre pressure.

As the number of wheel passes increased, emergence declined sharply with corresponding increases in cone resistance and bulk density and decreases in air-filled porosity at a depth of 30 mm (Fig. 1). There was a linear relation between
crop emergence and soil air-filled porosity.

Fig. 1. Effect of number of tractor wheel passes on cone resistance and air-filled porosity at 30 mm depth and plant population at emergence.

Soil below the seedbed, but above the ploughing depth, was also affected by the treatments as shown in Table 2, but there were no treatment effects on either bulk density or cone resistance below the depth of ploughing.

Measurement of dry bulk densities revealed no recovery from the compaction treatments at any depth by the mid-growth stage. By harvest time dry bulk density at 30 mm depth had decreased by a mean 173 kg m\(^{-3}\) compared with planting time for the two, four and six pass treatments only. At 180 mm no recovery was detected.

Grain yields at harvest are shown in Table 3. There was a marked reduction in yield as the number of wheel passes increased and yields were closely related to plant establishment values (Fig. 2).
Table 2

Soil properties at 180 mm depth

<table>
<thead>
<tr>
<th>Number of wheel passes</th>
<th>Cone resistance, kPa</th>
<th>Dry bulk density, kg m(^{-3})</th>
<th>Air-filled porosity, % w/w</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero</td>
<td>742</td>
<td>1293</td>
<td>9.2</td>
</tr>
<tr>
<td>One R(^+)</td>
<td>1065</td>
<td>1382</td>
<td>2.0</td>
</tr>
<tr>
<td>One</td>
<td>1090</td>
<td>1350</td>
<td>2.5</td>
</tr>
<tr>
<td>Two</td>
<td>1144</td>
<td>1408</td>
<td>1.3</td>
</tr>
<tr>
<td>Four</td>
<td>1162</td>
<td>1398</td>
<td>2.2</td>
</tr>
<tr>
<td>Six</td>
<td>1212</td>
<td>1370</td>
<td>1.1</td>
</tr>
<tr>
<td>S.E.</td>
<td>107.9</td>
<td>24.2</td>
<td>1.72</td>
</tr>
</tbody>
</table>

\(^+\) R = reduced tyre pressure.

Table 3

Effect of number of wheel passes at normal or reduced (R) inflation pressure on grain yield

<table>
<thead>
<tr>
<th>Number of wheel passes</th>
<th>0</th>
<th>1R</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain yield, t/ha</td>
<td>6.7</td>
<td>5.5</td>
<td>3.9</td>
<td>3.4</td>
<td>2.3</td>
<td>1.3</td>
<td>1.52</td>
</tr>
</tbody>
</table>

Fig. 2. Relation between plant populations at emergence and grain yields. (Numbers refer to wheel passes and R = reduced tyre pressure.)

Discussion

The proportion of land covered by tractor wheels during traditional seedbed preparation in Scotland is typically about 90%, some of the land being covered more than once (Soane,
Thus the one pass treatment in this experiment approximates to the soil conditions of farming practice. In such conditions, soils are often moist and therefore liable to compact considerably as the result of even a single pass of a tractor. In this experiment, the soil water content at a depth of 30 mm when the treatments were applied and the crop sown was just 1% w/w less than the cone penetrometer plastic limit (Campbell, 1976) of 27% w/w. At a depth of 180 mm the soil water content was 8% w/w above the cone penetrometer plastic limit of 23% w/w. The high compactability of such soil is reflected in there being little or no further increase in bulk density at either depth when the number of wheel passes exceeded two.

If the zero traffic treatment described here had been applied commercially on a square field of 1 ha and if there had been zero yield in the tramlines formed by the 430 mm wide tyres, then the overall field yield would have been approximately 5.8 t/ha. Use of the 12 m track toolframe which Chamen et al. (1980) have suggested is commercially feasible would have given an overall field yield of approximately 6.4 t/ha for the same tyre width. Such yields compare very favourably with the 3.9 t/ha obtained from the one pass treatment.

The dominant clay mineral in this soil is kaolinite and so there is little of the shrinking and swelling which allows other soils to recover spontaneously from compaction. Although this is consistent with the measured bulk densities, some surface cracks up to 10 mm wide and up to 40 mm deep were observed on all treatments just after the mid-growth stage. These may have contributed to the recovery from compaction detected at 30 mm depth.

The satisfactory crop establishment and grain yield of the zero traffic plots suggests that, although the soil is classified as unsuitable for the direct drilling of cereals, the operation might be satisfactorily undertaken in the absence of traffic. Such a possibility will be tested in the second year of the experiment when the same six levels of traffic will be applied to both ploughed and direct
Conclusions
1. For the soil and climatic conditions of this experiment, seedbed traffic can substantially reduce yields of winter barley.
2. Reduction of the front and rear tractor tyre inflation pressures to about half the minimum recommended values resulted in appreciably higher values of soil air-filled porosity, plant emergence and grain yield.

REFERENCES
EFFECT OF TWO SPRING CULTIVATION TECHNIQUES ON SOIL COMPACTION, ROOT GROWTH AND YIELDS OF SUGAR BEET.

Y. DUVAL
INRA - STATION D'AGRONOMIE, Rue Fernand Christ, BP. 101, 02004 LAON Cédex.

ABSTRACT: In a field experiment, a classical tillage (PA) and a simplified technique (PS) with fewer passes were compared. PS affected sugar beet root morphology and population without significant effect on yield. With a finer approach, soil compaction, root growth and yield were related to the variable \( \frac{P}{L} \). Production was reduced by 20 % for higher \( \frac{P}{L} \) values (\( P \) being the applied load and \( L \) the path width).

INTRODUCTION:

The use of heavier and more powerful equipment creates a greater probability of detrimental conditions mainly in soil structure. Many wheel passes resulting in a higher soil compaction lead to crop production decrease. The compaction degree has been related to soil type and to machinery operating conditions (1). Now, the phenomena are well-known (2) but field experiments are essentially based on simulated treatments (3, 4, 5). Soil compaction and its effects have been studied here after the methodology developed by Colomb (6). In the field, with normal procedures of the farmer, observations and measures are carried out under wheel tracks after different numbers of passes.

MATERIALS AND METHODS:

The experimental field was located at Pouilly/Serre (Aisne) on clayey sandy loam (silt loam according to Soil Survey Manual). This type of material is quite prone to compaction (7). Organic status, \( \text{pH} \) and nutrient contents were suitable. The field fertilization was 165-102-160 Kg.ha\(^{-1}\) given with usual techniques of weeding and plant protection.

Ploughing was carried out in December 1979 with a tribottom 16-inch plough, at a depth of 28 cm and a speed of 7 Km.h\(^{-1}\). During the superficial preparations (15/04/80) soil moisture was distributed as follows (figure 1). If the first 10 centimetres were rather dry, the moisture content in the 10 to 50 cm range was nearly the field capacity. In relation to the last ten years average, rainfall (table 1) during the growing season was 93 cm in excess, with a more irregular distribution.
Moisture content, % of dry weight

Table 1: Rainfall (mm) – (Meteorological Station of Pouilly/Serre)

<table>
<thead>
<tr>
<th>Months 1980</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>Sept.</th>
<th>Oct.</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17</td>
<td>51</td>
<td>91</td>
<td>92</td>
<td>65</td>
<td>22</td>
<td>82</td>
<td>420</td>
</tr>
<tr>
<td>Average 10 years</td>
<td>44</td>
<td>61</td>
<td>41</td>
<td>51</td>
<td>38</td>
<td>52</td>
<td>40</td>
<td>327</td>
</tr>
</tbody>
</table>

Two spring cultivation techniques were compared (figure 2): an usual farmer's technique (rather common in this country) (PA) vs a simplified technique as explained below (figure 2).

Figure 2: Applied cultivation techniques

TILLAGE
PA

LIQUIDS SPREADER (LS) + CANADIAN CULTIVATOR (CC)

SPRING TOOTH CULTIVATOR (STC)
ROLL-HARROW-CROSKILL (RHC)

SPRING TOOTH CULTIVATOR CROSKILL (STCC)

SEEDING (S)

The tilling equipment used is shown in table 2

Table 2: Tillage equipment.

<table>
<thead>
<tr>
<th>Cultivation operations</th>
<th>$x^2$</th>
<th>Width (m)</th>
<th>Speed (Km.h$^{-1}$)</th>
<th>Implement weight $P_0$ (Kg)</th>
<th>Tractor weight $P_t$ (Kg)</th>
<th>Rear wheel equipment</th>
<th>Path width</th>
<th>P/U Kg. cm$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS</td>
<td>0.5</td>
<td>24.0</td>
<td>6-7</td>
<td>3450</td>
<td>4000</td>
<td>single wheel</td>
<td>31</td>
<td>41</td>
</tr>
<tr>
<td>CC</td>
<td>1.0</td>
<td>5.5</td>
<td>8-9</td>
<td>1200</td>
<td>5100</td>
<td>dual wheels</td>
<td>39</td>
<td>97</td>
</tr>
<tr>
<td>STC</td>
<td>1.0</td>
<td>4.4</td>
<td>8-9</td>
<td>1000</td>
<td>4370</td>
<td>single wheel</td>
<td>33</td>
<td>41</td>
</tr>
<tr>
<td>STCC</td>
<td>1.0</td>
<td>4.4</td>
<td>7-8</td>
<td>2000</td>
<td>4370</td>
<td>single wheel</td>
<td>33</td>
<td>41</td>
</tr>
<tr>
<td>RHC</td>
<td>0.0</td>
<td>3.0</td>
<td>8-9</td>
<td>3100</td>
<td>3820</td>
<td>single wheel</td>
<td>30</td>
<td>98</td>
</tr>
<tr>
<td>S</td>
<td>0.0</td>
<td>5.4</td>
<td>6</td>
<td>1200</td>
<td>4100</td>
<td>single wheel</td>
<td>20</td>
<td>22</td>
</tr>
</tbody>
</table>
The different passes are characterized by the P/L ratio, P being the applied load on one rear wheel, L the path width on soil. Assuming that the load distribution is 1/3 on the front, 2/3 on the rear for the tractor, P is obtained from the equation: \( P = 0.5 \left( 0.66 P_t + aP_o \right) \). a values are: 0.0 (trailer impl.) - 0.5 (semi-mounted impl.) - 1.0 (mounted impl.).

There were two repetitions for each treatment (25 X 25m). Each in and out-going for one plot was indicated by a flexible plastic stake, marked and driven into the soil in the middle of each rear wheel path. Noting down the stakes location enabled the drawing of a map of passes per plot (scale: 16/10000) and the estimate by cutting up and weighing of percentage of areas affected by each pass. After drawing down the sugar beet rows, these maps were useful to locate the most representative points for observations and soil sampling. During the growing season, observations consisted of emergence average records, soil profiles description, density measurements (bulk density by ring method, textural bulk density by aggregate method) under each pass at four different depths (10, 20, 30, 60 cm). At crop season, the following parameters were measured: gross yield, sugar average and juice purity. On the same sample (four samples per treatment - one sample corresponds to 18 m²) the root morphology was studied: tap-roots grading, importance and depth of their possible branching.

RESULTS AND DISCUSSION:

1) Effects of techniques: The removal of only one pass has noticeably changed the pass frequencies distribution (figure 3).

The one-pass area being almost invariable the tillage simplification has resulted in an increase of non-rolled area percentage (+25%). This was compensated by lower proportions of areas affected by 2 passes and more.

The population record during the growing season showed a significant difference in favour of PA (15000 extra plants) (figure 4).

Within, a less dense population, plants had an increased potential growth in terms of accessible soil volume to root exploration or available space.
for leaf development. In the case of sugar beets, an increased tap-root diameter is obtained. Thus, the average diameter varies from 106 mm (PA) to 112 mm (PS) and the average weight of one sugar beet from 678 g (PA) to 800 g (PS). Nevertheless, the gross yield seems to remain favourable to PA preparation (table 3).

Table 3: Crop parameters

<table>
<thead>
<tr>
<th></th>
<th>Average diameter (mm)</th>
<th>Average weight (g)</th>
<th>Population (1000 plants ha(^{-1}))</th>
<th>Gross Yield (t ha(^{-1}))</th>
<th>Sugar content (%)</th>
<th>Sugar (t ha(^{-1}))</th>
<th>Yield 16% (t ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>106</td>
<td>678</td>
<td>95.01</td>
<td>68.5</td>
<td>17.6</td>
<td>11.93</td>
<td>78.1</td>
</tr>
<tr>
<td>PS</td>
<td>112</td>
<td>800</td>
<td>79.98</td>
<td>66.0</td>
<td>17.6</td>
<td>11.61</td>
<td>73.1</td>
</tr>
<tr>
<td>Significance (Fisher test)</td>
<td>xx</td>
<td>xx</td>
<td>xx</td>
<td>N.S</td>
<td>N.S</td>
<td>N.S</td>
<td>N.S</td>
</tr>
</tbody>
</table>

Juices purity analyses showed no significant difference.

The removal of one tillage operation had important consequences on the yield components. Sugar beet is very sensitive to seedbed quality, so the leveling and rolling insufficiency before seeding has resulted in a reduction in germination and sprouting speed for the PS treatment. During the vegetation period, the compensation had not prevented a final but not significant loss of 2.5 t ha\(^{-1}\).

Facing the distribution heterogeneity of passes on the plots and the particular stress that every one of them represented for the soil, it seemed necessary to change the approach scale to study the soil physical state effect on root morphology and yield. Then, preparation treatments (PA, PS) were considered as subtreatments sets (0 to n passes), the explicative variable becoming \( \frac{n}{\Pi} P/\Pi_i \).

2) Effects of applied stresses P/L:


Porosities measurements under wheel passes have shown an obvious decrease in the tilling horizon while stresses were less efficient under the ploughing pan (fig. 5 to 8).
Table 4 : \( \Delta P \) calculation (in the range of P/L values : 0-140 Kg.cm\(^{-1}\))

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>TOTAL POROSITY ( \Delta P ) (%)</th>
<th>Correlation coefficient</th>
<th>TEXTURAL POROSITY ( \Delta P ) (%)</th>
<th>Correlation coefficient</th>
<th>Structural porosity ( \Delta P ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5.84</td>
<td>- 0.712 ** ***</td>
<td>1.86</td>
<td>- 0.759 ** ***</td>
<td>3.98</td>
</tr>
<tr>
<td>20</td>
<td>4.52</td>
<td>- 0.679 ** ***</td>
<td>1.12</td>
<td>- 0.451 ***</td>
<td>3.40</td>
</tr>
<tr>
<td>30</td>
<td>1.71</td>
<td>- 0.506 * ***</td>
<td>0.40</td>
<td>- 0.151 **</td>
<td>1.34</td>
</tr>
<tr>
<td>40</td>
<td>2.13</td>
<td>- 0.364 (H)</td>
<td>0.22</td>
<td>- 0.070 **</td>
<td>1.91</td>
</tr>
</tbody>
</table>

Structural porosity was the main factor to explain the loss of calculated total porosity \( \Delta P \) (table 4). Yet, the significant decrease of textural porosity at 10 and 20 cm deep, emphasized the importance of stresses at this level. Regarding passes areas distribution as a function of P/L value (figure 9), the cumulative curves showed that differentiation was made for P/L < 87 Kg.cm\(^{-1}\), therefore in the fastest decreasing range of porosities. Obviously poral spaces could be considered as significantly different according to soil cultivation technique.

22. Root morphology and yield.

The responses of the sugar beet were : a population decrease and, by a compensation effect, an increase of average diameter and weight of tap-root. No significant effect was observed for branching, sugar content and juice purity.
Finally, yield decreased in relation to applied stress leading to 20% reduction in yield for severe treatments without influence of preparation quality (fig.10).

CONCLUSIONS:

In this experiment, the simplification of tillage led to a decrease in plant population and, perhaps, to a lower yield. This year, the seedbed quality was most dominant. Soil compaction under wheel tracks has resulted in a reduction of accessible poral space with consequences on root morphology and perhaps yield. Under other climatic conditions and more differentiated treatments soil physical state during root growth could appear as a predominant factor.

No conclusion can be drawn from a one-year experiment owing to cumulative effects of the reduction of textural porosity. It is the reason for trying to differentiate the tillage effects on seedbed quality on the one hand and on internal soil structure on the other hand.

ACKNOWLEDGMENTS: The author is very much indebted to M. Dominique ARNOULT, GAEC 201 at Fouilly/Serre, for his cooperation without which this study would not have been possible. ITB Alene members helped during the field investigation and their assistance is gratefully acknowledged.

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EFFECT OF FERTILIZATION ON SOIL TILLAGE

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Abstract
In a long term experiment, established in 1904, soil properties and yields were affected by different treatments of fertilising and manuring. The nutrient and humus contents of the experimental plots differ remarkably today.

The stability of soil aggregates is in close relation to the soil humus content. So on plots with a rather high humus content compaction in tracks of tractorwheels is much less than on plots with a low humus content. That applies also to the differences in yield between compacted (by wheels) and not compacted areas on the experimental plots.

Introduction
Growing short-living, mostly annual plants on the field requires an intensive soil cultivation every year. The use of heavy tractors and tillage implements during the time of unfavourable soil conditions can produce soil compaction in the top layer and the subsoil. Using the traditional seed-bed preparation up to 90 % of the field are covered with tracks of wheels (SOANE and PIDGEON, 1974). The effects of these tracks on the physical, chemical and biological soil characteristics as well as on yield and quality of field crops are often disregarded. Powerful tractors often induce a soil tillage in periods when soil conditions should not allow it.
The susceptibility of the topsoil to compaction depends on soil texture, soil structure and moisture content of the soil at cultivation. Particularly soils which are rich in silt, such as loess, tend to compaction. The stability of the soil structure is heavily influenced by the humus content of the soil (HALSTEAD and SOWDEN, 1970). In the intensive crop farming management this relation is neglected mostly. The danger of compaction by secondary tillage rises with increasing moisture content of the soil and also if the period between primary and secondary tillage is too short (HEEGE, 1978). This situation can be observed year by year in many farming districts of the Federal Republic of Germany, for example on the loess soils of Rhine region. Immediately after the harvest of sugar beet in October, November or December the soil cultivation for winter wheat is carried out, very often at wet and unfavourable soil conditions.

Materials and Methods

The named problems were studied in a long term manurial experiment in the Rhine district. This nutrient deficiency experiment has been established in the year 1904 to examine the influence of organic and mineral fertilization on soil characteristics, plant yields and quality (RICHARDSEN, 1919; DHEIN and MERTENS, 1955). Factor a) dung/control; factor b) N P K Ca - P K Ca/N - K Ca/N P - Ca/N P K. Crop rotation and manuring system of this plot have remained unchanged since the year 1953 (Table 1).

<table>
<thead>
<tr>
<th>Crop rotation</th>
<th>Dung (t/ha)</th>
<th>N (kg/ha)</th>
<th>P$_2$O$_5$ (kg/ha)</th>
<th>K$_2$O (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar beet</td>
<td>20</td>
<td>80</td>
<td>70</td>
<td>140</td>
</tr>
<tr>
<td>Winter wheat</td>
<td>-</td>
<td>60</td>
<td>70</td>
<td>140</td>
</tr>
<tr>
<td>Winter rye</td>
<td>20</td>
<td>40</td>
<td>70</td>
<td>140</td>
</tr>
<tr>
<td>Leguminosae</td>
<td>-</td>
<td>-</td>
<td>70</td>
<td>140</td>
</tr>
<tr>
<td>Potatoes</td>
<td>20</td>
<td>50</td>
<td>70</td>
<td>140</td>
</tr>
</tbody>
</table>

Table 1 - Crop rotation and manuring system
Results and Discussion

The different manuring which has been practised since decades causes important effects on soil characteristics as well as on the yield of the grown crops. The nutrient content of the soil reaches only a very low level in the corresponding deficiency plots. An additional manuring of dung may reduce the specific lack of nutrients but is not able to compensate it. The C-content of the soil could only be kept constant during a period of 30 years by an additional fertilization of dung, i.e. dung + mineral fertilizer + 20% leguminosae in the crop rotation. Applying only mineral fertilizers, the crop residues of this rotation - in spite of 20% leguminosae - are not sufficient to maintain the C-content of the soil for a longer time. CAPE, STURKIE and HITBOLD (1958) as well as RAUHE (1969) obtained the same results.

These soil characteristics are showing marked effects on other soil parameters as well. For example a close relation is existing between the aggregate stability and the C-content of the soil (Figure 1).

![Figure 1 - Aggregate stability](image)

From these facts are arising not only consequences for the balance of the air-, water- and nutrient contents of the soil but also for the nitrogen release and the decomposition of cellulose (FRANKEN, 1973). Conclusions
may be drawn likewise for the susceptibility of the soil to compaction which was examined here in laboratory experiments.

bulk density ($\text{g/cm}^3$)

![Graph showing bulk density vs. soil moisture content](image)

Figure 2 - Compaction at different soil moisture contents

$Y_1 = 1.458 + 0.032x + 0.0028x^2 - 0.000057x^3; B = 0.92; n = 9$

$Y_2 = 1.518 + 0.043x + 0.0044x^2 - 0.00011x^3; B = 0.90; n = 9$

Figure 2 shows that the danger of compaction increases with rising soil moisture content, which occurs for example by tilling the soil for the seeds-bed preparation of winter wheat. Comparing similar axle load a loess soil with a lower C-content (control) will become much more compacted than a loess soil with a higher C-content (with dung). In this case a higher C-content means higher stability of aggregates, as well.

Therefore, in critical periods such as soil cultivation in late autumn, soils with a balanced humus content are giving less problems, provided
that there are no compacted layers in the soil profile.

Field investigations on the above named long term experimental field have shown that tracks of tractorwheels, resulting from a seed-bed preparation on wet soil - especially at low humus content (control) - may result in a negative influence on soil structure and the yield of winter wheat (Figure 3).

Figure 3 - Grain yield of winter wheat (g/ m²)

The differences of yield between compacted (in tracks) and uncompacted soils (between tracks) are less when dung + mineral fertilizer are used instead of mineral fertilizer only. Soil compactions are reducing yields in connection with plant density and nutrient supply, that means, in compacted soils often a retarded N-mineralization can be watched. The basic difference in the level of yield between +/- dung plots is obviously induced by the nutrient supply, though dung always has been given to the proceeding crop and not to the winter wheat itself. Applying only mineral fertilizers, lack of N causes the strongest yield depressions.

These experiments are proving that soil compactions, caused by tracks of
tractor wheels, can induce important depressions of yield. Nevertheless soil compactions can never be avoided completely. In many cases, however, - a better supply of the soil with organic matter - a reduction of tracks by a combination of cultivating measures and - in extreme cases the avoiding of the use of heavy tractors and tillage implements during the time of wet and unfavourable soil conditions may help to decrease the negative effects of the tracks on soil characteristics, crop yield and quality. However in many cases, it is a practice to correct mistakes in soil cultivation by a higher amount of mineral fertilizers instead.

References


EFFECT OF CULTIVATION ON ORGANIC-MATTER STATUS AND COMPACTION BEHAVIOUR OF SOIL.

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ABSTRACT.

Mechanical properties of soils are shown to be markedly influenced by organic matters.

A Laboratory compaction test (Proctor) is used on both artificial mixtures and natural soil material. The specific influences of undecayed straw fragments and humic substances are assumed to explain more or less the behaviour of a hundred natural soils.

A model of organic matter evolution is proposed and points out the effect of residues incorporation depth on organic matter status of soils.

INTRODUCTION.

In the last decades, important changes in agricultural production imply more and more risks of soil physical degradation. The evolution of cultivation and production system provoked in France:

- a decreasing trend of soil organic matter content due to:
  - reduction of grazier production areas,
  - repeated removal of crop residues,
  - increasing ploughing depth.
- the emergence of new constraints in the management time-table.

To overcome those constraints it has been necessary:

- to ameliorate trafficability by increasing the power of the vehicles. The consequences have been an increase of their weight and the ability for them to work in wetter conditions. Those two elements contribute to increase the compaction hazards.
- to reduce the cultivation system, sometimes up to direct drilling.
But such techniques do not allow soil recovery after compaction as traditional techniques did.

Therefore, we are faced to two questions:
- What is the influence of soil organic matter (OM) in soil compressibility.
- Is there any mean to control the OM stock in the top soil layer.

1/ ORGANIC MATTERS AND SOIL COMPACTION.

Modifications induced by OM in the compressibility of soil have been observed, incorporating to strictly mineral soil material either free OM (e.g. straw fragments) or bounded to clay OM (e.g. humic substances (HA), polyethylene glycol (PEG)) (J. GUERIF, 1979).

The Proctor test has been used, for compaction, at the standard energy (0.6 MJ.m\(^{-3}\)) and at a modified energy (0.15 MJ.m\(^{-3}\)).

It is possible to define, on Proctor curves, two particular points. Their water contents \(W_0\), \(W_m\) are corresponding to changes in the behaviour of soil during compaction.

\(W_0\) - The water content \(W_0\) of this characteristic point is such that generally at lower water contents the material reaches compactness almost independently of the water content, while at higher water contents the compacted dry bulk density increases markedly with increasing water content. The values of \(W_0\) depend as a linear function on the clay content and on the energy used for compaction (A. FAURE, 1978).

Recent works have shown that for \(W > W_0\) the compaction is time-dependent while for \(W < W_0\), it is not (J. GUERIF, 1981).

\(W_m\) - The water content of that particular point is known as the optimum Proctor which is the water content at which the compaction leads to the maximum of compactness and the sample is quasi-saturated. Further compression would need drainage.

The free OM (here 2 % weight straw fragments) induces a decrease of the bulk density of the tested soil material (fig. 1). This supplementary pore space is partly due to the sterical effect of the organic fragments. Moreover the same values of the water limits \(W_c\) and \(W_m\) are observed for the mineral material compacted at 0.5 MJ.m\(^{-3}\) and for the sample which contains 2 % of straw but compacted at 0.6 MJ.m\(^{-3}\). According to their mechanical properties a relaxation of the sample can be observed. This relaxation expresses an elastoplastic behaviour of the sample. The elasticity of the free organic fragments could explain the increase of the water-content of the limits previously defined.


_Bounded OM_ do not seem to modify the limit \( W_c \), but they are able to increase or decrease the water content at the optimum Proctor (fig. 2). Hydration processes are modified and we assume that rheological properties of clay are also modified.

The importance of the influence of those mechanisms has been verified on about hundred different soils covering a wide range of granulometry and OM content (J. GUERIF, A. FAURE, 1979).

Thus, the existence of behaviours observed on artificial mixtures has been confirmed with natural soil materials:

(i) \( W_c \) depends directly on the mineral constitution of the soil material and more precisely, for a given compaction energy, \( W_c \) is an ascending linear function of the clay content.

(ii) The increase of OM content induces:
- a decrease of the bulk density; at the optimum Proctor for standard energy (0.5 MJ.m\(^{-3}\)) we have:

\[
\frac{1}{\gamma_{dm}} = 0.197 \, A + 2.645 \, OM + 0.503
\]

\( \gamma_{dm} \) = density at the optimum Proctor \( g.cm^{-3} \)

\( A \) = Clay content \( g.g^{-1} \)

\( OM \) = Organic matter content \( g.g^{-1} \)

\( n = 91 \)

\( r = 0.873 \)
- an increase of the water content of the limits $W_C - W_m$

\[
\hat{W}_C = 0.27 A + 1.52 \text{ OM} \quad n = 55 \quad r = 0.84 \\
\hat{W}_m = 0.246 A + 1.642 \text{ OM} + 0.089 \quad n = 91 \quad r = 0.90
\]

2/ ORGANIC MATTER EVOLUTION AND SOIL TILLAGE.

As we tried to demonstrate Organic matters are very important in the compressibility of top soil layers. They do represent one of the only constituents of the soil upon which man is able to act. And OM could be considered as a mean to fight against compaction processes.

But the study of the mechanical properties of soils, as induced by organic matters, will only be fully valorized if concurrently we succeed to set up, even a simple and rough mean to predict the long term evolution of the OM stock of top soil layers. Either to be able to control its level or to imagine the consequences of the introduction of new techniques in a crop and cultivation system.

We attempted with a long term field experiment concerning minimum tillage:

- (i) to modelize roughly the evolution of OM.
- (ii) to show out the influence of tillage techniques on this OM evolution.

The field experiment.

For a maize-winter wheat rotation, long term effects of mouldboard ploughing (0-25 cm) $|L_0|$, shallow cultivation (0-10 cm) $|L_1|$ and zero-tillage $|L_2|$ are compared since 1970. Crop residues are incorporated $|L_0|$, $L_1$ or left on the soil surface $|L_2|$. The OM stock just before incorporation of the residues is known by sampling and measuring soil carbon content (Anne's method) and density (Yray probe) (sampling : 4 samples per plot, 8 plots per treatment).

Different incorporating depths induced important differences in the
The model.

The model is a budgeting model. It contains annual crop residues as input and annual mineralization as output.

The main hypothesis concerning the model are:

- (i) because of the chosen time span, the soil microflora is not to be explicitly taken into account.
- (ii) the annual output is considered to be a proportional part of the measured OM stock. (a first-order kinetics equation. [HENIN et al, 1945])

If : \( C_n \) is the soil carbon mass sampled in the year "n".

- \( m_n \) is the mass of carbon of the incorporated crop residues.
- \( k_1 \) is the mean coefficient of transformation of crop residues into soil OM within one year.
- \( k_2 \) is the coefficient of mineralization.

and balancing the budget the equation is:

\[
C_{n+1} - C_n = k_1 m_n - k_2 C_n \quad \text{if } n=1
\]

The integration yields:

\[
C_n = C_0 (1 - k_2)^n + k_1 \sum_{i=0}^{n-1} (1 - k_2)^i m_{n-i-1}
\]

About the parameters it is assumed that:

- \( k_2 \) is only a pedoclimatic parameter mainly dependant on temperature and independent on the nature and quantity of the crop residues. We suppose that \( k_2 \) is a constant for a given geographic locus.
- \( k_1 \) is dependant on biochemical constitution of the buried residues, tillage techniques and soil OM content. Quite always data concerning root residues are not available. In that case, because of the correlation, often admitted, between aerial parts and root residues, the influence of root residues is implicitly included in \( k_1 \).

Influence of tillage depth on OM evolution.

If, for any of the three treatments, the stock of soil Carbon/ha is evaluated over the same mass of soil (i.e. the plough layer mass) it appears that the higher is the C concentration (i.e. the shallower is the cultivation) the slower is the decay.

Using \( k_1 \) and \( k_2 \) statistically evaluated the influence of straw removal on the trend of OM evolution can be roughly predicted (fig. 4).
Fig. 4 – Prediction of the carbon stock.

**Conclusion.**

Soil response to compaction is markedly influenced by OM.

- (i) soil pore space seems to be more or less protected.
- (ii) the consistency limits, as defined by the Proctor test, \( W_c \) and \( W_m \) increase with OM content.

Those laboratory results being verified on the field, a better trafficability and a restraint of soil compaction damages are expected to be obtained by an appropriate management of the OM status.

**References.**


LONG-TERM EFFECTS OF VEHICLES WITH HIGH AXLE LOAD ON SUBSOIL COMPACTION AND CROP RESPONSE.

by Inge Håkansson

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ABSTRACT

In 1976-1978 nine field experiments were started in Sweden with traffic by a 26 ton vehicle. Measurements in 1978 revealed soil compaction to a depth of 50 cm. During the initial years large negative crop response was obtained on sites with high clay content. The crop response gradually decreased with time, though measurements in 1980 did not indicate any alleviation of the subsoil compaction since 1978.

To increase the information on the persistence of subsoil compaction by vehicles with high axle load, and the crop response, an international working-group was formed with participants from Northwestern Europe and North-America. An international series of experiments with common treatments is now being started. The objective is to get a basis for recommendations for upper limits of field application of axle load.

SWEDISH EXPERIMENTS.

Research work on soil and crop response to machinery traffic has been in progress in Sweden for more than 20 years. A summary of the results was recently published (Håkansson & Danfors, 1981). A recent part of the experimental work is a group of field experiments for studying the effects of subsoil compaction caused by vehicles with high axle load.

The background for these experiments is as follows. Available information shows that compaction penetrates deeper and persists longer as axle
load increases. At the highest axle loads in current use the compaction may penetrate deep into the subsoil. Compaction at the 40 cm depth or deeper may persist for decades, even in areas with deep annual freezing. Tillage to alleviate the compaction becomes more difficult and expensive the deeper the compaction penetrates. It is therefore of big interest to investigate under which conditions compaction of deep subsoil layers gives significant negative effects on the crops. Where it does, it seems advisable to restrict the axle load to avoid such compaction.

Nine high axle load experiments were started in 1976-1978 on soils with clay contents ranging from 6 to 70 percent. The compaction treatments were applied at start of the experiments, with the soil at field capacity moisture content, using a vehicle with a weight of 26 tons (metric), 10 tons on a single front axle, and 16 tons on a rear tandem axle unit. The persistence of the compaction effects, and the crop response, will be studied during a ten-year period.

Some results from the first experimental years were reported earlier (Håkansson, 1979, 1980, Håkansson & Danfors, 1981). In the autumn of 1978 bulk density and vane shear resistance of the subsoil were determined. It was clearly seen that the traffic had resulted in compaction to a depth of about 50 cm. Two years later the vane shear resistance was determined again. No alleviation of the compaction in the meantime could be detected.

The crop yield results received up to 1981 are shown in Fig. 1. On soils with low clay content there were very small effects on the yield, but on soils with high clay content there were large negative effects during the initial years. These effects, however, gradually decreased with time, and by the fifth year, were very small.

The first years results can be assumed to be caused, to a big extent, by the compaction of the plough layer. Results of other experiments, however, (Håkansson & Danfors, 1981) show that the effects of plough layer compaction, in a situation with annual ploughing and freezing, disappear within a four-year period, and can not be expected to affect the crop yield after that time. However, even in the experiments reported here, nearly all crop yield effects had disappeared within a four-year period.

The subsoil measurements and the crop yield data thus show somewhat
FIGURE 1. Crop yield effects of traffic with a 26 ton vehicle; results of nine Swedish field experiments 1976-1981. The diagram shows regression lines for year no 1 to year no 5 for a treatment with the plot surface covered by tracks from the vehicle four times. Y = relative crop yield in compacted plots (uncompacted = 100). C = clay content in the upper part of the subsoil. The regression equations are as follows:

Year no 1: \[ Y = 97 - 0.39C; \quad r = -0.61; \quad \overline{Y} = 83 \]
Year no 2: \[ Y = 104 - 0.22C; \quad r = -0.63; \quad \overline{Y} = 96 \]
Year no 3: \[ Y = 102 - 0.17C; \quad r = -0.51; \quad \overline{Y} = 96 \]
Year no 4: \[ Y = 105 - 0.15C; \quad r = -0.78^*; \quad \overline{Y} = 100 \]
Year no 5: \[ Y = 102 - 0.07C; \quad r = -0.86^*; \quad \overline{Y} = 100 \]

\( \overline{Y} \) = mean relative yield in seven of the nine experiments, harvested throughout a five-year period.
contradictory results; the crop yield effects have nearly disappeared, though there still seems to be compaction effects persisting in the soil. This may have several explanations. One may be that compaction of the subsoil to the extent obtained does not have any negative effects on the crop. Then the first years effects should be the result of the plough layer compaction only. The first years effects, however, seem to be somewhat too large to support this hypothesis. Another possibility may be that the subsoil compaction affects the crop under certain weather conditions only, and that such conditions have not been prevailing on the experimental sites during the last few years. If this is true some effects may appear again in the future. A third possibility may be that some new cracks, earthworm holes and similar continuous large pores have developed through the compacted layers, extensive enough to remove the hindrances to root development but not to change a soil property such as strength. Whatever the reason, it seems necessary to run the experiments for another few years, and to carry out continued subsoil measurements.

The Swedish experimental program has not been extensive enough to satisfactorily answer the questions raised. The results clearly show that the effects of the treatments are very different on different sites. For satisfactory answers, therefore, an increased number of experimental sites seemed necessary. This, however, was not possible for one small country alone.

INTERNATIONAL COOPERATION

The initial results of the Swedish experiments were presented at the poster session of the 1979 ISTRO-conference in Stuttgart-Hohenheim. This gave rise to discussions on the formation of an international working-group on soil compaction by vehicles with high axle load, and on starting an international series of experiments.

The main reason for international cooperation on this theme is that the market for farm machinery is very international. The results of the experiments may give rise to recommendations having a large influence on the design of this machinery. Therefore it would be very desirable to have the recommendations based on experiments in several countries. However,
it can be foreseen that the experimental results, and the recommendations which might follow, will be very dependent upon soil, crop, and climatic conditions. Therefore, the international cooperation should initially be restricted to reasonably uniform physiographic regions.

Northwestern Europe and similar areas of North-America were suggested as one suitable region. Scientists from several countries in this region met in Uppsala, Sweden, in September 1980. The participants discussed the present state of knowledge concerning the effects on soils and crops of traffic with very heavy machinery, and concluded that new experiments were needed. Therefore, a working-group was formed, the participants of which would try to initiate such experiments in their respective countries. Guidelines for the experiments were also worked out. A report of the meeting is published (Working Group on Soil Compaction, 1980).

It was decided that each of the joint experiments should contain at least two common treatments, one control treatment, and one treatment with traffic at field capacity moisture content with a vehicle having a load of 10 tons (metric) per single axle or 16 tons per tandem axle unit. These loads were chosen because they form the upper load limits for the highways in most of the participating countries. However, it was recommended that the experiments also contain additional treatments according to local interests. The objective of the joint experiments is to form a basis for recommendations for upper limits of field application of axle load. For this purpose the experiments will be designed to reveal the depth and persistence of the compaction, and the crop response. In the end the compaction effects on different types of soils must be weighed against the technical benefits of using the high axle loads.

The farm machinery is very expensive and the axle loads used may have a large influence on the costs as well as the performance of the machinery. Therefore it is of great economic importance that the choice of axle load is based on knowledge of the effects rather than on ignorance of them or undue fear for unknown effects. For some situations the final result may be that there is no need for axle load restrictions within the range of loads which is of interest for technical reasons. However, even a result in that direction will be of great importance, and justifies the experimentation.
It must be stressed here that the axle load limits recommended will, naturally, be influenced by the wheel equipment used. Furthermore, restrictions of the axle loads do not necessarily imply restrictions of the total weights of the vehicles. However, when the weights increase over certain limits the number of axles and wheels also must be increased. This may strongly influence the design of the vehicles.

Up to now (November 1981) the efforts have resulted in four new experiments already being started, one in Norway and three in Minnesota, USA. Some others are planned to be started in a near future. The international cooperation therefore should soon result in a considerably increased knowledge on the subject concerned.

REFERENCES


The changes of the soil structure and the physical properties of soil being compacted

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Summary

The investigation concerned physical properties of brown soil formed from loess. The soil was compacted in an instrument with deformation and force recording. We found considerable decrease in pore space, air permeability and pore volume (for pores > 100 μm in diameter). Microscopic investigation reveals that the layer being in direct contact with the pressing element is subject to the greatest compaction. Beneath, one finds a looser layer, which again is followed by a layer of a greater compaction at the level of about 10 mm.

Introduction

Heavy traffic of cultivation machinery causes considerable changes of soil structure in the wheel-tracks. This is evidenced by a marked decrease in pore space [4, 5], air permeability [1, 4] and macropore volume [2], which in turn results in worse gas-exchange. This normally leads to lower crop yields [4]. The intensity of gas-exchange decreases parallel to an increase in unit load [2, 4, 5].

Increased soil compaction due to machinery traffic causes also greater strength resistance [3] and consequently increases energy expenditure in soil cultivation. Strength resistance increases to an extreme degree when the pressure affecting the soil is greater than 98.1 kN/m² (1 kG/cm²) [3].
The goal of our investigation was to define the influence of load on soil deformation and the concomitant changes in soil.

Method

The investigation was carried out on brown soil formed from loess. The soil from the arable layer was poured into metal cylinders (100 cm$^3$) and special boxes. 6 series of probes consisting of 8 items each were prepared. Soil moisture ranged within 12-13% and porosity within 61.7 - 62.7%. One series of probes was left intact, whereas others were processed by a pressure device with a deformation and force recorder. The probes were pressed with a stamp $\phi$ 50 mm for 20 s. The pressure applied was 49.05 kN/m$^2$ (0.5 kG/cm$^2$), 68.7 kN/m$^2$ (0.7 kG/cm$^2$), 98.1 kN/m$^2$ (1 kG/cm$^2$), 196.2 kN/m$^2$ (2 kG/cm$^2$) and 490.5 kN/m$^2$ (5 kG/cm$^2$).

For all the probes contained in cylinders we delimited air permeability by means of an LPiR 1 apparatus which is used for measuring permeability of molding mass. The value of air permeability is expressed in cm$^4$/g min.

On the basis of probe deformation curves the change of pore space under compaction was calculated.

The probes contained in boxes were, after all measurements, impregnated with polyester resin Polimal 109 in order to prepare nontransparent soil microsections. As soon as the impregnated probes hardened, they were cut across in the centre and ground. By means of a microscope and point method the measurements of solid phase and pore quantity were taken in a chosen central zone of compaction. This zone was 24 mm wide. In-depth measurements of solid phase and pore quantity were carried out every 1 mm reaching 15 mm deep.

Results

The pressure affecting soil results, first of all, in its vertical deformation. This deformation clearly depends on the amount of pressure. A unit load of 49.05 kN/m$^2$ (0.5 kG/cm$^2$) causes soil deformation of approximately 8.5 mm within 20 s.
The period of considerable deformation growth (ending with an abrupt curve slump) ranges between 6-8 s. For a unit load of 490.5 kN/m² (5 kG/cm²) the deformation reaches about 19 mm, whereas the period of considerable deformation growth equals 1.5 s. (fig.1).

Fig.1. Deformation of soil

Therefore one may conclude that smaller pressure affects the soil in a less drastic manner and induces smaller vertical deformation. This is due to the fact that soil may resist the pressures it is subject to. However, great loads exceed the forces which bind soil structure, so that soil loses its potential for resisting the load and consequently the concomitant
changes are very great.

Vertical deformation of soil is followed by its volume deformation. Loading results in decreased pore space (fig. 2) and lower macropore volume (i.e., pores with a diameter > 100μm (fig.3)). The greater the pressure used, the greater the changes. A load of 49.05 kN/m² decreases porosity from 62.3% to 44.6%, and a load of 490.5 kN/m² decreases from 48.06% to 43-32% (depending on the layer) and to
26-13%, respectively.

Lower soil porosity and macropore volume decreases as well its aptitude for gas exchange, which is evidenced by air permeability (fig.4). This property is a particularly reliable indication of soil compaction. Even a load as small as 49.05 kN/m² results in a decrease of air permeability from 1266 cm⁴/g min to 250 cm⁴/g min.

Fig.4. Air permeability of soil

Proportionally to constant increase of pressure the value of air permeability gets even smaller, so that for 490.5 kN/m² it reaches the value of 38.4 cm⁴/g min.

On the basis of the above results one may conclude what follows:

Firstly, loads lower than 98.1 kN/m² induce soil changes of a very similar character. This is evidenced by the extent of deformation (fig.1) and by the resulting changes of air properties (fig.2, 3, 4).

Secondly, the load of 196.2 kN/m² seems to be the critical value. This is borne out by the extent and character of deformation (a very abrupt curve - fall) and by a decrease of pore space and air permeability.

While analysing the microscopic results in greater detail, one may notice a characteristic pattern of macropores within the 15 mm layer of compacted soil (fig.3). Namely, the volume
of macropores increases systematically only to the depth of 4-10 mm, and below a more compacted zone may be observed.

Besides, in the least compacted probes (49.05 and 68.7 kN/m²), one may observe considerable condensation of macropores in the layer being in direct contact with the elements under compaction.

This is an effect of relaxation of a rather weakly compacted soil matter. These regularities obviously hold for a definite condition of soil at the moment of compaction, which here is loose soil of medium humidity. However, the results obtained in the course of the investigation seem to suggest fairly clearly that the influence of the compactive force on soil, being a multi-phase, polydisperse matter, is extremely complex and hence analyses of this sort must be carried on in future.

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Precompaction stress determination on precompacted soil.

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Abstract.

The quantity "equivalent precompaction stress" is proposed as a characteristic of the resistance against further compaction of soil. A simple procedure to determine this quantity on field samples is presented.

1. Introduction.

Soil compaction is very common. Main causes are soil settling and field traffic. Soil that has been subjected to a compaction process, will be called precompacted soil. In field operations farmers often deal with precompacted soil, and try to keep further compaction at a minimum.

The resistance against further compaction of a precompacted soil depends on soil type, porosity, moisture content, degree of aggregation, length of time-interval between precompaction and further compaction, number and character of drying/wetting cycles between precompaction and further compaction, and moisture content that prevailed at precompaction. It is true that any loading of a precompacted soil will lead to some further compaction, but below a certain stress this will be very restricted and clearly less sensitive to pressure increases than above that stress. This paper presents a simple method to determine that particular stress.

2. A measure of the resistance against further compaction.

Fig. 1 presents the relationship between stress and void ratio e in uni-axial compression for an initially loose soil that was loaded to a 2.17 bar stress and unloaded, immediately followed by a reloading to 10.15 bar and unloading. So, the second loading involves further compaction of precompacted soil. Maximum stress at precompaction (2.17 bar) may be considered as a measure of resistance against further compaction. It is
assumed that stresses higher than that value induce significant further compaction, and lower stresses do not. We call this stress $\sigma_p$.

Suppose only the curve-part $AE$ is known. Then $\sigma_p$ can be estimated from that curve-part using the following method.

1. make a semi-logarithmic plot as in fig. 1b,
2. draw a line $l$ in such a way that $l$ parallels $AB$ and $AF$ equals $0.02e$,
3. extend the linear part $DE$ to find tangent $m$,
4. the intersection point $C$ of $m$ and $l$ provides an estimate of $\sigma_p$.

Section 3 describes how the method was developed.

The method can be extended to field samples of precompacted soil.

To this end, a compaction curve as in fig. 1b should be measured on the field sample, and the described method applied to that curve. Because now the relation between precompaction and further compaction is less obvious than in the case in fig. 1 where a known precompaction preceded immediately, $\sigma_p$ determined on a field sample will be referred to as an equivalent
precompaction stress, denoted by $\sigma_{ep}$.

3. Development of the method.

In a uni-axial compression test, loose soil was precompacted to a certain stress and unloaded, immediately followed by reloading to a higher stress and then unloaded again. The precompaction stress $\sigma_p$ and the $e$-log $\sigma$ relationship in further compaction were measured and plotted as in Fig. 2. Drawing vertical $\sigma = \sigma_p$ and tangent $m$ gives the point of intersection $C$. Line $\ell$ is drawn through $C$ and parallel to $AB$. Line $\ell$ intersects the $\sigma$-axis in $F$. The length of line-element $AF$ is expressed in units of void ratio, $\Delta e = a$ (In Fig. 2 $\Delta e = .910 - .885 = 0.025$, so $a = 0.025$).

54 samples were tested in this way. The experiments involved 3 soil types, 3 moisture content levels, 3 precompaction stress levels and one replication. First, the soil was sieved through a 3.4 mm screen and moistened by spraying. Compaction was in cylinders with a height of 50 mm and an inner diameter of 81 mm. Pressing plate velocity was linear at a rate of 3 mm/sec. Each sample provided an individual $a$-value. From these values a mean value was calculated and that mean value is applied in step 2 of the method presented in the previous section.
fig. 3

predicted $\sigma_p \text{ bar}$

Ede sand

Lexkesveer loam

Wageningen silty clay loam

"true" $\sigma_p \text{ bar}$
4. Examination of the method.

The method of section 2 was now applied to the e-log $\sigma$ relationships in further compaction of the samples mentioned in section 3 as if precompaction stresses were unknown. This resulted in "estimated" precompaction stresses that can be compared to the known "true" precompaction stresses. The results are given in table 1 and in fig. 3. It appeared that, in general, the estimation is good. Misprediction only occurred for the heaviest soil in wet condition and at high precompaction stress. In this case the soil was almost saturated at reloading.

5. Discussion and conclusion.

The method presented is simple and reliable. Further attention should be paid to, how much different insignificant and significant further compaction are under various conditions and, how accurate $\sigma_{ep}$ can be estimated as the boundary in between. Note that a $\sigma_{ep}$ value presents only a momentaneous picture. The value will vary with
1. the prevailing moisture content,
2. time elapsed after precompaction,
3. number and character of drying/wetting cycles.

Up to now $\sigma_{ep}$ determinations on field samples have been carried out for
- $\sigma_{ep}$ determination in spring on ploughed soil that was ploughed in autumn,
- determination of a $\sigma_{ep}$-depth relationship for a soil profile,
- determination of $\sigma_{ep}$ at $pF = 2.5$ for field experiments with various artificial compaction levels.
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INFLUENCE OF TIRES CONSTRUCTION ON SOIL COMPACTION

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Abstract

The main goal of investigation given in this paper is to analyse the influence of tire construction on the soil compaction processes. Experimental investigation includes eight bias (conventional) and radial tires which have been compared in three different agricultural (firm) soils. During measurements, dynamic load, inflation pressure and travel reduction were varied and soil bulk density and penetration resistance and footprint geometry were measured. The results showed that radial tires has caused some more compaction in one of three investigated soils. There were essentially no differences in compaction between bias and radial ply tires in the other two types of soils. Generally, the advantage of bias tire, as far as the compaction is concerned, was insignificant for firm agricultural soils.

Introduction

Compaction problem in agriculture has been one of the vastly investigated problems for the last twenty years. Influence of the soil compaction under heavy loaded agricultural machinery on yields has been proved many times.
The scientific research dealing with the soil compaction showed that trailer wheels and tractor wheels in furrows when ploughing are likely to be the most serious cause of compaction. Using lower inflation pressure tires with larger footprint area, may significantly reduce compaction under trailer wheels. It may seem easy, but the extra cost which is involved, should be justified by benefits of less compaction. However, reduction of the soil compaction under tractor wheels is more difficult.

It is known that different devices attain different tractive performances and different distribution of forces in the contact area. It means that the benefits obtained by construction of tractor tires causing less compaction, have to cover not only the extra cost, but it has to give enough traction, as well. Anyway, in order to reduce the soil compaction, something has to be changed in tractor tire construction, but experimental work must include tractive performance as well as soil compaction behavior.

Using the test facilities of the USDA National Tillage Machinery Laboratory at Auburn, Alabama, eight radial ply and bias ply tires have been run on Norfolk sandy loam, Hiwassee loam and Lloyd clay. Exploratory tests were run in May, 1981, using 16.9-38, 18.4-34, 18.4-42 and 24.5-32 tractor tires in both type of construction, bias and radial. Selected tires were as similar as possible, except varying construction. Lug spacing, lug high, rubber compounding, etc, were close to constant.

During the experiments, inflation pressure, travel reduction and dynamic load were varied in the next ranges:
- dynamic load: from 0 to (about) 50 kN,
- travel reduction: from 0 to 30% and
- inflation pressure: from 82.7 to 138.0 kPa.

Radial ply tires and bias ply tires were compared in three types of soils which were rather firm than soft. It is known that the advantage of the radial ply tires are greatest in the firm soils in relation bias ply, from the point of view of the tractive perfor-
mance, therefore the firm soil state has been chosen for the investigation of the soil compaction properties.

The idea of parallel investigation of the soil compaction under radial ply and bias ply tires came from the prior investigations which reported /3/ greater pull at any given soil conditions, except very cohesive clay, and any slip, for the radials. At the same time, lower rolling resistance and fuel consumption for the radial tires, were found.

In case that radial tires produce less compaction, the advantage of this type of construction would be absolute.

Results and discussion

The final tests were run in Norfolk sandy loam, Hiwassee loam and Lloyd clay. Sinkage, width of wheel trucks, soil bulk density, moisture content and penetrometer resistance were measured on each 75 cm along of the truck.

The initial tests were run on concrete pavement, just in order to find the dynamic rolling radius.

The analysis of collected data showed that the soil bulk density is the most suitable parameter for discussion of the difference between bias ply and radial ply tractor tires in relation with the soil compaction.

Differences connected to the sinkage and width of wheel trucks were significant along the truck but, it was very difficult to show how much of it depends on the increasing load and how much on the soil parameters.

The same kind of difficulty was connected by penetrometer resistance. Precisely, the soil profile had not the same strength along the depth before tests, so, that the different sinkage produces different measuring levels of penetrometer readings and results were unsuitable for relative observations.

Figure 1. shows the test results from all of the investigated soils, Norfolk sandy loam, Hiwassee loam and Lloyd clay, and for four of
Figure 1. Dynamic load versus soil bulk density lines for three different soils and four tires, two radials and two bias (the same dimensions).

Eight tested tires. Dynamic load versus soil bulk density lines show some advantage of bias ply tires in Lloyd clay (firm state), but differences are not more than 0.05 gr/cm³. Lines for the other two soils, Norfolk sandy loam and Hiwassee loam also show some advantage for bias ply tires, but this time only for 18.4-42 tire. For 18.4-34 tire, radial ply proves a better one. It means that for "lighter" soils, tire dimensions have more significant influence on soil compaction than tire construction.

Generally speaking, there were slight differences in soil bulk densities for all of the investigated tires. Using given results it could be difficult to conclude that any one of the tested tire constructions show appreciable advantage in soil compaction area. During test in Hiwassee loam and Lloyd clay inflation pressure was changed. The influence of inflation pressure on soil bulk density are give in Figure 2. The results show significant influence of
inflation pressure on soil compaction processes (soil bulk density, as had been expected, but no appreciable advantage for one of the tested tire construction. The lines in Fig. 2. indicate visible

![Diagram](image)

Figure 2. Dynamic load versus soil bulk density for different inflation pressures of tested tires.

that the smaller tire diameter produces more compaction than the bigger one for the majority of tested tire and soil condition. It means that geometry of footprint area has significant influence on soil compaction system.

Tests in Norfolk bin have included travel reduction variation from 0 to 30\% for 18.4-34 and 18.4-42 tires (both of the investigated tire construction). Results which include the dependence of soil bulk density on dynamic load for different travel reduction are given in Fig. 3. Lines in Figure 3. show that radial ply tires have a little less sensibility, other words, increase of travel reduction produces less influence on soil bulk density.
Conclusions

1. Bias ply carcass construction produces little less compaction in relation to radial ply for more of investigated firm soil condition and tire dimension.

2. Tests in investigated firm agricultural soils show no appreciable advantage for both carcass construction when travel reduction and inflation pressure were changed.

3. Deeper analysis if influence of tire construction on soil compaction should include the analysis of compacted soil profile which has also been done during tests.

References

CONSOLIDATION AND COMPACTION OF TILLED GRUMUSOL IN A CITRUS ORCHARD

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ABSTRACT

Soil, water and air contents were monitored during 3.5 years following subsoiling, to determine its long-term efficiency under conditions of winter rains, summer irrigations and minimized wheel tracking. The factorial experimental set-up was of drained, undrained, tilled and untilled treatments. Half-life of the soil loosening effect was about 3 years in untracked, compared to less than 1.5 years in wheel tracked areas. Subsurface drainage reduced soil consolidation only temporarily and its effect on soil recompaction was small. The water distribution pattern of sprinklers had a pronounced and lasting effect on soil consolidation.

INTRODUCTION

Deep tillage is practised in the alluvial grumusols of northern Israel, prior to planting of orchards. Subsoiling between tree rows is considered by some farmers to improve drainage conditions. The following questions arise: A. are the rates of reconsolidation and compaction of the tilled soil low enough to ensure a lasting significant soil loosening effect during the 5 years of tree establishment; B. is tree root growth actually improved by soil loosening; C. can the rates of consolidation and compaction be reduced by subsurface drainage (draining the perched water from the tilled soil layer in winter); D. can the rate of compaction be reduced by postponing first wheel tracking and use of low surface pressure tractors; and E. is subsurface drainage efficiency improved by deep tillage?

Preliminary observations in a grapefruit orchard, on a 58% clay grumusol, indicated that one year after subsoiling a considerable soil loosening effect still remained. However, tractor traffic almost eliminated the soil loosening. Inferring from experience with field crops (Steinhardt & Trafford, 1974; Steinhardt, 1976) and from theoretical analysis (Steinhardt, 1974) the answers to questions C. and D. were presumed to be positive.

The objective of the work reported here was to obtain quantitative data on tillage and drainage interactions in a mature orchard, with the intention of also applying the results to new plantations.
METHODS

An experiment was conducted in a 4 x 6 m spaced, 15-year old grapefruit orchard in the Western Galilee, on grumusol with 66% clay, 11% silt, 22% sand and 1% organic matter. Treatments applied to tree rows, in 3 to 6 replicates, were: A. CONTROL, surfaced drained only; B. TILLED, subsoiled in autumn to 45 cm depth, with vibrating arms (Schulte-Karring, 1975) - 1. between rows with 4 arms, to a width of 2.8 m, first year on one side of row and the following year on the other side, and 2. across rows with one arm, to a width of 0.7 m, first year only; C. DRAINED, with plastic drains on both sides of the tree row, 6 m apart and 0.8 m deep; and D. DRAINED & TILLED, treatments combined.

Winter rains were 500-600 mm. Irrigations during summer (400 mm) were applied below canopy, by one sprinkler per two trees, its wetting diameter being about equal to the spacing of 8 m. Accordingly, soil water percentage in the 15- and 30-cm depth was 3 to 6% greater on the near sprinkler side of trees than on the far side of the trees. The tilled inter-row spaces were wheel tracked only 1/2 and 1 year after subsoiling. Fruits were conveyed in winter with a 400 x 15.5 (50 KPa pressure) wheel tractor, with a maximal 1300 kg rear axle load. Soil, water and air contents were monitored by the "Gamma double probe" method of Soane et al. (1971) and soil water tensions by tensiometers.

RESULTS

Table 1  Soil air contents and soil water tensions, February 1975, three months after drain installation and subsoiling (values in a row followed by the same letter are not significantly different).

<table>
<thead>
<tr>
<th>Site of Observation</th>
<th>Soil Depth</th>
<th>CONTROL</th>
<th>TILLED</th>
<th>DRAINED</th>
<th>DRAINED &amp; TILLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below Trees</td>
<td>cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(untilled only)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.5-22.5</td>
<td>8.7 b,c</td>
<td>7.9 c</td>
<td>9.8 a,b</td>
<td>11.1 a</td>
<td></td>
</tr>
<tr>
<td>22.5-37.5</td>
<td>4.3 a,b</td>
<td>3.3 b</td>
<td>6.1 a</td>
<td>3.9 a,b</td>
<td></td>
</tr>
<tr>
<td>Between Tree Rows</td>
<td>cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.8 c</td>
<td>22.8 a</td>
<td>9.5 b</td>
<td>23.5 a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.9 c</td>
<td>16.1 b</td>
<td>5.7 c</td>
<td>23.1 a</td>
<td></td>
</tr>
<tr>
<td>Below Trees</td>
<td>cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(untilled only)</td>
<td>30</td>
<td>8.9 a</td>
<td>4.7 b</td>
<td>10.7 a</td>
<td>9.9 a</td>
</tr>
</tbody>
</table>

§ In wheel tracks. † About 1 m from drain. ¶ About 2 m from drain.
Soil conditions during the first winter after initiation of treatments are demonstrated in Table 1. Below the trees, the drainage effect was significant only when combined with tillage, while the tillage alone reduced water tensions and aeration, due to impairment of surface drainage, as observed during rainstorms.

Fig. 1. Consolidation and compaction after subsoiling in the autumn seasons of 1974 (0, +) and 1975 (0, ⊗), in untracked and wheel tracked areas, respectively; averages of TILLED and DRAINED & TILLED († first wheel tracking; ‡ range of bulk densities below canopy, as detailed in Table 2).

The soil loosening effect, as determined by bulk density change, and its subsequent loss are shown in Fig. 1. The rates of consolidation of the two subsoilings were similar. Rates of consolidation were also similar below the canopy and between wheel tracks. A decreased rate of soil consolidation was observed in the first winter in the lower soil layer in DRAINED & TILLED as compared to TILLED. However, this effect vanished during the following summer and was not obtained in the following drier winter, after subsoiling the other side of the tree rows. The rate of soil compaction was not significantly reduced by drainage. Still, the final average reduction in recompaction, observed 2 and 3 years after the two subsoilings, was 0.05 g/cm³; significant at the 10% level only, but representing a 20% reduction in recompaction. Wetting
conditions during irrigations had a pronounced effect on consolidation and root development, as demonstrated in Fig. 2 and Table 2.

Fig. 2. Feeder roots in 0-15 cm layer and air content in 7.5-22.5 cm layer, below canopy, about 2 m from trunk, as function of distance from sprinkler; in untilled (0) and tilled (O) areas; in summer 1.5 years after subsoiling (air contents observed in May and again in August).

The average effect of tillage on root development, at the 0 and 4 m distances, was significant. The results in Fig. 2 suggest that rooting is affected by aeration more than by soil penetrability. The reduced consolidation on the "dry" as compared to the "wet" side had a contradictory effect on soil water percentage and soil water storage in the upper (looser) and lower (denser) soil layers. (For calculation of storage from percentage see Steinhardt, 1978). It is noteworthy that the variance of soil bulk densities between rows, on a scale of tenth of meters, was not higher than the variance on a scale of meters between the two sides of trees (comparing "wet" and "dry" to their differences, in Table 2).

Subsoiling reduced tree growth temporarily. During the first two years following tillage, trunk circumference increased at 2/3 rate of the increase in untilled treatments, but in the following year growth rates were about equal. Yields were not affected significantly by treatments. However, one year after the first subsoiling the yield in the tilled treatments was about 10% lower than
in the untilled ones.

Table 2. Soil, water and air contents in winter (averages for TILLED and DRAINED & TILLED, and their standard deviations) 0.2 m from sprinkler (wet-) and 4 m from sprinkler (dry - sides of trees) three years after subsoiling (soil water tensions at 30 cm depth were 3 and 0 KPa, in DRAINED & TILLED and TILLED, respectively; average air content difference due to drainage was 1.8%, ns).

<table>
<thead>
<tr>
<th>Soil Layer cm</th>
<th>Side of Tree</th>
<th>Bulk Density g/cm³</th>
<th>Relative Consolidation a) %</th>
<th>Moisture Percentage g/g, %</th>
<th>Air Content cm³/cm³, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.5-22.5</td>
<td>Wet</td>
<td>1.187±.047</td>
<td>75</td>
<td>41.1±2.3</td>
<td>6.2±2.0</td>
</tr>
<tr>
<td></td>
<td>Dry</td>
<td>1.134±.040</td>
<td>55</td>
<td>40.3±1.8</td>
<td>11.3±3.5</td>
</tr>
<tr>
<td></td>
<td>Dry</td>
<td>-.053±.074</td>
<td>-20</td>
<td>-.8±2.1</td>
<td>+5.1±4.6</td>
</tr>
<tr>
<td></td>
<td>Wet</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22.5-37.5</td>
<td>Wet</td>
<td>1.243±.033</td>
<td>64</td>
<td>38.8±2.1</td>
<td>4.5±2.0</td>
</tr>
<tr>
<td></td>
<td>Dry</td>
<td>1.182±.037</td>
<td>44</td>
<td>40.5±1.6</td>
<td>7.2±2.9</td>
</tr>
<tr>
<td></td>
<td>Dry</td>
<td>-.061±.060</td>
<td>-20</td>
<td>+1.7±1.7</td>
<td>+2.7±3.8</td>
</tr>
<tr>
<td></td>
<td>Wet</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a) = (BD observed - BD after tillage)/(BD before tillage - BD after tillage).
b) Differences evaluated by paired observations on ten trees, one in each replication.
*, ns = significant and non significant differences, respectively.

DISCUSSION AND CONCLUSIONS

A considerable soil loosening effect with a half-life of nearly three years was obtained by the subsoiling (Fig. 1). The half-life was reduced to about two years due to over-irrigation in the vicinity of the sprinklers. As over-irrigation also impaired aeration and root growth (Fig. 2) it ought to be eliminated by proper design of the irrigation system.

Minimized wheel tracking was not compared to a usual-tracking control. However, when compared to the preliminary observations on compaction by usual tracking, seemingly the rate and degree of compaction were reduced. In spite of postponing the first compaction up to one year, half-life of soil loosening in the wheel tracks was less than 1.5 years.

Subsurface drainage was improved by subsoiling, and soil consolidation and compaction were reduced by the drainage. However, the benefits of subsurface drainage were estimated to be too small to justify the large costs of drain installation.
The impairment of soil surface drainage due to tillage may be nullified by ridging. Ridging has also been shown to improve the internal drainage in the ridged soil (Steinhardt et al., 1972) and is used in most new plantations on clay soils in Israel.

The temporarily decreased trunk growth in the subsoiled treatments may have been the result of enhanced root growth on these treatments. The indicated yield reduction due to subsoiling calls upon precaution in tillage of mature citrus groves.

Soil loosening improved citrus root growth, but it has still to be shown that it also improves tree establishment and yields. However, such an improvement has been demonstrated in banana plantations on marly hydromorphic grumusols (Ziv, 1962).

REFERENCES
Effect of the Depth of Basic Tillage and Additional Soil Compaction After Harvest on the Yield, Deformations and Diseases of Sugarbeet Roots
(Preliminary report)

Subotic, B., Stanacev, S.,
Technological-Agricultural Institute, Zrenjanin, Institute of Field and Vegetable Crops, Novi Sad, Yugoslavia

Abstract: In the course of two years we studied the effect of the depth of basic tillage of the soil of medium mechanical texture as well as the effect of additional soil compaction on the yield, deformations, and diseases of sugarbeet roots. It was found that deep tillage affected positively and additional soil compaction negatively the yield and the root disease "rhizomania".

INTRODUCTION

Deformations of sugarbeet roots occurred in Yugoslavia for the first time in 1977 (Marić, Maširević, 1977). The symptoms of the disease resembled those described in Italy under the name of "rhizomania". The changes in the roots are manifested in the form of a strong or weak chlorosis of the leaves which rapidly perish thereafter, retarded growth of roots which intensively produce side growths which results in the typical "beardedness". Besides, a number of beets are subject to stuntedness and branching which further lower the yields. Marić et al. (1979) reported the reductions in root yields up to 50% and in sugar content from 2 to 4%. "Rhizomania" and similar diseases occur on the soils of heavy mechanical texture and on the soils whose physical properties have been aggravated by inadequate basic tillage or additional soil compaction caused by the use of heavy tractors on wet soil. According to Marić et al. (1979), one of the principal reasons for the occurrence of "rhizomania" is the set of unfavorable physical properties in the plowing layer. Deep basic tillage reduced the incidence of "rhizomania" to the mere 2-3% in the plot which had 70% of disea-
sed plants in the previous year.

To check the above results, we established a trial on the soil of favorable physical properties.

**METHOD**

The trial was conducted after the method of "long plots" to examine the effects of the depth of basic tillage (25, 35, and 45 cm) and the intensity of additional soil compaction. We determined the volumic weight of the soil. After the harvest, we calculated the yields of roots and the number of deformed roots. The deformations were expressed in the percents of branched, branched and bearded, and bearded beets. We also measured the average diameter and length of the root per variants of the depth of basic tillage and the degree of additional soil compaction. The average vegetative season of sugarbeet was 175 days.

**RESULTS**

1. **Changes in volumic weight**

Table 1. Volumic weight in the soil layer 0-20 cm at the beginning of vegetative season (gr/ccm)

<table>
<thead>
<tr>
<th>Intensity of comp.</th>
<th>Depth of basic tillage (cm)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td>No compaction</td>
<td>1.32</td>
<td>1.37</td>
</tr>
<tr>
<td>One add. passage</td>
<td>1.43</td>
<td>1.44</td>
</tr>
<tr>
<td>Two add. passages</td>
<td>1.45</td>
<td>1.47</td>
</tr>
<tr>
<td>Average</td>
<td>1.40</td>
<td>1.43</td>
</tr>
</tbody>
</table>

Volumic weight in the soil layer 0-20 cm (Table 1) depended at the beginning of the vegetative season more on additional compaction than on the depth of basic tillage. It should be pointed out that one additional tractor passage considerably increased the compaction -by 0.09 gr/ccm. The second passage brought a smaller increase in the volumic weight of the soil - only by 0.02 gr/ccm. Increased compaction at the depth below 20 cm probably has stronger negative effect on sugarbeet yield and the occurrence of deformed beets than two tractor passages.

2. **Incidence of deformed beets**

Table 2 shows the occurrence of different types of deformations of the root depending on the depth of basic tillage.
The deepening of basic tillage reduced the number of deformed and "rhizomanic" beets. Within the total number of deformed beets, the branched ones with no signs of beardedness were most frequent at all three depths of basic tillage. The percentages of branched and bearded or bearded beets were incomparably lower, ranging from 12.9 to 20.6% in dependence of the depth of basic tillage. The latter two types of deformation were most frequent with the shallowest tillage.

Tab. 2. Occurrence of deformed roots at different depths of basic tillage (%)

<table>
<thead>
<tr>
<th>Basic till. depth</th>
<th>% of branched</th>
<th>% of branched and bearded</th>
<th>% of bearded</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 cm</td>
<td>40.8</td>
<td>13.7</td>
<td>6.9</td>
<td>61.5</td>
</tr>
<tr>
<td>35 cm</td>
<td>31.0</td>
<td>5.9</td>
<td>9.0</td>
<td>45.9</td>
</tr>
<tr>
<td>45 cm</td>
<td>29.8</td>
<td>9.0</td>
<td>3.9</td>
<td>42.7</td>
</tr>
</tbody>
</table>

Additional soil compaction (Table 3) increased the incidence of deformed beets proportionally to the degree of compaction. Regardless of the depth of basic tillage, the lowest percentage of deformed beets was found in the variant without soil compaction (28.9%), the highest in the variant of two tractor passages (68.0%). The increase in the number of deformed beets was 135%. The degree of soil compaction determined first of all the portion of branched beets, then the portion of branched and bearded beets, while the portion of bearded beets, considered as a symptom of "rhizomania", was least affected. The last type of deformation occurred with the same intensity in both variants of soil compaction but its incidence in the variant without additional compaction was virtually negligible.

3. Root diameter and length

Table 4 shows the average dependance of root diameter and length on the depth of basic tillage and additional soil compaction.

The deepening of basic cultivation induced changes in the morphological characters of beets. The diameter did not change much, the length increased proportionally to the depth of basic tillage. The increase was more pronounced in 1980 than in 1981. On the average for the two years, the above regularity
Table 3. Effect of the degree of additional soil compaction on the incidence of root deformations

<table>
<thead>
<tr>
<th>Intensity of comp.</th>
<th>Basic tillage depth (cm)</th>
<th>% of branched</th>
<th>% of branched and bearded</th>
<th>% of bearded</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No compaction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>26.7</td>
<td>6.0</td>
<td>2.5</td>
<td>35.2</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>24.2</td>
<td>2.5</td>
<td>-</td>
<td>26.7</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>19.5</td>
<td>4.0</td>
<td>1.0</td>
<td>24.5</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>23.5</td>
<td>4.2</td>
<td>1.2</td>
<td>28.9</td>
<td></td>
</tr>
<tr>
<td>One add. passage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>37.6</td>
<td>16.5</td>
<td>8.5</td>
<td>62.6</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>23.6</td>
<td>6.2</td>
<td>14.5</td>
<td>44.3</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>27.1</td>
<td>8.0</td>
<td>5.7</td>
<td>40.8</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>29.4</td>
<td>10.2</td>
<td>9.6</td>
<td>49.2</td>
<td></td>
</tr>
<tr>
<td>Two add. passages</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>54.1</td>
<td>18.0</td>
<td>10.0</td>
<td>82.1</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>41.7</td>
<td>8.7</td>
<td>12.5</td>
<td>62.9</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>39.5</td>
<td>14.5</td>
<td>5.0</td>
<td>59.0</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>45.1</td>
<td>13.7</td>
<td>9.2</td>
<td>68.0</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Effect of the depth of basic tillage and additional compaction on root diameter and length

<table>
<thead>
<tr>
<th>Intensity of comp.</th>
<th>Basic tillage depth (cm)</th>
<th>Diam. length</th>
<th>Diam. length</th>
<th>Diam. length</th>
</tr>
</thead>
<tbody>
<tr>
<td>No compaction</td>
<td></td>
<td>25</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td>7.8</td>
<td>30.7</td>
<td>7.9</td>
<td>35.2</td>
<td>7.6</td>
</tr>
<tr>
<td>One add. passage</td>
<td></td>
<td>8.7</td>
<td>28.1</td>
<td>8.2</td>
</tr>
<tr>
<td>Two add. passages</td>
<td></td>
<td>9.5</td>
<td>26.3</td>
<td>8.7</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>8.6</td>
<td>28.3</td>
<td>8.3</td>
</tr>
</tbody>
</table>

was clearly evident with the variants of additional soil compaction.

The additional compaction brought morphological changes, i.e., the roots had a larger diameter (7.7, 8.4, and 9.3 cm, respectively) and a smaller length (33.4, 30.7, and 28.9 cm, respectively).

4. Yields of roots and "biological" sugar

The variant of basic tillage at 35 cm brought the highest average yields of roots and sugar. The tillage at 45
cm had slightly lower yields, the tillage at 25 cm the lowest (Tables 5 and 6).

However, if we compare the yields of the variants of 35 and 45 cm in the part of the trial without additional compaction, we can see that the yields were on the same level, i.e., yield reductions in the latter variant resulted from additional soil compaction only in 1981. In 1980, the yields of roots were in proportion with the depth of basic tillage. Additional compaction brought proportional reductions in the yields of roots and "biological" sugar, both on the average for the trial and for each depth of basic tillage separately.

Tab. 5. Root yields (t/ha)

<table>
<thead>
<tr>
<th>Intensity of comp.</th>
<th>Basic tillage depth (cm)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td>No compaction</td>
<td>64,6</td>
<td>70,0</td>
</tr>
<tr>
<td>One add. passage</td>
<td>64,5</td>
<td>65,3</td>
</tr>
<tr>
<td>Two add. passages</td>
<td>60,8</td>
<td>63,7</td>
</tr>
<tr>
<td>Average</td>
<td>63,0</td>
<td>65,6</td>
</tr>
<tr>
<td>LSD 5% for tillage depth</td>
<td>0,832</td>
<td>compaction 1,068</td>
</tr>
</tbody>
</table>

Tab. 6. Yields of "biological" sugar (kg/ha)

<table>
<thead>
<tr>
<th>Intensity of comp.</th>
<th>Basic tillage depth (cm)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td>No compaction</td>
<td>9410</td>
<td>10590</td>
</tr>
<tr>
<td>One add. passage</td>
<td>9390</td>
<td>9880</td>
</tr>
<tr>
<td>Two add. passages</td>
<td>9700</td>
<td>9390</td>
</tr>
<tr>
<td>Average</td>
<td>9120</td>
<td>9820</td>
</tr>
<tr>
<td>LSD 5% for tillage depth</td>
<td>123</td>
<td>compaction 159</td>
</tr>
</tbody>
</table>

The results of this trial, regardless of the differences in the effects of basic tillage at 45 cm registered in 1981, confirm the statement of Marić et al. (1979) that the physical properties of the plowing layer of soil and the depth of basic tillage determine the expression of a sugar beet disease
similar to "rhizomania". The results indicated a practical solution of the problem which may be achieved by deepening the basic tillage and by reducing the number of cultural practices in spring which cause soil compaction.

CONCLUSION

1. The increases in the depth of basic tillage from 25 to 35 and 45 cm reduced the number of deformed and "rhizomanic" roots, and increased the length of roots and yields of roots and "biological" sugar.

2. Additional soil compaction following sugarbeet planting and emergence increased the volumetric weight of the soil, which in turn increased the number of deformed roots and the diameter of the root, and reduced the length of the root and the yields of roots and "biological" sugar.

LITERATURE CITED


EFFECTS OF TIRES ON RECENTLY TILLED SOILS

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ABSTRACT

This study supplements an on-going series of studies on the effect of vehicular traffic on soil. Some of the effects of a single pass of an agricultural tractor tire on recently tilled soils are reported. Heavier dynamic loads increase compaction of soils that are trafficked by vehicles whose soil contact areas do not increase as load is increased. Soils are less responsive to load on tires. Therefore, the effect of a track is compared with that of a flexible tire. The effect of wheel slip (or travel reduction) is also nearly negligible. Since it is recognized that increasing load and slip increases forces exerted on soil, data are presented to show how some forces are expended. An additional study in recently tilled, but moderately tamped, soil shows that small internal tire pressure increases are often effective in increasing soil density.

INTRODUCTION

Vehicles trafficking farmed fields are blamed for the soil compaction problem so prevalent today. In mechanized nations, the soil engaging portion of these vehicles is frequently the pneumatic tire. Under soil conditions for good trafficability, about 50 to 75% of the energy available as torque on the wheel may be transformed into traction by the tire. Some of the remaining energy is expended in distorting the tire carcass, while the rest reacts on soil. Under less desirable trafficability conditions, more energy may be expended in the soil.

At the National Tillage Machinery Laboratory (NTML) in Auburn, Alabama, test equipment is available to evaluate the energy inputs and efficiency of various tractive devices. Tractive efficiency of various tire designs under certain dynamic loads, inflation pressures, and slip (travel reduction) have been reported by engineers at the NTML (Reed et al., 1953; Forrest et al., 1962; Burt et al., 1979). However, what these forces do to soil has been largely ignored, necessitating detailed studies of the relevant factors.

METHODS

The data presented in this report came from tire tests in five large soil bins. Three soils within the bins were from the lower A horizon of a Davidson clay (Rodic paleudults), a Lloyd clay (Typic haplustolls) composed of well structured kaolinitic materials, and a heavy Vaden silty clay (Aquentic chromuderts) of predominantly montmorillonitic material. The other two bins were filled with soil material from the lower A horizon of a Hiwassee sandy loam (Typic rhodustolls) which over the years had become badly puddled, and a Norfolk sandy loam (Typic paleustolls) in somewhat better physical condition.
In the basic study reported, a simulated plexan was formed in each bin at a depth varying from about 20 to 30 cm from the original surface. The soils were coldboard ploved and bladed level. At the time of testing, the Davidson bin had a bulk density of 1.19 ± 0.01 g/cm³ at a moisture content of 20.00 ± 0.51% in the 0 to 5 cm depth, the Lloyd bin 1.09 ± 0.01 g/cm³ at 21.24 ± 0.43%, the Vailen bin 1.03 ± 0.01 g/cm³ at 25.01 ± 0.44%, the Hiwassee bin 1.24 ± 0.02 g/cm³ at 3.87 ± 0.26%, and the Norfolk bin 1.29 ± 0.01 g/cm³ at 9.48 ± 0.33%. (Each value is the mean and standard deviation of ten replicates.) All the dynamic load and slip data came from the single fitting in each of these five soils. Internal tire pressure data came from another fitting of just two of the bins. For this study the Lloyd bin had a bulk density of 1.22 ± 0.01 g/cm³ and a moisture content of 22.37 ± 0.17%, and in the Hiwassee bin the values were 1.69 ± 0.01 g/cm³ at 8.98 ± 0.15%.

An R-1, 8-ply, 20.8R38 tire was used in the basic study. In this study, all relevant factors were held constant except for the one variable being tested. Data on the effect of dynamic load and slip on these soils were obtained as the factor being tested was gradually increased throughout the run. Runs were duplicated and penetrometer readings and volume weight samples were taken at the 0-5 cm depth every 1.5 m in the center of the tire path of each run. Density samples were taken from the firm soil beneath the loosen edge blocks sheared by the treads of the tire. Measurements of all forces on the tire were obtained at each sampling location to ensure that controlled factors were acceptable. Sinkage values to the sheared, or to the recompacted, surface in the tire pathway were obtained at several locations. Cross sectional areas of the soil compacted were determined in order to estimate the volume of soil affected by the forces applied by the tire.

The data presented on internal tire pressures came from only the Lloyd and Hiwassee bins. In these tests slip was held constant and load was varied on two different 18.4-34, R-1 tires. Each tire was run at two inflation pressures (110 and 138 kPa) in the same bin fitting. The bulk density values were replicated ten times. Data were composited for both tires in both soils to generalize the effect of the pressure difference.

RESULTS AND DISCUSSION

Dynamic Load

It is well known that some load on a drive wheel is needed to develop traction. It is also known that excessive loading in soft soil destroys flotation and causes vehicles to bog. All tests were conducted in soil conditions that allowed flotation. Figure 1 shows the curve of mean soil bulk density values for a pneumatic tire inflated to 124 kPa and slip held at 12% in each of the five soils with dynamic loads varying from about 5 to 35 kN. Rated load for this tire is 30.3 kN.

Figure 2 shows a set of curves in the same soils and in the same bin fitting, using a track in which the contact area did not vary appreciably as the load was increased. Slip was held at 6%.

Figure 3 compares the track and a 20.8R38 tire. Four dynamic load values were selected from Figures 1 and 2, and overall means were determined at these values from the duplicated runs in the five soils. Curves from the means of the maximum penetrometer readings for each soil under these four loads are superimposed.
After an initial increase in bulk density for the Norfolk (TM), Nissee (TWS), Davidson (TWD), Lloyd (TWL), and Vaiden (TWB) soils, there was no further increase with additional increases in dynamic load on a tire.

Fig. 2. With the track, the bulk density of each soil increased continually as dynamic load increased. (NML Photo No. P10,334a)

These curves show that only under the track did additional loads affect bulk density and soil strength. With the tire, except for the very lightest loads, soil strength and density were not affected. The volume of soil compacted by the tire did not increase, either, as load was increased. How was the additional energy expended by the tire?

Fig. 3. Composited density and strength data from the five soils compare the track and the 20.8R38 tire. (NML Photo No. P10,334c)

Fig. 4. Profiles from the Lloyd bin show that increasing loads on a 20.8R38 tire inflated to 126 kPa increased the rut depth. (NML Photo No. P10,334d)

Figure 4 shows that more tire force has been transmitted to shear force by increasing dynamic load. Apparently, with flexible pneumatic tires, the compacting effects of increased loads are quite reduced due to distortion of the tire carcass which increases the contact area. Related studies show that when tire inflation pressures and loads are varied, but held within the range recommended by the manufacturers, the actual contact pressure applied to the soil remains remarkably constant.
Although the length of contact for a particular tire increases as load is increased, the increase in width of contact is often only marginal.

Within the normal range of loads on a flexible tire, there is minimal increase in width, depth, volume, and denseness of soil compacted by a moving vehicle as load is increased beyond a certain point. This does not imply that vehicle weight should be ignored during the design phase, as significantly heavier loads will require larger tires with higher ply ratings and greater inflation pressures to safely handle the greater weight.

**Air Pressure**

Careful attention to internal pressure within tires is often neglected. Figure 5 shows the effect of dynamic load on soil bulk density and resistance to penetration when a tire is inflated to different internal pressures. The compositing data show that a pressure increase of 28 kPa produced a mean bulk density increase of about 0.03 g/cm³ while the cone index was increased about 10%. Both the cone index and soil bulk density values were influenced more by a minor increase in internal tire pressure than by large increases in load beyond about 20 kN.

Small increases in internal tire pressure often stiffen the tire carcass, thus decreasing the contact area. In previously uncompacted soil, the resultant decrease in contact area results in a higher contact pressure, producing a slightly higher bulk density. In such studies, internal pressure must be kept identical during the run as loading is increased, since increasing load frequently distorts the carcass, causing a reduction in the volume for air within the tire. If the test is conducted over a great distance, the additional flexing of the carcass can heat the air within and both conditions will increase the internal tire pressure. Although soil bulk density can be reduced by deflating a tire, carcass damage can result when load or speed of travel exceed the design features of the carcass.

**Travel Reduction**

The effects of tire slip on soil are poorly understood. Often peak performance of a pneumatic tire is achieved at about 15 to 20% slip. This translates to 15 to 20% more fuel—fuel paid for but not utilized effectively for this performance. Excessive slip also increases the rate of tire wear, can increase carcass damage, and can sometimes cause wear and tear to the tractor. But what does tire slippage do to soil?

Figure 6 shows the effect of slippage on the compositing bulk density and penetrometer resistance values when the dynamic load was 30 kN and the inflation pressure was 124 kPa. During the first pass, the compositing bulk density values stayed within a range of 0.01 g/cm³, and the cone index value had a range of 12 at the four slippage points used to develop these curves. This implies that
slippage had a minimal effect on the firm soil at the bottom of the tire path. Critical examination of many tests shows that bulk density of the soil beneath the tire path has not been increased noticeably by slippage. Measurement of the volume of soil compressed beneath the tire path rarely shows an increase (usually a decrease), so the extra energy was not utilized to compress a greater volume of soil.

Figure 6. Using a 20.838 tire, the bulk density and cone index values composed from the five soil bins show a negligible effect from slippage (travel reduction).

(FNL Photo No. P10,334f)

Figure 7 shows a typical set of depth-to-rut-bottom diagrams created by a single pass made during this study in the Lloyd clay bin. The 8-ply, 20.838 radial tire created a rut of increasing depth as slip was increased. It appears that the mean profile is slightly concave at lower slippage and tends to flatten with more slippage, and even tends to become convex as slippage increases (or tire distortions are) increased.

When the internal strength of a soil exceeds the frictional forces between the tire lug and the soil surface at the contact zone, one can visualize tire slippage at the contact with a minimum of soil movement. When friction at the tire contact exceeds the internal strength of soil beneath a slipping tire, one can visualize large soil chunks torn away between each tire tread contact, leaving a surface of less compressed soil and a reduced volume of intact firmed soil in the path. Much of the force of a spinning wheel is apparently expended in increasing distortion of the tire or in compacting and moving the sheared soil blocks which frequently remain loose in the tire path rut. It might be argued from the agricultural point of view that the tire performs more as a tillage tool, rototilling the soil compressed into clods that may themselves be less permeable to air, water, and roots, but leaving adequate space between them for air, water, and root passage.
CONCLUSIONS

Some of the energy developed by fans transport is used in movement and some in doing "something" to the soil. Forces applied by vehicles to soil do not simply push particles beneath the wheel into a more compact arrangement. Magnitudes and even the overall effects can be expected to vary from those shown under some combinations of conditions. Following the application of enough dynamic load to distort the tire carcass, additional increases do not appear to increase compaction appreciably. Neither does slip (travel reduction) appear to increase soil bulk density. However, even relatively small increases in the internal air pressure of a tire can increase the soil bulk density. Multiple passes in the identical location can increase bulk density, but each additional pass does so in a magnitude which declines rapidly.

REFERENCES


4. THE ROLE OF TILLAGE IN WEED AND DISEASE CONTROL
THE ROLE OF TILLAGE IN WEEDCONTROL

J.J. Klooster

Institute of Agricultural Engineering, Mansholtlaan 10, Wageningen - the Netherlands

Abstract
There is an increased interest in mechanical weed control. The weed in the row is the biggest problem. Different implements are suitable to transport soil for covering the weeds.
Introduction

The last few years are characterized by an increased interest in mechanical weed control. More expensive chemicals, e.g. research costs, and an increased care for the secondary effects of the use of herbicides are important factors for the farmer. Other groups in the society recommend a reduction of the use of poisoned chemicals.

General

There are three opportunities to control and prevent the weeds:
1. in autumn, after the harvest
2. in spring, before sowing
3. during the growing season.

1 After the harvest there are possibilities to prevent the weed with a number of cultivations (stubble plough and cultivator). Narrowing of the crop rotation - warepotatoes, cereals with a green manure and sugar beets - reduces the opportunities for secondary and primary tillage. This is insufficient for a good weed control system, especially with respect to root weeds.

2 In spring the arable farmer will wait until the soil is dry enough for traffic, traction and tillage; in one or two shallow cultivations he will prepare a seedbed. This will not help to exhaust the weed. In horticulture there are more possibilities, because they practice more sowing dates of the same product in order to stagger harvest dates.

3 During the growing season mechanical weed control can be carried out between the rows with a narrow distance of the rows of 25 cm. The weed in the rows offers the biggest problem. However there are possibilities left for tillage, if there is a difference in length between the culture plants and weed. With very little herbicides chemical in the rows after sowing it is possible to suppress the weed for a while. In a later stage we can cover the young small weed plants with soil from in between the rows.

Research in butter beans and some cabbage have proved this approach.

Implements

For covering weed plants we need loose soil between the rows.
We can use:
- Strip rotary harrow (type Lilistone). With this implement it is possible to get a good result on sandy soil.
The circumference of the heavy elements is equipped with hooks, which penetrate into the soil. Placing the elements at an angle with regard to the row we can influence the soil transport to or from the rows.

In the Netherlands this implements is used in maize (rowdistance 75 cm).

When the maize plants are small, there is an inter-row soil transport. Later on we can get soil transport to the row. High speeds (± 10 km/h) and more operations are necessary.

- Steerage hoe.
  The quantity of loose soil is depending on workdepth, soil type and moisture. With a raised backside of the hoe or separate ridgers the loose soil can be transported too the row; a proper speed is very important.

- Inter-row multipowered rotary cultivator.
  With this implement it is easy to prepare enough loose soil; separate ridging bodies transport the soil mass to the row.

The intensive crumbling however is not suitable for all soil types. Sandy organic soils offer relatively good possibilities. For a good result correct speed is necessary also here.

Research

Experimentals were carried out in butter beans and cabbage on soil with high organic matter.

These results are shown in table 1.

Using ridgers to cover the weeds in the row, equal or better results can be obtained than when we using a normal quantity of band spray in the row. But it is needed to perform more cultivations, just in time. Only when the weed is small this method will succeed.

Experimentals are also available in maize to prove that weed control in mechanical way doesn't include a negative influence on the yield. Therefore we have used a rotary cultivator with 4 workdepths - ranging from 4-10 cm including control field 0 cm - and a workwidth of 50 cm.

The results in fig. 1 show that in both of the years there was a positive influence of tillage. Maybe the roots have been encouraged to grow in the depth just after the cultivation, not only remaining in the top of the soil.

The ridging bodies we used were suitable for different distances between the rows. In this case the side-plates were adjustable along a central part of the ridging body.
Conclusion

By experiments during the growing season we have found that different implements can be used to transport soil for covering the young small weeds in the row.

Alert action and correct timing are very important features in the approach of integrated (mechanical/chemical) weed control.

References


Annual report 1980, Experimental farm Heino.
Table 1  Weed control on chemical and mechanical way.

<table>
<thead>
<tr>
<th>crops</th>
<th>weed control</th>
<th>chemical</th>
<th>interrow cultivations</th>
<th>interrow cultivations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>plot</td>
<td>plot</td>
<td>plot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>butter beans</td>
<td>15</td>
<td>7</td>
<td>32</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>cabbage</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

* plots size 50x50 cm
Tillage influence on the yield in maize

dry matter in tons per ha

workdepth
$7^\circ$ leaf-stage

1979
1980
WEED CONTROL BY TILLAGE TOOL ACTIONS
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Abstract
Increasing costs of chemicals and the increasing amount of "problem weeds" have renewed the interest of weed control by tillage. Each tillage operation influences and controls weeds by tool actions, such as: covering, cutting, sorting and uprooting. Various possibilities of mechanical weed control by tillage tool actions during stubble cultivation, the main tillage operation, seed-bed preparation and inter-row cultivations are discussed.

INTRODUCTION
One might have the idea that nowadays weed control is completely carried out by chemicals. However, the increasing costs of chemicals, e.g., for sugarbeet i/3 of the imputed costs, and the increasing amount of "problem weeds" made farmers recall that, before the introduction of chemicals, weed control was completely carried out by tillage operations. In this connection Kuipers (1974) calls attention to the fact that each tillage operation influences and mostly controls weed growth: Fig. 1. The population of weed seeds, stored in the arable layer, can only be influenced by tillage on the long term; on short term tillage means eradication of present weeds. Weed control by tillage tool actions is mainly based on uprooting, cutting and covering of the weeds with soil, whereas timing,
intensity, weather and soil conditions influence the results considerably (Staas-Ebregt et al., 1980). Results of experiments, for the greater part carried out at or in cooperation with the Tillage Laboratory, are reported.

STUBBLE CULTIVATIONS

Well done stubble cultivations are especially effective for the control of rhizome and tuber propagated weeds. Couch grass can be controlled by drying, exhausting and rotting of the rhizomes, to be realized by cutting and cutting sorting. When weather conditions prevent the completion of mechanical couch grass control, results of a final chemical weed control are favoured by previous mechanical measures (Andringa et al., 1978).

Cutting

Cutting of rhizomes by blade rotary cultivator with a maximum bite length of 10 cm, an open hood and two repetitions (Fail, 1956), controls regrowth and promotes exhaustion and dying of rhizomes.

Cutting + sorting

Cutting by ploughing loosens the whole layer and sorting by tined cultivation realizes the upward transport of rhizomes, the crumbling and drying of the cultivated layer and the control of new suckers.

Sorting

Up to 400,000 tuber per ha, left on the field by the potato harvester, cause serious fyto-sanitary and competition problems. When the mould-board plough is replaced by a tined cultivator, soil and tubers are sorted; small aggregates are transported downward and the relatively large tubers stay in the top layer (Fig. 2), where they should be killed by frost. This method is not very reliable for The Netherlands, however, because tubers situated 10 cm below surface, were calculated to be frozen in only 20% of the years (1940-1970) (Aarts, 1981).

MAIN TILLAGE OPERATION

Inversion

Sufficiently deep ploughing with good inversion, the unique effect of the mould-board plough, eradicates the majority of the present weeds (Kuipers, 1981).
and so improves yields. This was found in moderate climates (Table I) and in the (humid) tropics (Table II). When in Surinam mould-board ploughing was replaced by rotary cultivation, the yield of six crops declined with 8\% on the average and with minimum tillage with 18\%, greatly as a consequence of the increased weed population (Van der Sar, 1976).

Table I. Effect of cultivation on presence of blackgrass in continuous winter wheat (Fryer, 1979)

<table>
<thead>
<tr>
<th>System</th>
<th>Plants/m² in Nov./Dec. 1975</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Compton</td>
</tr>
<tr>
<td>Plough</td>
<td>28</td>
</tr>
<tr>
<td>Deep tine</td>
<td>131</td>
</tr>
<tr>
<td>Shallow tine</td>
<td>146</td>
</tr>
<tr>
<td>Direct drill</td>
<td>159</td>
</tr>
<tr>
<td>Blackgrass herbicides used</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table II. Main tillage operation and time (h/ha) needed for weed control in Surinam (Kouwenhoven, 1973)

<table>
<thead>
<tr>
<th>System</th>
<th>Long dry season</th>
<th>Long rainy season</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plough</td>
<td>420</td>
<td>1065</td>
</tr>
<tr>
<td>Rotary cultivator</td>
<td>700</td>
<td>1465</td>
</tr>
<tr>
<td>Direct drill</td>
<td>885</td>
<td>1325</td>
</tr>
</tbody>
</table>

Table III. Type of main tillage operation and the number of weeds per m² in spring (Aarts et al., 1981)

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>Plough</th>
<th>Tined cultivator</th>
</tr>
</thead>
<tbody>
<tr>
<td>31/3/1981</td>
<td>106</td>
<td>115</td>
</tr>
<tr>
<td>15/5/1981</td>
<td>374</td>
<td>529</td>
</tr>
</tbody>
</table>

Recent research in The Netherlands on the influence of method and time of the main tillage operation on various soil types gave similar results: replacement of mould-board plough by a tined cultivator did increase the weed population (Table III) and volunteers from grain and grass. Absence of soil inversion has also an effect on the weed population on the long term: Fig. 3.

Fig. 3. Conjectured changes in the British weed flora over 4 decades (Fryer, 1979)
Timing
In The Netherlands traditionally sandy soils are ploughed shortly before seedbed preparation in view of the control of present weeds. This effect was investigated from 1978-1980 with three ploughing periods and mechanical compaction by driving over the field with dual tyres (Table IV).

Table IV. Ploughing period and the number of weeds/m² counted at the end of May on sandy soils (Kouwenhoven et al., 1981)

<table>
<thead>
<tr>
<th>Period</th>
<th>I (till the end of Jan.) (rel.)</th>
<th>II (Febr. - March) (rel.)</th>
<th>III (Apr.) (rel.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1978 dry (May)</td>
<td>131 (83)</td>
<td>157 (100)</td>
<td>---</td>
</tr>
<tr>
<td>1979 wet</td>
<td></td>
<td>163 (100)</td>
<td>171 (105)</td>
</tr>
<tr>
<td>compacted</td>
<td></td>
<td></td>
<td>248 (152)</td>
</tr>
<tr>
<td>1980 dry (May)</td>
<td>84 (115)</td>
<td>73 (100)</td>
<td>56 (77)</td>
</tr>
<tr>
<td>compacted</td>
<td>86 (93)</td>
<td>92 (100)</td>
<td>80 (87)</td>
</tr>
</tbody>
</table>

Ploughing in April gave more, but smaller, weeds at the end of May in 1978 (dry) and in 1979 (wet) and less in 1980 (dry). Compaction increased the number of weeds with about 30%, which is in accordance with Roberts & Hewson (1970), who found an increase of 29% by rolling.

SEED-BED PREPARATION

Crumbling
Seed-bed preparations are carried out to produce a favourable crumbled structure for the start of the (next) crop. Crumbling ($\leq 3$ mm) is related with the emergence of the crop and apparently also with weed growth: we found about 50 times ($1600/m^2$) more weeds on a sandy soil than on heavier soils (Aarts et al., 1981). A high degree of crumblng, produced by high intensity tillage, shifts weed population into the direction of annuals (Koch & Hurle, 1978). For the seeds of a crop, emergence on fine soils will be related with moisture and warmth conductivity, but for weed seeds, being generally not between but within clods, the increasing mechanical resistance with an increasing size of the clods, might be the reason that less weeds emerge on relatively coarse seed-beds; Table V.

Table V. Number of seeds ready for germination per 1000 g over-dry soil as influenced by clod size (Terpstra, 1978)

<table>
<thead>
<tr>
<th>Clod size, mm</th>
<th>Number of seeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-6</td>
<td>37.6</td>
</tr>
<tr>
<td>10-16</td>
<td>35.1</td>
</tr>
<tr>
<td>20-35</td>
<td>32.6</td>
</tr>
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</table>
Sorting
During seed-bed preparation fine soil aggregates, (weed)seeds and chemicals are placed near, or into the seed placement zone by sorting. Weed seeds that are not within (large) clods can be incorporated to such a depth (> 0-5 cm below surface), that emergence becomes impossible.

Covering
Much more important for the control of seed propagated weeds is the covering of the seedlings with soil. If the weeds are 2-3 cm tall, a cover of 2-3 cm will be fatal for most of them (Fig. 4.).

Uprooting
Uprooting, being much less important in weed control than covering, is also more effective when the weeds are small, but uprooting itself is more difficult. That is why early harrowing is to be recommended.

INTER-ROW CULTIVATIONS
Cutting
Cutting during inter-row cultivations is carried out by scuffles and hoes. Hoeing is less dependent on the growth stage of the weeds than other inter-row cultivations, so it can be carried out during a longer period. In principle all weeds between the rows are eradicated, the tall weeds by cutting and the small weeds by covering with soil. Within the rows, however, motorized hoeing cannot be carried out.

Cutting only is less effective for weed control than uprooting and covering. This was demonstrated by experiments with a spring tined cultivator, a rolling cultivator and a scuffle with small plants (Terpstra, 1977). With taller plants cutting will be more effective. The hoe-ridger combines (uprooting) cutting and covering.

Fig. 4. Depth of soil covering and the percentage of killed weeds (Kouwenhoven & Terpstra, 1979)

Fig. 5. Steketee hoe-ridger; (a) topview; (b) frontview; (c) sideview; (e) sideview with back of the hoe lifted
Covering
The main tillage tool effect during inter-row cultivations is covering weeds with soil, not only between the rows, but also within the rows. The percentage of killed weeds is directly connected with the depth of the soil cover: Fig. 4. Wet weather after cultivation reduces weed killing with 25-30% (Terpstra, 1977). The rolling cultivator, often used to control weeds within the maize rows, is most effective in a "aggressive" position and a travelling speed of at least 2 m/s. Though root damage (with working depth varying from 4-10 cm) did occur, rolling cultivation improved yield and most with a working depth of 6 cm (Aarts, 1980). In sugarbeet, the last inter-row cultivation before the closing of the crop with a hoe-ridger, is often a combination of uprooting and covering. Terpstra and Kouwenhoven (1981) found that in the path of the hoe 57% of the weeds were killed by covering with soil and 33% by uprooting and drying at the soil surface. In accordance with Kees (1962), alongside the path of the hoe 45% of the weeds were killed by a soil cover of 1.5 to 2 cm, being lethal for respectively small (3 cm) and large (8 cm) weeds, in a band of 5-10 cm aside of the path of the hoe. The width of the band could be increased by a slight backward tilting of the rake angle of the hoe (Fig. 5e).

CONCLUSIONS
1. Each tillage operation influences and often controls weed population by covering, cutting and uprooting.
2. (Soil inverting) stubble cultivation controls perennials better than chemicals, but is more dependent on the weather than chemical weed control.
3. Soil inversion by mould-board ploughs is most effective in weed control as well on the short as on the long term.
4. High crumbling degree shifts weed population into the annuals; on the long term direct drilling is attended with an increase of grass weeds.
5. Mechanical weed control within rows can be carried out by ridging; chemical weed control only within the rows saves 80% of the costs of the chemical.
6. Timing of tillage operations influences weed growth and so weed control.

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EFFECT OF THE DEPTH OF BASIC TILLAGE AND ADDITIONAL SOIL COMPACTION ON THE YIELD OF SUGARBEET GROWN IN SOILS OF HEAVY MECHANICAL TEXTURE AND ON THE OCCURRENCE OF A DISEASE RESEMBLING RHIZOMANIA

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Dr. S. Stanačev, Dr. V. Dobrenov,
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Abstract

During a three-year period, the authors conducted field experiments on a soil of heavy mechanical texture to study the effect of basic tillage in fall and soil compaction in spring on the intensity of a disease resembling rhizomania and root yield of sugarbeet. The deepening of the plowing layer from 25 to 45 cm reduced the volumetric weight of the soil which in turn decreased the incidence of the disease and increased root yields. Additional soil compaction in spring increased the incidence of the disease and decreased root yields, especially when the plowing layer was trampled when wet.

Introduction

A more intensive occurrence of a sugarbeet disease causing the beardedness of the root, stuntedness of the plant, and leaf chlorosis was observed for the first time in Vojvodina and Slavonia in 1977 (Marić and Maširević, 1977). The symptoms displayed were similar to those of rhizomania which had been described in Italy (Canova, 1959; Bonngiovanni, 1964).

There is a number of hypotheses on the etiology of rhizomania: the "exhaustion" of the soil, the presence of Polymixa betae on the lateral rootlets causing stuntedness (Keskin, 1964; Koch,
1967; Habibi, 1969), and finally, that the occurrence of the disease may be related with some viruses. Canova (1966) was the first one to isolate a virus strain from diseased plants. Tamada and Baba (1973) stated that Beet necrotic yellow vein virus, present in resting spores of P. betae, is the probable cause of the beardedness of the root. Later on, some authors related the occurrence of rhizomania with the presence of two viruses and two lower fungi (Faccioli and Giunchedi, 1974), and three viruses in the roots of diseased plants (Putz and Vuittenes, 1974; Cuszala and Putz, 1977). A study of Falc and Duffus (1977) did not confirm the existence of causative relations among rhizomania, viruses, and P. betae. Some Yugoslav authors (Sutić and Milovanović, 1978; Tošić et al., 1978), having accepted the virus hypothesis, declared that various abnormalities of the root (stuntedness, beardedness, branching, and straitening of the root) may be considered as one disease which was named "infective stuntedness of sugarbeet root". Milovanović et al. (1978) concluded on the basis of a one-year experiment that the causes of the disease should not be looked for in the method of soil cultivation, i.e. in physical changes of the soil.

Material and Method

The objective of this study was to find relationship between the methods of cultivation of soils with a heavy mechanical composition on one side and the occurrence of the disease resembling rhizomania on the other. The variety in the symptoms appearing on infected plants (beardedness, stuntedness, branching, and straitening of the root) hinted at a complex nature of the disease which was further confirmed by the fact that the disease occurred most frequently on heavy soils, in depressions, and on the edges of plots where machines would turn when performing cultural practices in spring.

A three-year field experiment was conducted on the soil of heavy mechanical composition, in a plot which had about 70% of sugarbeet plants grown in 1978 diseased by rhizomania. A half of the plot was planted with wheat in fall 1978 and the other half
(5ha) was prepared for sugarbeet planting in spring 1979. The basic tillage performed in late October included three tillage depths: 25, 35 and 45 cm. In 1980 and 1981 the experiment was extended to the first half of the plot, with wheat as the preceding crop, and additional two variants of basic tillage (25+35; 25+45). Each variant of basic tillage was exposed to additional pressing, i.e., one or two tractor passages through the experimental plot in spring, after the emergence of sugarbeet plants.

All variants were examined for soil moisture and volume weight before sugarbeet planting and several times during the growth period. Also, we followed the development of the disease and the occurrence of Polymixia betae on the roots. After harvest, we calculated the yield of roots, content of sugar, and the number of diseased plants.

Results

The data in Table 1 show that the examined variants of basic tillage and additional pressing of soil varied significantly in the number of diseased plants and the yields realized. In 1979, when sugarbeet was planted after sugarbeet, the variant of basic tillage at 25 cm had the largest number of diseased plants (55-62%) and the lowest root yield (29.4-34.3 t/ha). The variant of tillage at 45 cm had the smallest number of diseased plants (2-12%) and the highest yield (49.6-54.6 t/ha). The additional soil compaction in spring affected the occurrence of the disease only in the variant of tillage at 45 cm (no compaction 2%, additional compaction 2x-12%). Still it may be stated that the depth of basic tillage had in this year the highest effect on the occurrence of the disease and yields. The obtained results are particularly important because this plot suffered intensively from rhizomania in the preceding year.

The results obtained in 1980 were identical. The shallow tillage (25 cm) brought the largest number of diseased plants (29-34%) and the lowest yield (37.7-46.6 t/ha). The deepening of the plowing layer reduced the incidence of diseased plants and increased root yields. Two plowings in fall rendered best effects.
Table 1. Effect of basic tillage (number and depth of plowing) and additional soil compaction on the occurrence of rhizomania and root yields of sugarbeet grown in the period 1979-1981.

<table>
<thead>
<tr>
<th>Depth of basic tillage, no.of plowings and tractor passages</th>
<th>% of stunted and bearded plants</th>
<th>Root yield t/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>One plowing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>53</td>
<td>34.1 62.4</td>
</tr>
<tr>
<td>B</td>
<td>60</td>
<td>29.8 55.5</td>
</tr>
<tr>
<td>C</td>
<td>53</td>
<td>29.4 42.4</td>
</tr>
<tr>
<td>35 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>28</td>
<td>15.9 43.4</td>
</tr>
<tr>
<td>B</td>
<td>20</td>
<td>13.2 39.2</td>
</tr>
<tr>
<td>C</td>
<td>23</td>
<td>11.2 31.9</td>
</tr>
<tr>
<td>45 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>15</td>
<td>10.9 62.8</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>8.9 56.1</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>3.0 6.8</td>
</tr>
<tr>
<td>Two plowings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25+35 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>17.3</td>
<td>37.9</td>
</tr>
<tr>
<td>B</td>
<td>14.4</td>
<td>41.4</td>
</tr>
<tr>
<td>C</td>
<td>7.5</td>
<td>17.8</td>
</tr>
<tr>
<td>25+45 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>3.9</td>
<td>48.3</td>
</tr>
<tr>
<td>B</td>
<td>3.9</td>
<td>34.9</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Legend: A - one tractor passage between the rows  
B - two tractor passages between the rows  
C - without additional soil compaction

In 1980 too, additional soil compaction affected the occurrence of rhizomania only with deeper basic tillage.
Additional soil compaction after sugarbeet emergence in spring had highest effects in 1981. High percentages of stunted and bearded plants were registered in all variants of basic tillage with additional compaction of soil. There were no significant differences in the intensity of occurrence of rhizomania between the variants with one and two tractor passages through the field, probably on account of the fact that this practice was performed on a rather wet soil. The lowest percentages of diseased plants were obtained in the variants of basic tillage on 25+45 and 45 cm without additional pressing the soil, (6.6 and 6.8%, respectively). These variants also brought the highest yields (52.5 and 60.2 t/ha, respectively).

Basic tillage and additional soil compaction significantly affected the volumic weight of the soil. Water and air regimen improved with the deepening of the plowing layer. Tractor passages after sugarbeet emergence aggravated considerably the volume weight of the surface layer of the plowing layer (0-20 cm) in relation to the variant without additional soil compaction.

Following the development of the disease during the growth period, it was observed that the incidence of beardedness and other root abnormalities intensified in dry periods of the vegetation. Prominent symptoms were usually encountered in the course of June. A long period of drought at the beginning of the vegetative season of 1981 influenced the occurrence of the disease to early May. At that time Polymixa betae could not be found on the roots of the diseased plants. It was obvious that the fungus did not develop in the soil with a low moisture content and thus it could not serve as a carrier of viruses.

In the experiments as well as in commercial production, we found a number of proofs that mechanical factors of heavy soils (the content of clay + silt = 80%) may disturb the development of sugarbeet root. Our study showed that unfavorable physical properties of such soils may be further aggravated by ill-timed cultural practices which intensify soil compaction. The sugarbeet root cannot penetrate the soil and in certain conditions its tip neotroses and numeros side rootlets are formed. The effect of the mechanical factor is visible with almost all diseased plants, i.e.
the root narrows abruptly into a tail. Polymixa betae inhabits the roots of diseased plants when increased soil moisture permits it. Therefore, the fungus and viruses occur not as the cause but rather as a consequence of a certain condition of sugarbeet plants.

Repeating the experiments in production plots, we obtained results which were identical with the experimental ones. Further studies are necessary on the improvement of physical properties of heavy soils in order to make them more suitable for sugarbeet growing.

Conclusion

Following conclusions may be drawn on the basis of a three-year study on the effect of basic tillage and additional soil compaction on the occurrence of a disease resembling rhizomania (beardedness, stuntedness, and straitening of the root) and sugarbeet yield:

1. The depth of basic tillage and the number of plowings in fall had a high effect on the intensity of the occurrence of the disease and root yield. The deepening of the plowing layer from 25 to 45 cm reduced the number of diseased plants to a tolerable level and increased the yield of roots significantly. Two plowings in fall brought even better results.

2. The effect of additional soil compaction in spring on the occurrence of the disease and root yield depended mostly on the depth of basic tillage in fall. The disease was intensified by additional soil compaction, especially in the variants of deep tillage. Negative effects of soil compaction were emphasized when the practice was performed on wet soil in spring 1981.

3. The increase in the volume weight of the soil intensified the incidence of the disease resembling rhizomania.

The influence of Soil Tillage on Weedness of Wheat

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Abstract

The weedness of winter wheat depends on the method of soil tillage and amount of mineral fertilizers.

In treatments with soil tillage using the rotary hoe a higher weediness was found than in the treatment with ploughing, ranging from 23.6 - 100.9 weed plants/m² (76.12 - 638.60%).

Higher amounts of mineral fertilizers reduced the number of weed plants in winter wheat, when tilling the soil with a plough.

Introduction

The diversity of implements for soil tillage, time of application, the mode and quality of operation affect the soil and weediness of the crop grown.

The time, mode and depth of stubble field tillage particularly affect the germination and emergence of weeds (Božić, 1975, 1977). This becomes even more evident in short monoculture of wheat. By fertilizing winter wheat with NPK mineral fertilizers, the total weediness is reduced (Koljađin, 1977).
Material and Method

A field trial was used to investigate the effect of the method of soil tillage and amount of mineral fertilizers on weediness of winter wheat in 3-year monoculture. The trial was conducted in four replications on chernozem type of soil in Zemun Polje during 1972 - 1974. The elementary plot was 30 m².

Three methods of soil tillage were investigated: 1. Tillage in July with plough to 30 cm depth, 2. Tillage in July with rotary hoe (10 cm), and 3. Tillage in July and August with rotary hoe.

In the treatment tillage with plough, diskling was performed in August.

Seedbed preparation was carried out by diskling.

The following amounts of fertilizers were used: a) N₆₀ P₆₀ K₃₂ and b) N₁₂₀ P₁₂₀ K₆₄. The total amount of PK and 1/4 N were applied during soil tillage. The remaining part of nitrogen was used for side-dressing.

Planting of the variety Kavkaz was performed in October (450/m² germinated kernels).

During the phase of tillering of the crop, the herbicide Banvel P was applied (4 l/ha).

Weed samples were taken using the square method in the spike-formation phase of wheat.

The average 3-year temperature for the last three months in the growing season (April, May and June) was 15.96°C and the precipitation 246.6 mm (S o Š i Ž, 1975).

Results and Discussion

The qualitative and quantitative composition of the weed flora varies depending on the method of soil tillage and amount of mineral fertilizers (Tab. 1). Fifteen weed species were found on the trial field: in all treatments Convolvulus arvensis L., in five treatments Cirsium arvense (L.) Scop., Amaranthus retroflexus L., and Solanum nigrum (L.) Will, and in four treatments Chenopodium album L.

The lowest weediness of the winter wheat was found in treatment with ploughing: 31,0/m² and 15,8 plants/m² with a low and
Tab. 1. Floristic and quantitative composition of weeds in winter wheat during 1972 - 1974 (number/m²)

<table>
<thead>
<tr>
<th>Ord. number</th>
<th>Name of weed</th>
<th>N₀₀</th>
<th>P₀₀</th>
<th>K₃₂</th>
<th>N₁₂₀</th>
<th>P₁₂₀</th>
<th>K₃₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Convolvulus arvensis L</td>
<td>4.3</td>
<td>27.2</td>
<td>69.9</td>
<td>4.4</td>
<td>31.7</td>
<td>94.6</td>
</tr>
<tr>
<td>2.</td>
<td>Amaranthus retroflexus L</td>
<td>-</td>
<td>3.7</td>
<td>5.3</td>
<td>0.3</td>
<td>0.4</td>
<td>3.0</td>
</tr>
<tr>
<td>3.</td>
<td>Cirsium arvense (L) Scop.</td>
<td>-</td>
<td>4.0</td>
<td>15.0</td>
<td>1.3</td>
<td>1.8</td>
<td>18.4</td>
</tr>
<tr>
<td>4.</td>
<td>Chenopodium album L.</td>
<td>4.3</td>
<td>6.7</td>
<td>-</td>
<td>5.2</td>
<td>3.5</td>
<td>-</td>
</tr>
<tr>
<td>5.</td>
<td>Solanum nigrum (L.) Will.</td>
<td>1.0</td>
<td>0.7</td>
<td>-</td>
<td>0.3</td>
<td>1.0</td>
<td>0.7</td>
</tr>
<tr>
<td>6.</td>
<td>Polygonum convolvulus L.</td>
<td>17.4</td>
<td>2.7</td>
<td>4.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7.</td>
<td>Veronica arvensis L.</td>
<td>1.3</td>
<td>-</td>
<td>6.0</td>
<td>-</td>
<td>2.1</td>
<td>-</td>
</tr>
<tr>
<td>8.</td>
<td>Capsella bursa-pastoris Med.</td>
<td>-</td>
<td>-</td>
<td>4.7</td>
<td>3.0</td>
<td>1.3</td>
<td>-</td>
</tr>
<tr>
<td>9.</td>
<td>Lamium amplexicaule L.</td>
<td>-</td>
<td>-</td>
<td>2.7</td>
<td>-</td>
<td>2.7</td>
<td>-</td>
</tr>
<tr>
<td>10.</td>
<td>Setaria glanca F.B.</td>
<td>-</td>
<td>0.7</td>
<td>-</td>
<td>1.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>11.</td>
<td>Setaria glanca F.B.</td>
<td>-</td>
<td>0.7</td>
<td>-</td>
<td>1.3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>12.</td>
<td>Panicum crus-galli L.</td>
<td>-</td>
<td>4.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13.</td>
<td>Bromus inermis L.</td>
<td>-</td>
<td>3.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>14.</td>
<td>Polygonum lapathifolium L.</td>
<td>-</td>
<td>0.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>15.</td>
<td>Delfinium consolida L.</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.3</td>
<td>-</td>
</tr>
</tbody>
</table>

Total number | 31.0 | 54.6 | 107.6 | 15.8 | 47.3 | 116.7 |
%            | 100.00 | 176.12 | 347.09 | 100.00 | 299.36 | 738.60 |

Number of perennial weeds | 4.3 | 31.2 | 84.9 | 5.7 | 33.5 | 113.0 |

Relat. part. of pere. weeds | 13.87 | 57.40 | 78.90 | 36.07 | 70.82 | 96.82 |

Effect of fert. on weeds(%) | 100.00 | 100.00 | 100.00 | 50.96 | 86.63 | 108.45 |
high fertilizer dose, respectively. In treatments with rotary hoe, weediness was higher and varied from $23.6 - 76.6/m^2$ ($76.12 - 247.09\%$) with a low fertilizer dose and from $31.5 - 100.9/m^2$ ($199.36 - 638.0\%$). The influence of the method of soil tillage on the composition of weeds becomes evident, if the portion of perennial weeds is observed. Thus, in the treatment with ploughing the number of perennial weeds was $4.3 - 5.7/m^2$ in the treatment with soil tillage in July using the rotary hoe $31.2 - 33.5/m^2$ and in the treatment with soil tillage in July and August using the rotary hoe $34.9 - 113.0/m^2$. This tendency becomes particularly obvious when the relative participation of perennial weeds in the total weediness is observed. It was $13.87 - 36.07\%$ in the treatment with ploughing and $57.4 - 96.82\%$ in tilling the soil with the rotary hoe.

A more intensive tillage of soil using the rotary hoe (July and August) in treatment 3, causes an increase in the number of perennial weeds compared to treatment 2 (rotary hoe in July). The increase in perennial weeds was $53.7 - 79.5$ weed plants/m$^2$ ($172.11 - 237.31\%$).

The use of the rotary hoe for soil tillage in growing winter wheat as a three-year monoculture affects most of all perennial weeds the occurrence of Convolvulus arvensis(L.) Scop, particularly if this implement is used twice. Cirsium arvense (L.) Scop does not react as favourably to a multiple tillage of the soil with the rotary hoe.

By applying greater amounts of mineral fertilizers, the total weediness was reduced in the treatment with ploughing by $15.2$ plants/m$^2$ ($49.09\%$), while this effect was lower in the treatment of soil tillage with the rotary hoe. Namely, in the treatment of soil tillage in July with the rotary hoe, the total weediness was reduced using a high compared to a low fertilizer dose by $7.3$ weed plants/m$^2$ ($13.37\%$) and increased when tilling the soil in July and August by $9.1$ m$^2$ ($8.45\%$).
Literature


EFFECT OF THE SYSTEM OF BASIC SOIL TILLAGE, NITROGEN FERTILIZATION, AND HERBICIDE APPLICATION IN THREE-CROP ROTATION ON WEED SYNUSIA AND SOIL PRODUCTIVITY

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Abstract. A three-crop rotation sugarbeet-corn-wheat was examined for the effects of continual tillage at 35 cm, tillage at 35 cm for sugarbeet and at 20 cm for corn and wheat, two levels of nitrogen application, and two methods of weed control, mechanical and chemical. The continual tillage at 35 cm and the higher dose of nitrogen secured an increased productivity of the rotation. The chemical weed control had a positive effect on the productivity and reduced weeds most efficiently.

Introduction

Positive effects of deep basic tillage on the yields of sugarbeet, wheat, and corn have been confirmed in our country by Stanačev (1964), Jevtić (1962), Drezgić et al. (1967), Spasojević (1972), etc. Examining the efficiency of establishment of arable land and the period of its use to the time of re-establishment, Drezgić et al. (1972) concluded that for corn, wheat, and sunflower, grown in a four-crop rotation with sugarbeet for which arable land was established, the soil may be cultivated much shallower without yield reductions. Stojanović (1979) confirmed earlier findings that sugarbeet requires deep tillage even in the period between the establishment and re-establishment of arable land.

Russell (1950) maintained that an additional nitrogen fertilization alleviated the damages caused by the competition with weeds to the yields of sugarbeet. Discussing the importan-
ce of soil and weed synusia, Scott et al. (1972) observed that excess nitrogen was more stimulating for the growth of weeds, especially Chenopodium album, than sugarbeet. A specific effect of nitrogen on the yields and quality of wheat, corn, and sugarbeet is well-known (Stanačev et al., 1974; Spasojević, 1972; Drezgić et al., 1967). According to Siwicky (1970), a deep tillage reduces the weeds in sugarbeet by 20%, the effect being somewhat higher with fall cultivation than with spring cultivation.

In the above three crops, weeds are controlled most efficiently with herbicides; considerable reductions in the percentage of weeds are also effected with a system of basic tillage. It has been known earlier that perennial weed species, which possess rhizomes, may be efficiently controlled by changing the depth of basic tillage and by soil cultivation at certain time. On account of their selectivity, herbicides control efficiently only some members of weed synusia in the agroecotope while other weeds are less affected or remain unharmed. A weed species may overpopulate if freed from competition. A combination of several herbicides in a rotation conjoined with agrotechnical measures of crop protection, primarily the system of basic tillage of the rotation, may reduce largely the percentage of weeds and prevent the overpopulation of some weed species. Still, such combinations may contain a latent danger of weed overpopulation.

The objective of this study was to examine the synergistic action of the system of basic tillage, nitrogen fertilization, and the method of weed control in a long-term stationary trial as well as to determine its effect on the productivity of the crops grown and the frequency of weeds.

METHOD

A three-crop rotation sugarbeet-corn-wheat was established in 1974. The rotation was examined for the following agrotechnical factors:

A. The depth of basic tillage
   a) 35 cm for all three crops
   b) 35 cm for sugarbeet, 20 cm for corn and wheat
B. Dose of nitrogen
   a) 100 kg/ha
   b) 200 kg/ha

C. Method of weed control
   a) Chemical (sugarbeet: Roneet 4 l/ha, Venzar 0.6 kg/ha; corn: Agelon 3 l/ha; wheat: Deherban 2 l/ha)
   b) Mechanical weeding

This paper reviews the research results from the period 1979-1981, i.e., from the third year of the second cycle and the first two years of the third cycle of the three-crop rotation.

RESULTS

1. Productivity of the rotation. Tables 1, 2, and 3 show the effects of the examined factors on the yields of sugarbeet, corn, and wheat, respectively, expressed as three-year averages.

   a) Effect of the system of basic tillage. The continual cultivation at 35 cm increased the yield of sugarbeet by 3.62 t/ha, or 7.4% in relation to the variant of differentiated cultivation (Table 1). This positive effect persisted regardless of the method of herbicide application and nitrogen doses. These results confirm those of Stanačev (1964) and Stojanović (1979).

   Tab.1. Sugarbeet yields (t/ha) - 1979-1981 average

<table>
<thead>
<tr>
<th>Herb. appl.</th>
<th>Dose of N</th>
<th>Tillage Depth</th>
<th>Average</th>
<th>Diff. in N</th>
<th>Diff. in weed cont.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20/35</td>
<td>35/35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tre-</td>
<td>100</td>
<td></td>
<td>47.75</td>
<td>51.85</td>
<td>49.80</td>
</tr>
<tr>
<td>ated</td>
<td>200</td>
<td></td>
<td>52.35</td>
<td>56.94</td>
<td>55.14 +5.34</td>
</tr>
<tr>
<td>Average</td>
<td>50.55</td>
<td></td>
<td>54.39</td>
<td>52.47</td>
<td>+3.84 +3.25 +3.68</td>
</tr>
<tr>
<td>Non-</td>
<td>100</td>
<td></td>
<td>43.94</td>
<td>46.48</td>
<td>45.21</td>
</tr>
<tr>
<td>ated</td>
<td>200</td>
<td></td>
<td>50.67</td>
<td>54.24</td>
<td>52.80 +7.59</td>
</tr>
<tr>
<td>Average</td>
<td>47.30</td>
<td></td>
<td>50.71</td>
<td>49.00</td>
<td>+3.41</td>
</tr>
<tr>
<td>for he-</td>
<td>100</td>
<td></td>
<td>45.85</td>
<td>49.16</td>
<td>47.50 +4.59</td>
</tr>
<tr>
<td>rb.</td>
<td>200</td>
<td></td>
<td>52.01</td>
<td>55.94</td>
<td>53.98 +6.48</td>
</tr>
<tr>
<td>Average</td>
<td>48.93</td>
<td></td>
<td>52.55</td>
<td>50.74</td>
<td>+3.62 3.47</td>
</tr>
</tbody>
</table>

   LSD 5% - for individual treatmenst 3.96; for interaction of two factors 5.62; for interaction of three factors 7.95
The yield of corn was not largely affected by the system of basic tillage. The cultivation at 35 cm increased the yield by 660 kg/ha or 6.6% (grain yield at 14% moisture) in relation to the variant of differentiated cultivation. The difference was more pronounced in the variant without herbicide application because the absence of this practice emphasized the reduction in weed frequency after the deeper tillage.

Tab. 2. Corn yields (kg/ha) - 1979-1981 average

<table>
<thead>
<tr>
<th>Herb. appl.</th>
<th>Dose of Tillage</th>
<th>Depth Average Diff. in Avg. Diff. in N weed cont.</th>
<th>N kg/ha 20/35</th>
<th>35/35</th>
<th>in N basic tillage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treated</td>
<td>100</td>
<td>9800</td>
<td>10070</td>
<td>9940</td>
<td>10740</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>10740</td>
<td>11280</td>
<td>11010</td>
<td>1070</td>
</tr>
<tr>
<td>Average</td>
<td>10270</td>
<td>10670</td>
<td>10470</td>
<td>400</td>
<td>+520</td>
</tr>
<tr>
<td>Non-treated</td>
<td>100</td>
<td>9480</td>
<td>10240</td>
<td>9860</td>
<td>10010</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>10010</td>
<td>11110</td>
<td>10560</td>
<td>700</td>
</tr>
<tr>
<td>Average</td>
<td>9750</td>
<td>10680</td>
<td>10210</td>
<td>930</td>
<td></td>
</tr>
<tr>
<td>Average for</td>
<td>100</td>
<td>9690</td>
<td>10160</td>
<td>9900</td>
<td>+80</td>
</tr>
<tr>
<td>herb.</td>
<td>200</td>
<td>10380</td>
<td>11190</td>
<td>10780</td>
<td>880</td>
</tr>
<tr>
<td>Average for</td>
<td>10010</td>
<td>10670</td>
<td>1034</td>
<td>660</td>
<td>+260</td>
</tr>
<tr>
<td>LSD 5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- for individual treatments</td>
<td>600</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- for interaction of two factors</td>
<td>820</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- for interaction of three factors</td>
<td>1220</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The continual cultivation at 35 cm increased the yield of wheat by 210 kg/ha in relation to the variant of differentiated cultivation. This small difference, only 4.1%, agrees with the results obtained in the first two cycles of the crop rotation examined. Since wheat followed corn in the rotation, the shallower tillage sufficed for a complete plowing in of corn harvest residues. The chemical weed control brought somewhat larger differences in wheat yields between the two systems of tillage while the omission of herbicides made the yields in the systems of basic tillage equal.

b) **Effect of the dose of nitrogen.**

On the three-year average, the larger dose of nitrogen increased the yield of sugar beet by 6480 kg/ha or 13.6% in
Tab. 3. Wheat yields (kg/ha) - 1979-1981 average

<table>
<thead>
<tr>
<th>Herb. appl.</th>
<th>Dose of Tillage depth</th>
<th>Average N kg/ha</th>
<th>Diff. in N basic weed cont. tillage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20/35</td>
<td>35/35</td>
<td></td>
</tr>
<tr>
<td>Treated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>4550</td>
<td>4940</td>
<td>4750</td>
</tr>
<tr>
<td>200</td>
<td>4760</td>
<td>5100</td>
<td>4930</td>
</tr>
<tr>
<td>Average</td>
<td>4660</td>
<td>5020</td>
<td>4840</td>
</tr>
<tr>
<td>Non-treated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>4920</td>
<td>4980</td>
<td>4950</td>
</tr>
<tr>
<td>200</td>
<td>5060</td>
<td>5090</td>
<td>5070</td>
</tr>
<tr>
<td>Average</td>
<td>4990</td>
<td>5030</td>
<td>5010</td>
</tr>
<tr>
<td>Average for</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>herb.</td>
<td>4740</td>
<td>4960</td>
<td>4850</td>
</tr>
<tr>
<td>200</td>
<td>4910</td>
<td>5090</td>
<td>5000</td>
</tr>
<tr>
<td>Average for</td>
<td>4820</td>
<td>5030</td>
<td>4930</td>
</tr>
<tr>
<td>trial</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSD 5% - for individual treatments</td>
<td>230</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- for interaction of two factors</td>
<td>330</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- for interaction of three factors</td>
<td>460</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

relation to the smaller dose. The tendency of yield increase after the application of more nitrogen was observed in both systems of basic tillage and both methods of weed control. Still, the largest increase was registered when the application of 200 kg/ha of N was combined with the mechanical weeding. The larger dose of nitrogen increased the yield of corn only by 880 kg/ha or 8.9% in relation to the smaller dose (Table 2).

The larger dose of nitrogen increased the yield of wheat, on the three-year average, only by 150 kg/ha. Similar tendencies were observed in both systems of basic tillage and both methods of weed control.

c) Effect of the method of weed control.

On the three-year average, the chemical method of weed control increased the yield of sugarbeet by 3470 kg/ha. With the lower dose of nitrogen, the difference was 4590 kg/ha, with the higher only 2370 kg/ha. In combination with the differentiated tillage, the chemical method increased the yield of roots by 3250 kg/ha in relation to the mechanical method. In co-
Tab. 4. Average number of weeds per m² in sugarbeet, corn, and wheat (1979-1981)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Dose</th>
<th>Sugarbeet</th>
<th>Corn</th>
<th>Wheat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Di- Mono- To- Mono- To- Mono- To-</td>
<td>Di- Mono- To- Mono- To- Mono- To-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>co- co- co- co- co- co- co- co-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tillage</td>
<td>Dose</td>
<td>Sugarbeet</td>
<td>Corn</td>
<td>Wheat</td>
</tr>
<tr>
<td></td>
<td>Di- Mono- To- Mono- To- Mono- To-</td>
<td>Di- Mono- To- Mono- To- Mono- To-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>co- co- co- co- co- co- co- co-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>depth cm</td>
<td>20/35</td>
<td>40,1</td>
<td>1,1</td>
<td>41,2</td>
</tr>
<tr>
<td></td>
<td>35/35</td>
<td>34,4</td>
<td>1,2</td>
<td>35,6</td>
</tr>
<tr>
<td>Dose of N kg/ha</td>
<td>100</td>
<td>31,2</td>
<td>1,4</td>
<td>32,6</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>40,7</td>
<td>0,9</td>
<td>41,6</td>
</tr>
<tr>
<td>Herb. Treated appl.</td>
<td>9,1</td>
<td>0,7</td>
<td>9,8</td>
<td>17,2</td>
</tr>
<tr>
<td></td>
<td>Non-treated</td>
<td>62,7</td>
<td>1,8</td>
<td>64,5</td>
</tr>
</tbody>
</table>

+ only for 1979

Combination with the continual tillage at 35 cm, the difference was 3680 kg/ha in favor of the chemical method of weed control.

With corn, the chemical method brought the three-year average yield increase of only 206 kg/ha. Yield differences between the methods of weed control were larger when corn was fertilized with 200 kg/ha of N and tilled at 20 cm.

The method of weed control did not have high effect on wheat yield. The earlier observation that wheat brings higher yields without herbicide application was confirmed. The combination of herbicide application and the basic tillage at 20 cm brought a lower yield than the average for the trial. Therefore, there are grounds for recommending the omission of herbicides for wheat grown in a three-crop rotation with sugarbeet and corn to which herbicides are applied.

2. The average number of weeds.

The average number of weeds per m² for the crops grown is given in Table 4.

The cultural practices applied had little effect on the frequency of monocotyledon weeds in the crops grown on account of a low frequency of this weed group. The largest reduc-
tion of monocotyledon weeds was effected by herbicide application.Dicotyledon weeds were much more frequent. The application of herbicides brought the largest reductions of weeds in the row crops-85.5 and 75.5%. The larger dose of nitrogen increased the frequency of weeds in sugarbeet and corn by 50 and 124%, respectively. The continual tillage at 35 cm reduced the weeds in sugarbeet and corn by 14.2 and 9.6%, respectively.

LITERATURE CITED
5. TILLAGE IN SYSTEMS OF PLANT PRODUCTION
EFFECT OF THE CROPPING SYSTEM ON THE YIELDS OF WHEAT, CORN, AND SOYBEAN GROWN ON SLIGHTLY CALCAREOUS CHERNOZEM

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Faculty of Agriculture
Institute of Field and Vegetable Crops
Novi Sad, Yugoslavia

ABSTRACT

In the period 1971-1981 we examined the effect of different systems of tillage on the yields of wheat, corn, and soybean grown in extensive and intensive crop rotations and monoculture. We studied the effects of fertilization, tillage depth, and crop rotation on the yields of the crops examined.

INTRODUCTION

Wheat, corn, and soybean are paid particular attention in Yugoslavia and especially in Vojvodina, the first two crops on account of their importance, the last one on account of its rapid expansion in recent years. Research programs on these crops are accordingly quite intensive.

One of the targets in research work are the studies of optimum cultural practices which would secure higher yields of the examined crops.

Climatic and edaphic conditions of Vojvodina are suitable for a successful and profitable production of these crops. It is thus important to know to which extent wheat, corn, and soybean make use of these natural potentials in different systems of land use.

The objective of this study was to determine the productive potentials of wheat, corn, and soybean in Vojvodina in dependance of environmental conditions and the anthropogenic factor.

MATERIAL AND METHOD

To consider the productional potentials of wheat, corn, and soybean and to determine the effects of climatic, soil, and anthropogenic factors on the productivity of the examined crops, we used the results of long-term field trials. The trials were established in 1946/47 /Stojković et al., 1972/.

For this paper we used the results from the period 1971-1981 for wheat and corn and the period 1972-1981 for soybean. The following systems of land use were examined:
1. Extensive two-crop rotation, unfertilized, established in 1946/47.
2. Extensive three-crop rotation, unfertilized, established in 1946/47.
3. 12-crop rotation fertilized with organic and mineral fertilizers, established in 1950/51.

The intensive rotations and the monoculture of wheat were fertilized with 100 kg/ha N, 60 kg/ha P, and 40 kg/ha K, expressed in pure nutrients.

Corn was fertilized with 120 kg/ha N, 80 kg/ha P, and 60 kg/ha K, expressed in pure nutrients. The manuring, performed every two, three, or four years in dependance of the rotation, corresponded to the quantity of 10 tons of manure per hectare annually.

The intensive rotations of soybean were fertilized with 40 kg/ha N, 60 kg/ha P, and 40 kg/ha K, expressed in pure nutrients.
The depths of tillage in the systems 1, 2, and 3 were 20 and 35 cm. In the system 3, the half tilled at 20 cm was fertilized with half of the quantities of fertilizers stated above.

The depth of tillage in the systems 4, 5, and 6 was 30 cm. The amounts of mineral and organic fertilizers used were the same as for the tillage at 35 cm /12-crop rotation/.

RESULTS

To obtain a better insight into the research results, we considered separately the effect of environmental conditions on the yields from the effect of the anthropogenic factor.

Effect of the environment

In the 11-year research period, the environment, i.e., weather conditions, brought large variations in the average yields of wheat, corn, and soybean grown in the examined systems of land use. The yields ranged from 2,721 to 5,273 kg/ha, 4,616 to 8,682 kg/ha, and 1,074 to 2,514 kg/ha, respectively.

The above yield variations helped us divide the research years 1971-1981 into favorable, medium, and unfavorable ones.

Tab. 1 - Suitability of the research years for wheat, corn, and soybean production

<table>
<thead>
<tr>
<th></th>
<th></th>
<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>Wheat</td>
<td>P N</td>
<td>N P</td>
<td>N P</td>
<td>P P</td>
<td>N P</td>
<td>P O</td>
<td>P P</td>
<td>N P</td>
<td>P P</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>N P</td>
<td>O N</td>
<td>O N</td>
<td>P P</td>
<td>O P</td>
<td>P O</td>
<td>P P</td>
<td>O P</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybean</td>
<td>O P</td>
<td>N N</td>
<td>P P</td>
<td>P O</td>
<td>P O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

P = favorable; 0 = medium; N = unfavorable

In the favorable years, the average yields of wheat ranged from 4,000 to 5,273 kg/ha, in the medium years from 3,627 to 3,965 kg/ha, and in the unfavorable years from 2,721 to 3,379 kg/ha.

In the case of corn, the variations ranged from 7,938 to 8,682 kg/ha, 6,071 to 7,111 kg/ha, and 4,616 to 5,912 kg/ha, respectively.

In the case of soybean, the variations ranged from 1,832 to 2,514 kg/ha, 1,511 to 1,565 kg/ha, and 1,074 to 1,325 kg/ha, respectively.

Table 1 shows that the research period had 5 favorable, 2 medium, and 4 unfavorable years for wheat. For corn, the ratio was 5, 4, and 2 years, respectively. For soybean, the ratio was...
6, 3, and 2 years, respectively.

Effect of the anthropogenic factor

The anthropogenic factor includes a number of practices of which we examined the effects of fertilization, tillage depth, crop rotation, and monoculture.

Effect of fertilization. - The examined systems of land use, especially the fertilized and unfertilized two-crop rotations, provided reliable data for a comparison of the effects of fertilization /Table 2/. Fertilization had the highest effect on wheat of all the examined factors /Stojković, 1968; Stojković et al., 1973/74/. Comparing the extensive two-crop rotation /unfertilized/ with the intensive two-crop rotation /fertilized with organic and mineral fertilizers/, we can see that the latter system brought the average yield increase over the 11-year period was 3,596 kg/ha or 314.3 %.

The average increase in the yield of corn the intensive two-crop rotation over the extensive two-crop rotation was 6,814 kg/ha or 287.1 %.

The effect of fertilization was somewhat lower in the three-crop rotation. The yield of wheat in the intensive three-crop rotation was higher by 3,597 kg/ha or 226.6 % than in the extensive three-crop rotation. In the case of corn, the increase was 5,295 kg/ha or 139.9 %.

Fertilization had the lowest effect on soybean - the difference in the average yields obtained in the intensive and the extensive three-crop rotation was 969 kg/ha or 87.9 %.

The introduction of the annual legume into the three-crop rotation reduced the effect of application of organic and mineral fertilizers in relation to the two-crop rotation of wheat and corn.

Effect of the depth of tillage. - We examined the effect of the depth of tillage in extensive and intensive conditions of production /Table 2/.

The deepening of tillage to 35 cm in the extensive two-crop rotation increased the yield of wheat by only 66 kg/ha or 5.9 % in relation to the tillage at 20 cm. In the extensive three-crop rotation, the increase was 204 kg/ha or 13.7 %.

In the case of corn, the differences were 207 kg/ha or 9.1 % and 409 kg/ha or 11.4 %, respectively. With soybean grown in the extensive three-crop rotation, the tillage at 35 cm
Tab. 2 - Yields of wheat, corn, and Soybean /kg/ha/ in the period 1971-1981 affected by different systems of land use

<table>
<thead>
<tr>
<th>Year</th>
<th>Crop</th>
<th>Extensive 2-crop</th>
<th>Extensive 3-crop</th>
<th>Intensive 12-crop</th>
<th>Intensive 2-crop</th>
<th>Intensive 3-crop</th>
<th>Mono-culture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Tillage depth, cm</td>
<td>Tillage depth, cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1972-1981</td>
<td>Soybean</td>
<td>1.018 1.186 1.102</td>
<td></td>
<td>2.048 2.147 2.097</td>
<td></td>
<td>2.071</td>
<td></td>
</tr>
</tbody>
</table>
increased the yield by 168 kg/ha or 16.5%.

In the extensive three-crop rotations, the deeper tillage brought larger increases in the yields of wheat and corn in relation to the shallower tillage because of the introduction of the legume in the rotation.

In conditions of the intensive application of organic and mineral fertilizers combined with the growing of soybean /12-crop rotation/, the depth of tillage had a considerably smaller effect on the yields - the increases in the yields of wheat, corn, and soybean with the tillage at 35 cm were 119 kg/ha or 2.4%, only 4 kg/ha or 0.04%, and 99 kg/ha or 4.8%, respectively.

Effect of crop growing in crop rotation and monoculture.- When analysing the yields achieved in crop rotations, it is necessary to consider separately those obtained in extensive and those obtained in intensive conditions of production.

The extensive three-crop rotation increased the yield of wheat by 443 kg/ha or 38.7% in relation to the two-crop rotation as the result of the introduction of soybean into the rotation. The increase in the yield of corn was 1,413 kg/ha or 59.5%.

The intensive three-crop rotation increased the yield of wheat by 444 kg/ha or 9.4% in relation to the two-crop rotation. Conversely, the yield of corn was reduced by 106 kg/ha or 1.2%. These figures show that the introduction of soybean into the rotation was considerably less effective in the intensive than in the extensive conditions of production.

The yields of wheat were lower in monoculture than in the intensive crop rotations. The yields in the intensive two-crop rotation, intensive three-crop rotation, and 12-crop rotation exceeded those in the monoculture by 345 kg/ha or 7.8%, 789 kg/ha or 17.9%, and 645 kg/ha or 14.7%, respectively. It may be concluded for the agroecological conditions of Vojvodina that wheat favored the growing in intensive rotations rather than in monoculture.

The monoculture decreased to an extent the yields of corn in relation to the yields obtained in the intensive crop rotations. The increases in the intensive two-crop rotation, intensive three-crop rotation, and 12-crop rotation were 531 kg/ha or 5.9%, 404 kg/ha or 4.7%, and 143 kg/ha or 1.6%, respectively. These results indicate the tolerance of corn to growing in monoculture but still the yields are depressed to a measure in relation to
those obtained in intensive rotations.

CONCLUSIONS

1. In conditions of Vojvodina, the productivity of wheat, corn, and soybean depended on the weather conditions in the year of growing.

2. Among the anthropogenic factors, fertilization was most effective. The average increases in the yields of wheat, corn, and soybean following fertilization were 3,597 kg/ha or 263.5%, 6,054 kg/ha or 213.5%, and 969 kg/ha or 87.9%, respectively.

3. The effect of tillage depth was more pronounced in the extensive rotations than in the intensive ones. In the former rotations, the deeper tillage increased the yields of wheat, corn, and soybean by 13.7%, 11.4%, and 16.5%, respectively. In the latter rotations, the increases were 2.4%, 0.04%, and 4.8%, respectively.

4. The effect of crop rotations was more pronounced in the extensive conditions /unfertilized/ than in the intensive ones. The yields of wheat and corn were increased by 38.7 and 59.5%, respectively, in the extensive rotations, by 9.4% to 17.9% and only up to 5.9%, respectively, in the intensive ones.

Wheat was found to be unsuitable for growing in monoculture while corn confirmed its tolerance to the conditions of monoculture.

5. The obtained results enabled us to differentiate the yields achieved, i.e., to determine the complex effects of the examined practices in the conditions of Vojvodina.

In the extensive conditions, without fertilization, the yields of wheat, corn, and soybean ranged from 1,111 to 1,689 kg/ha, 2,270 to 3,991 kg/ha, and 1,018 to 1,186 kg/ha, respectively. In the intensive conditions, the yields ranged from 4,395 /monoculture/ to 5,184 kg/ha /three-crop rotation/, 8,674 /monoculture/ to 9,187 kg/ha /two-crop rotation/, and 2,048 /12-crop rotation, tillage at 20 cm/ to 2,147 kg/ha /12-crop rotation, tillage at 35 cm/, respectively.

REFERENCES


Abstract

New tillage methods (shallow ploughing, deep chiseling or sub-soiling + shallow ploughing, minimum tillage) were compared to the traditional deep ploughing (.45 m dept for cereals, .55 m for summer crops) in a farm scale experiment on very heavy soil in Umbria (Central Italy). The first observations on mechanical aspects (field capacity and fuel consumption) are presented. They show that: 1) the deep ploughing is the costliest tillage method both for time and fuel; 2) the "two layers" tillage method (chisel or subsoiler + ploughing) demanded much less time and energy, as well breaking up the same depth of soil; 3) shallow ploughing and, mainly, minimum tillage allowed big savings.

Introduction

Deep soil tillage by large mouldboard ploughs is the basic tillage method in the Italian agriculture; .40-.45 m deep ploughing is usual for winter cereals, .50-.60 m is common for non-irrigated summer crops. This method has a very high cost in energy and time in the very heavy clay soils so largely represented in Italy.

This stimulates to study new tillage methods based on less deep ploughing and/or new implements able to reduce the soil-working cost, still retaining the commonly admitted benefits of deep tillage (deeper root penetration, greater soil water storage, reduced runoff) without its negative effects on soil (organic matter dilution, soil layer inversion, large clod formation, costly secondary tillage operations).
This aim could be reached through different ways: 1) reduction of ploughing depth, 2) deep soil work by chisel or subsoiler plus shallow ploughing; 3) minimum or no tillage.

A farm scale experiment was begun in summer 1981 to ascertain the long term effects of these tillage methods, new for the Italian agricultural practice, on crop growth and yields and on soil chemical and physical properties related to soil fertility.

Materials and methods

The experiment is carried out in the large (700 hectares) S. Apollinare farm of the Foundation for Agricultural Education, located 20 km far from Perugia (Central Italy), at about 250 m a.s.l., on hills having a 7-9% slope.

Soil is an alluvium belonging to the brown type, very deep. It is very rich in clay (35-50%), sub-alkali in pH (7.8) thanks to high content of Calcium carbonate, rich in potash, rather poor in phosphorus and nitrogen (10-12%).

The soil physical properties are fairly favourable for water capacity but rather unfavourable from the aeration and mechanical point of view. The soil is extremely hard, stone-like, when it is dry, very plastic and poorly aerated when wet. So, it is very difficult to work. Fortunately, the clay does swell and crack well under the effect of cycles of wetting and drying and/or freezing, so that the soil can assume a good tilth.

The farming system includes breeding cows, calves raising and crop growing. Crops in rotation are based on 50% of winter cereals (wheat and barley), 25% of summer crops (sunflower, sugar-beet, hybrid seed maize), 25% of lucerne. Moreover, grapes and olive trees are grown.

The farm cultivated ground is divided into plots 30 m large by drainage open ditches; plot length varies from about 200 to 600 m. The different rotation sections of the farm are constituted by several of such plots, which have all had an identical history for many years, receiving the same crops, fertilizers and cultural practices. On these sections, the traditional method is compared to the new tillage method (or methods) on at least 3 full plots functioning as replications. In this way randomized block experimental designs have been adopted on farm scale, so allowing to obtain practical data both on me-
Technica! aspects (soil working time and consumptions) and crop practices and yields.

Experimental work has begun on six rotation sections on a total area of 47 ha under experiment. In summer 1981 the tillage treatments were applied for the following crops: 1) wheat after wheat; 2) wheat after sunflower; 3) wheat after sugar-beet; 4) wheat after 3-years old lucerne; 5) summer crop (it is not yet decided whether sugar-beet or sunflower) after barley; 6) lucerne after wheat.

The experimental treatments have the following general feature.

Winter cereals. The usual tillage operations for winter cereals in the experiment farm are mouldboard ploughing at .45 m depth, followed by several passages of disc and/or spike harrows to refine the large clods produced by the plough. The experimental comparisons were the following ones:

.45 m deep ploughing vs. shallow ploughing (.30 m)

and/or vs. chisel + ploughing

and/or vs. minimum tillage (by disc harrow).

Minimum tillage is considered practicable only after the summer crops whose organic residues do not represent problems for tillage practices or seeding operation, such as sunflower, sugar-beet, silage maize, etc.. On the contrary, minimum tillage seems less practicable after crops which give regrowth (i.e. lucerne) or leave very important quantities of rough residues (as grain maize or sorghum).

Direct drilling (no tillage) has not been taken into consideration because of several difficulties: reluctance of farm managers; exaggerated cost and weight of the special direct drilling seeding-machines; non mobile fertilizers placement; uncontrollable weed growth.

Summer crops and lucerne. The deep ploughing (.55 m) is considered an important dry-farming method in the heavy soils of the experimental farm for crops which grow in summer when rains are scarce and irregular. So, we discarded both minimum tillage and no tillage for these crops and we compared the tillage methods as follows: .55 m deep ploughing vs. chiseling + ploughing. This by considering that it could be advantageous that soil not be totally inverted, as well retaining the soil deep breaking up.
Our intention is to continue to apply these tillage methods year after year for the whole rotation cycle on the same plots in order to ascertain: 1) how crop yields are affected by them; 2) which are their cumulative, long-term effects on soil properties related to soil fertility (structure stability, organic matter evolution, nutrient profiles, weed seeds population, etc.); 3) how large is the reduction of the tillage cost and whether the balance-sheet "costs-profits" will be improved.

Here we present only the very preliminary data on the mechanical aspects of the first experimentation year.

**Tillage operations and implements.**

The tractors used were:
- 4-wheel drive FIAT 1880DT, 180HP, 132 kW
- Track-laying FIAT-ALLIS 14CTA, 150HP, 118 kW
- Track-laying FIAT 130C, 130HP, 96 kW.

The tillage implements used in the experiment were:
- 2-furrow trailed mouldboard plough Nardi, able to work to .55 m depth on 1.1 m width.
- 2-furrow mounted mould-board plough So.Ge.Ma., able to work to .45 m depth on a .90 m width.
- 4-furrow semi-mounted mould-board plough Goizin Doucet, able to work to .30 m depth on a 1.80 m width.
- Mounted chisel-plough ORMAl, 2.50 m of width, with 5 rigid standards that can operate at a maximum depth of .50 m; the tools had a rather curve shape.
- Mounted sub-soiler So.Ge.Ma., 2.70 m of width with 3 rigid vertical standards able to reach a maximum depth of .90 m.
- Mounted two-row disc harrow, 4 m of width.

The primary tillage operations were carried out in July and August on plots which had been under cereals, in September and October on plots under sunflower, sugar-beet and lucerne.

Deep ploughing, primary shallow ploughing, chiseling and sub-soiling were carried out as soon as possible after the harvest of the previous crops and contemporaneously within the rotation sections.
The observations during tillage operations were: effective operating time, time losses, forward speed, wheel slipping, etc. But we will only present here the essential data for sake of brevity:

**Effective field capacity.** It is the actual average rate of coverage by the machines based upon the total field time. It includes the amount of time lost in field during the operation (turn at row ends, fuel refill). It is expressed as hectares per hour.

**Fuel consumption.** It is expressed in kilograms of gasoil per hectare.

All the data are expressed as absolute and relative values, the last being referred to the traditional method, as control. In the case of the double (or "two layers") tillage (chiseling or sub-soiling plus ploughing) we calculated and presented the total data of the two operations.

**Results.** Table 1 shows the results.

**Field capacity.** The new tillage methods showed a higher working capacity than the control, independently from slope, soil type and moisture, tractor type, previous crop, plot area.

Minimum tillage by disc harrow increased 7-to 11-fold the field capacity. Shallow ploughing (.30 m deep) increased f.c. by 33 to 50%. The "two-layers" tillage method (chisel or subsoiler plus plough) increased f.c. by 39+70%, being equal the depth of worked soil.

**Fuel consumption.** The traditional deep ploughing always required the highest fuel consumptions (often more than 90 kg/ha, never less than 59 kg/ha).

Disc harrowing consumed less than 10 kg/ha. By shallow ploughing fuel consumption was reduced by 26+54%. The "two layers" tillage allowed to save 21-50% fuel.

**Conclusions**

Deep ploughing is confirmed to be a very high time and fuel consuming method. An appreciable saving seems to be possible in operation time and fuel consumption by reducing the tillage depth and/or substituting mould-board plough by different implements. It remain to ascertain the technical and economic validity of the proposed alternative tillage methods through the analysis of crop yields and soil fertility evolution.
Table 1. Comparison between tillage methods: field capacity and fuel consumption.

<table>
<thead>
<tr>
<th>Farm sections</th>
<th>Previous crop</th>
<th>Area ha</th>
<th>Tillage methods</th>
<th>Tractors implements (see Notes)</th>
<th>Depth m</th>
<th>Effective Field Capacity ha/h</th>
<th>Fuel consumption</th>
<th>kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Next crop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
<td>13</td>
<td>Deep ploughing (contr.) A/2</td>
<td>.45</td>
<td>.36</td>
<td>.59</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Shallow ploughing A/2</td>
<td>.30</td>
<td>.48</td>
<td>33</td>
<td>44</td>
<td>-26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Chiseling + A/5</td>
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<td>.50</td>
<td>39</td>
<td>44</td>
<td>-24</td>
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<tr>
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<td></td>
<td></td>
<td>ploughing A/3</td>
<td>.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Wheat</td>
<td></td>
<td>4</td>
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<td>.23</td>
<td>76</td>
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<td></td>
<td></td>
<td>Shallow ploughing A/2</td>
<td>.30</td>
<td>.32</td>
<td>39</td>
<td>55</td>
<td>-27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Subsoiling + A/4</td>
<td>.50</td>
<td>.33</td>
<td>43</td>
<td>60</td>
<td>-21</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ploughing A/3</td>
<td>.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lucerne</td>
<td></td>
<td>7.5</td>
<td>Deep ploughing (contr.) A/2</td>
<td>.45</td>
<td>.32</td>
<td>61</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
<td></td>
<td>Shallow ploughing A/3</td>
<td>.30</td>
<td>.48</td>
<td>50</td>
<td>28</td>
<td>-54</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Disking A/6</td>
<td>.10</td>
<td>2.63</td>
<td>720</td>
<td>10</td>
<td>-84</td>
</tr>
<tr>
<td>Sunflower</td>
<td></td>
<td>7.5</td>
<td>Deep ploughing (contr.) C/1</td>
<td>.45</td>
<td>.17</td>
<td>91</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
<td></td>
<td>Disking A/6</td>
<td>.10</td>
<td>2.13</td>
<td>1150</td>
<td>9</td>
<td>-91</td>
</tr>
<tr>
<td>Sugar-beet</td>
<td></td>
<td>3.5</td>
<td>Deep ploughing (contr.) C/1</td>
<td>.55</td>
<td>.23</td>
<td>94</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
<td></td>
<td>Disking A/6</td>
<td>.10</td>
<td>2.13</td>
<td>1150</td>
<td>9</td>
<td>-91</td>
</tr>
<tr>
<td>Barley</td>
<td></td>
<td>7.2</td>
<td>Deep ploughing (contr.) A/4</td>
<td>.55</td>
<td>.36</td>
<td>57</td>
<td>57</td>
<td>-47</td>
</tr>
<tr>
<td>Summer crop</td>
<td></td>
<td></td>
<td>Subsoiler + A/4</td>
<td>.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ploughing A/3</td>
<td>.30</td>
<td>.36</td>
<td>57</td>
<td>50</td>
<td>-40</td>
</tr>
<tr>
<td>Wheat</td>
<td></td>
<td>10</td>
<td>Deep ploughing (contr.) B/1</td>
<td>.55</td>
<td>.26</td>
<td>96</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Lucerne</td>
<td></td>
<td></td>
<td>Subsoiler + A/4</td>
<td>.55</td>
<td>.45</td>
<td>73</td>
<td>48</td>
<td>-50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ploughing A/3</td>
<td>.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tractors
A. 4-wheel drive FIAT 1880DT, 132kW.
B. Tracklaying FIAT-ALLIS 14CTA, 118kW.
C. Tracklaying FIAT 130C, 96kW.

 Implements
1. 2-furrow mould-board plough Nardi
2. 2-furrow mounted mould-board plough So.Ge.Ma.
3. 4-furrow semi-mounted mould-board Doucet
5. Chisel-plough (5-standards, at.50 m) ORMA
6. Disc harrow.

Acknowledgements. We thank: Ente Sviluppo Agricolo Umbria for the financial support, Fondazione Istruzione Agraria for the organization support, FIAT Trattori, Nardi, So.Ge.Ma., ORMA and Marchetti for the use of tractors and implements.
SOIL TILLAGE IN THE PRODUCTION SYSTEM MAIZE - WHEAT

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Luka Dragić

Maize Research Institute Zemun Polje, Beograd-Zemun, Yugoslavia

Abstract

In Yugoslavia, maize is usually planted after wheat. Yugoslavia is predominately a mountainous country. In the Mountainous region, maize is also planted after wheat as in the other parts of the country. For this reason, we have investigated the effect of primary tillage on yield of maize and wheat on sloped terrain in a two-field crop rotation system maize-wheat.

Materials and methods

The investigation was conducted on the following types of soil: 1. brown forest soil, 2. smonitza, 3. pseudogley and 4. reddish-brown soil during 1977 and 1980.

We have investigated the following factors:

a) Maize (treatments)
   1. primary tillage and fertilization in the fall
   2. primary tillage in the fall, fertilization in the spring
   3. primary tillage and fertilization in the spring

b) Wheat (treatments)
   1. Standard, tillage 25-30 cm
   2. Disking 8-10 cm

Results and discussion

Brown forest soil was formed on loess. It is a loose type of soil moisture-retentive, light-textured, with good granulometric properties and total porosity. Due to favourable physical and mechanical properties, the time of primary tillage and fertilization of the soil for growing maize on brown forest soil (Table 1) after wheat grown according to the standard method, did significantly affect the maize yield.
Table 1. - Maize yield (t/ha) as affected by the time of primary tillage and fertilization after wheat grown in the standard way

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>Year</th>
<th>Time of primary tillage and fertilization</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Tillage and fertilization in the fall</td>
<td>Tillage in the fall</td>
</tr>
<tr>
<td>Brown forest soil</td>
<td>1977</td>
<td>7.512</td>
<td>7.425</td>
</tr>
<tr>
<td></td>
<td>1978</td>
<td>8.191</td>
<td>8.447</td>
</tr>
<tr>
<td></td>
<td>1979</td>
<td>7.989</td>
<td>8.638</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>8.190</td>
<td>8.458</td>
</tr>
<tr>
<td></td>
<td>1978</td>
<td>8.248</td>
<td>8.504</td>
</tr>
<tr>
<td></td>
<td>1979</td>
<td>10.461</td>
<td>10.456</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>8.550</td>
<td>9.038</td>
</tr>
<tr>
<td>Pseudogley soil</td>
<td>1977</td>
<td>6.910</td>
<td>6.786</td>
</tr>
<tr>
<td></td>
<td>1978</td>
<td>5.866</td>
<td>6.096</td>
</tr>
<tr>
<td></td>
<td>1979</td>
<td>8.378</td>
<td>7.765</td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td>7.088</td>
<td>6.955</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>8.060</td>
<td>6.900</td>
</tr>
<tr>
<td>Reddish-brown soil</td>
<td>1977</td>
<td>7.491</td>
<td>7.520</td>
</tr>
<tr>
<td></td>
<td>1979</td>
<td>10.505</td>
<td>10.207</td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>8.523</td>
<td>8.486</td>
</tr>
</tbody>
</table>

Smonitza is in different phases of metamorphosis. It is of considerable potential fertility. It is categorized as a heavy clay soil. Due to such physical and mechanical properties of the smonitza soil, the time of primary tillage, after wheat grown in the standard way (Table 1), considerably affects the maize yield.

The timely tillage of pseudogley soil is of particular significance for the development of a loose soil of good quality, the increase of water reserves and improvement of major features of the arable layer. Our investigations have shown that even with such soils as pseudogley (poor physical, mechanical and chemical properties), a timely tillage and fertilization significantly affects maize yield. The treatment "primary tillage and fertilization in the fall" compared to the two other treatments, gave a higher maize yield.

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Reddish-brown soil on limestone covers a considerable area in Yugoslavia. According to its composition it is classified as medium heavy loam. Due to such physical properties of this soil, the time of primary tillage and fertilization of the soil for maize (Table 1), after wheat grown in the standard way, affected to a certain degree the maize yield.

The time of tillage and fertilization for maize grown on brown forest soil in the preceding year did not significantly affect the grain yield in the following year when wheat was grown in the standard way (Table 2).

Table 2.- Yield of wheat (t/ha) grown in the standard way as affected by the time of primary tillage and fertilization for maize in the preceding year

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>Year</th>
<th>Time of primary tillage and fertilization</th>
<th>Fall</th>
<th>Fall-spring</th>
<th>Spring</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown forest soil</td>
<td>1977</td>
<td>4.126</td>
<td>4.041</td>
<td>3.941</td>
<td>4.036</td>
<td></td>
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<tr>
<td></td>
<td>1979</td>
<td>3.997</td>
<td>3.612</td>
<td>3.514</td>
<td>3.608</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>4.024</td>
<td>3.898</td>
<td>3.681</td>
<td>3.826</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1979</td>
<td>3.842</td>
<td>3.816</td>
<td>3.832</td>
<td>3.830</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td>3.995</td>
<td>3.968</td>
<td>3.945</td>
<td>3.982</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>4.108</td>
<td>4.104</td>
<td>4.073</td>
<td>4.096</td>
<td></td>
</tr>
<tr>
<td>Pseudogley</td>
<td>1977</td>
<td>3.510</td>
<td>3.496</td>
<td>3.469</td>
<td>3.482</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1978</td>
<td>3.545</td>
<td>4.075</td>
<td>3.448</td>
<td>3.528</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1979</td>
<td>3.048</td>
<td>3.056</td>
<td>3.008</td>
<td>3.037</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td>2.895</td>
<td>2.903</td>
<td>2.853</td>
<td>2.885</td>
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<td></td>
<td>3.249</td>
<td>3.382</td>
<td>3.193</td>
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</tr>
<tr>
<td>Reddish-brown soil</td>
<td>1977</td>
<td>4.137</td>
<td>4.096</td>
<td>3.977</td>
<td>4.073</td>
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<tr>
<td></td>
<td>1979</td>
<td>3.470</td>
<td>3.423</td>
<td>3.436</td>
<td>3.443</td>
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<tr>
<td>Average</td>
<td></td>
<td>3.884</td>
<td>3.745</td>
<td>3.699</td>
<td>3.743</td>
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</table>

Results obtained on smonitza soil (Table 2) indicate that the time of tillage and fertilization of maize does not significantly affect the maize yield in the following year, if wheat was grown in a standard way. Similar results were obtained for pseudogley, too. Yield of wheat, grown in the standard way
(Table 2) did not significantly depend on the time of tillage and fertilization of maize in the preceding year.

On the contrary, for reddish-brown soil on limestone, the time of tillage and fertilization (Table 2) of maize in the preceding year affected the yield of wheat in the following year.

The effect of primary tillage and fertilization of the soil for growing maize after wheat, grown with shallow tillage (disking) is given in Table 3. It was found that the time of tillage and fertilization of soil for growing maize after wheat with shallow tillage definitely depends on the type of soil. The highest maize yield was obtained in the treatment "primary tillage in the fall, fertilization in the spring", and the lowest yield in the treatment "primary tillage and fertilization in the spring" (Table 3).

Table 3.—Maize yield (t/ha) as affected by the time of primary tillage and fertilization after wheat grown on minimum tillage

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>Year</th>
<th>Time of primary tillage and fertilization</th>
<th></th>
<th></th>
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<tr>
<td></td>
<td></td>
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<td>Tillage in the fall, fertilization in the spring</td>
<td>Tillage and fertilization in the spring</td>
<td>Average</td>
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<td>Brown forest soil</td>
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<td>7.361</td>
<td>7.202</td>
<td>7.122</td>
<td>7.228</td>
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<td></td>
<td>1978</td>
<td>7.871</td>
<td>8.392</td>
<td>7.394</td>
<td>7.837</td>
</tr>
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<td></td>
<td>1979</td>
<td>7.958</td>
<td>8.531</td>
<td>8.667</td>
<td>8.338</td>
</tr>
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<td></td>
<td>1980</td>
<td>7.910</td>
<td>7.786</td>
<td>7.328</td>
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<td>7.772</td>
<td>7.978</td>
<td>7.626</td>
<td>7.783</td>
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<td>7.072</td>
<td>6.092</td>
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<td>1980</td>
<td>7.681</td>
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<td>7.380</td>
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<td>7.968</td>
<td>8.237</td>
<td>7.605</td>
<td>8.030</td>
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<tr>
<td>Pseudogly</td>
<td>1977</td>
<td>6.219</td>
<td>6.107</td>
<td>5.355</td>
<td>5.933</td>
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<td>5.680</td>
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<td>6.365</td>
<td>6.524</td>
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<td>6.308</td>
<td>5.484</td>
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<td>7.219</td>
<td>7.124</td>
<td>7.176</td>
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<tr>
<td></td>
<td>1979</td>
<td>10.242</td>
<td>10.207</td>
<td>10.319</td>
<td>10.256</td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td>Average</td>
<td>8.193</td>
<td>8.244</td>
<td>8.016</td>
</tr>
</tbody>
</table>
Wheat grown on shallow tillage (Table 4) did not significantly respond in yield, nor did the time of tillage and fertilization of maize in the preceding year.

Table 4. Yield of wheat (t/ha) grown on shallow tillage as affected by the time of tillage and fertilization for maize in the preceding year

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>Year</th>
<th>Time of primary tillage and fertilization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Spring</td>
</tr>
<tr>
<td>Brown forest soil</td>
<td>1977</td>
<td>3.411</td>
</tr>
<tr>
<td></td>
<td>1978</td>
<td>3.555</td>
</tr>
<tr>
<td></td>
<td>1979</td>
<td>2.062</td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td>2.123</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>2.788</td>
</tr>
<tr>
<td>Smonitza</td>
<td>1977</td>
<td>3.074</td>
</tr>
<tr>
<td></td>
<td>1978</td>
<td>3.089</td>
</tr>
<tr>
<td></td>
<td>1979</td>
<td>1.791</td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td>1.898</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>2.463</td>
</tr>
<tr>
<td>Pseudogley</td>
<td>1977</td>
<td>2.080</td>
</tr>
<tr>
<td></td>
<td>1978</td>
<td>2.159</td>
</tr>
<tr>
<td></td>
<td>1979</td>
<td>1.247</td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td>1.259</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>1.686</td>
</tr>
<tr>
<td>Reddish-brown soil</td>
<td>1977</td>
<td>2.778</td>
</tr>
<tr>
<td></td>
<td>1978</td>
<td>2.839</td>
</tr>
<tr>
<td></td>
<td>1979</td>
<td>1.646</td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td>1.678</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>2.235</td>
</tr>
</tbody>
</table>

It is significant to point out that in the two-field crop rotation system a higher maize yield was obtained after wheat grown in the standard way than with shallow tillage.

Soil tillage for wheat in the two-field crop rotation system, on the whole, affected significantly the yield of maize. A considerably higher maize yield was obtained in treatments with two-field crop rotation system after wheat grown in the standard way (Table 1 and 3). This treatment compared to the treatment where wheat was grown with shallow tillage, gave on the average for 1977/1980 a higher maize yield on brown forest soil, smonitza, pseudogley and reddish-brown soil by 5.6, 8.6, 13.3 and 2.9%, respectively.
Wheat yield (Table 2 and 4) depended considerably on the depth of soil tillage. Wheat grown in the standard way compared to shallow tillage gave a significantly higher grain yield. Differences in yield on brown forest soil, smonitza, pseudogley and reddish-brown soil were 46.0, 64.0, 91.5 and 74.0%. Differences in wheat yield are higher for medium-heavy, and heavy types of soils than for light soils.

Conclusion

Due to the heavy-textured and unstable structure of smonitza and pseudogley soils, it is desirable, from the standpoint of growing maize, to till these soils in the fall rather than in the spring.

The time of tillage and fertilization for maize grown on brown forest soil, smonitza, pseudogley and reddish-brown soil in the preceding year did not significantly affect the yield of wheat grown in the standard way in the following year.

The maize yield obtained in the two-field crop rotation system did not significantly depend on the time of tillage and fertilization of soil. There are differences in yield justified according to the "F" test, on all types of tested soils.

In the two-field crop rotation system, the yield of wheat grown on shallow tillage was not significantly affected by the time of tillage and fertilization of soil for maize.

Wheat yield is significantly affected by the depth of primary tillage of the soil. Wheat yield is always higher on deep than shallow tillage.
Literature


Influence of soil tillage on $P_2O_5$ and $K_2O$ content in plant.

M. FRANKINET * and L. GREVY **

Station de Phytotechnie
Chemin de Liroux - B 5800 Gembloux
Belgique

* Chef de travaux.
** Ingénieur technicien principal.

Abstract

For the conditions of this trial, soil with good reserves in $P_2O_5$ and $K_2O$ and mineral manure restitutions broadly applied, direct drilling or shallow cultivation affect lightly $P_2O_5$ and $K_2O$ contents for sugar beet (roots), spring barley and oats (grain), corn silage (whole plant), horse bean (vicia faba) and winter wheat (grains).

For $P_2O_5$, some significant differences appear. These are important for tops and leaves of sugar beet. This difference (20 % in relative value) must be counterbalanced by lower yields and by a higher coefficient of variation. For horse bean, contents are lower ($\approx - 5 \%$) for direct drilling. This is balanced by a higher level of grain production / ha ($\approx + 6 \%$).

Winter wheat differences are about 2 % related with the level of the nitrogen manure shaded by the existence of an interaction between nitrogen and soil loosening-effect.

For $K_2O$, the variability of results is higher and generally the results fluctuate in the same way that for $P_2O_5$ except for corn silage. Any statistical significant differences appear between means $K_2O$ contents for the six crops and for the twelve years involving these results.
Introduction

The reduction of ploughing depth till no-tillage draws in the long run a lot of consequences both for soil and crops.

It is now well known that continuous direct drilling induces an accumulation of phosphorus and potassium in the upper layer of the soil (DREW, 1977; DREW and SAKER, 1978; RAIMOND, 1975).

This increase goes together with higher organic matter content when harvest residues are not exported (VEZ, 1972-1977). But this phenomenon occurs without disturbance in the "input-output" balance of $P_2O_5$ and $K_2O$ in the first forty centimeters of the topsoil (RAIMOND, 1978).

Crop responses growing in such conditions are different according to the species. Winter wheat is almost unaffected by the mode of seedbed preparation.

For sugar beet (roots), direct drilling involves an important depletion of production.

Yield measurements are global and integrate a lot of factors bound with soil (structure, organic matter, compaction, moisture, ...) and climate.

If yield responses are varied, it seems to us interesting to verify, into this trial settled in 1961 if the content of $P_2O_5$ and $K_2O$ in plants are also affected by the various gradients measured in the soil samples.

Many authors have tabled this problems (LAL, 1979; KETCHESON, 1980; ELLIS, 1980; MOSHLER, 1975).

Results don't display large differences referring to plant content. More over, the little differences observed are rarely significant (RIGA, 1976; PEARSON, 1981).

Materials and methods

Since 1967, plant analysis are conducted with samples put apart at harvest time. This trial on depth of ploughing is carried out on a deep, fresh and fertile loam (loess). Means contents of $P_2O_5$ and $K_2O$ are respectively 41 and 26 mg/100 g of dry soil.

Agronomics results and a detailed description of soil and yields are described by FRANKINET and al (1978).

Experimental scheme may be shortly explained like this:

- three initial treatments (with equal nitrogen manure): normal ploughing (25-30 cm depth), half ploughing or shallow cultivation (15-20 cm depth) and no-tillage or direct drilling. For shallow cultivation and direct drilling, two variants are retained. On the one hand a nitrogen manure
supply and on the other hand a normal ploughing after three years of shallow cultivation or direct drilling. Let be a total of seven treatments (T):

1. direct drilling - normal nitrogen manure (D.D.)
2. direct drilling with extra nitrogen manure (D.D. N)
3. shallow cultivation (half ploughing) normal nitrogen manure (S.C.)
4. shallow cultivation with extra nitrogen manure (S.C. n) \( (n = N/2) \)
5. three years direct drilling with extra nitrogen manure + one year normal ploughing - normal nitrogen manure (3 D.D. N + P)
6. three years shallow cultivation with extra nitrogen manure + one year normal ploughing and normal nitrogen manure (3 S.C. n + P)
7. normal ploughing (25-30 cm depth) - normal nitrogen manure (P).

A four course rotation is implanted on four fields, each break is subdivided in four replications (R).

The rotation is : 1. Sugar beet. 2. Spring barley or oats. 3. Silage corn or horse bean (vicia faba). 4. Winter wheat.

At harvest time, each parcel for each crop is represented by a sample. Dry matter is determined by drying at 105°C till constant weight. After this, samples are ground with a hammer-mill.

Quantitative analysis of phosphorus and potassium (determined by the "Station de Chimie et de Physique agricoles" Gembloux) are made by the nitroperchlorical mineralization; the phosphorus content is obtained by the molybdovanadate ammoniacal method (colorimeter). The potassium content is obtained by photometrical method.

Phosphorus and potassium contents are expressed in \( P^2O_5 \) and \( K^2O \) \% of the dry matter \( (P^2O_5 = P \times 2.29 \) and \( K^2O = K \times 1.20) \).

Results and discussion

Phosphorus contents \( (P^2O_5 \% \) D.M.) appear in table 1 for the seven treatments and for the six crops.

In general, results vary more because of annual effects rather than the treatment effects, as indicated by the comparison of coefficients of variation, except for winter wheat.

Only horse bean and winter wheat show coefficients of variation relatively low \( (\approx 5 \%) \).

For the whole, coefficients of variation are effectively rather high and even exceed ten \% for tops and leaves (L) of sugar beet. An explanation is that material stays on the soil some hours or days before the samples are
Table 1. "Les Brisés" - Means contents of $P_2O_5$ expressed in $^{\circ}/_{oo}$ of dry matter

<table>
<thead>
<tr>
<th>N°</th>
<th>Treat.</th>
<th>SUGAR BEET</th>
<th>SPRING BARLEY</th>
<th>SPRING OATS</th>
<th>SILAGE CORN</th>
<th>HORSE BEAN</th>
<th>WINTER WHEAT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Roots &amp; Tops &amp; L.</td>
<td>8 years</td>
<td>4 years</td>
<td>5 years</td>
<td>7 years</td>
<td>5 years</td>
</tr>
<tr>
<td>1</td>
<td>D.D.</td>
<td>4.77</td>
<td>7.92</td>
<td>11.23</td>
<td>9.62</td>
<td>6.51</td>
<td>18.77</td>
</tr>
<tr>
<td>7</td>
<td>P</td>
<td>4.77</td>
<td>6.58</td>
<td>11.21</td>
<td>9.87</td>
<td>6.54</td>
<td>19.45</td>
</tr>
<tr>
<td></td>
<td>MEAN</td>
<td>4.72</td>
<td>7.03</td>
<td>11.21</td>
<td>9.68</td>
<td>6.58</td>
<td>19.10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STAND. DEVIAT.</th>
<th>Treat. x Years (T x R) in Y.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.385</td>
<td>0.951</td>
</tr>
<tr>
<td>0.327</td>
<td>0.743</td>
</tr>
<tr>
<td>0.524</td>
<td>0.006</td>
</tr>
<tr>
<td>0.327</td>
<td>0.743</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ALPHA</th>
<th>Treat. x Years (T x R) in Y.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.112</td>
<td>0.107</td>
</tr>
<tr>
<td>0.107</td>
<td>0.843</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COEF. OF VAR.</th>
<th>Treat. x Years (T x R) in Y.</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.2</td>
<td>13.5</td>
</tr>
<tr>
<td>8.2</td>
<td>13.5</td>
</tr>
</tbody>
</table>

Table 2. "Les Brisés" - Means contents of $K_2O$ expressed in $^{\circ}/_{oo}$ of dry matter

<table>
<thead>
<tr>
<th>N°</th>
<th>Treat.</th>
<th>SUGAR BEET</th>
<th>SPRING BARLEY</th>
<th>SPRING OATS</th>
<th>SILAGE CORN</th>
<th>HORSE BEAN</th>
<th>WINTER WHEAT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Roots &amp; Tops &amp; L.</td>
<td>8 years</td>
<td>4 years</td>
<td>5 years</td>
<td>7 years</td>
<td>5 years</td>
</tr>
<tr>
<td>1</td>
<td>D.D.</td>
<td>13.13</td>
<td>45.53</td>
<td>7.11</td>
<td>6.84</td>
<td>19.52</td>
<td>15.70</td>
</tr>
<tr>
<td>2</td>
<td>D.D. N</td>
<td>13.65</td>
<td>41.90</td>
<td>7.17</td>
<td>6.98</td>
<td>19.61</td>
<td>15.42</td>
</tr>
<tr>
<td>3</td>
<td>S.C.</td>
<td>12.72</td>
<td>39.18</td>
<td>6.93</td>
<td>6.94</td>
<td>18.76</td>
<td>15.82</td>
</tr>
<tr>
<td>4</td>
<td>S.C. n</td>
<td>12.72</td>
<td>41.70</td>
<td>7.02</td>
<td>6.86</td>
<td>18.54</td>
<td>15.88</td>
</tr>
<tr>
<td>5</td>
<td>3 D.D.N +P</td>
<td>13.61</td>
<td>37.73</td>
<td>7.10</td>
<td>7.27</td>
<td>20.04</td>
<td>15.72</td>
</tr>
<tr>
<td>6</td>
<td>3 S.C.n +P</td>
<td>13.11</td>
<td>38.17</td>
<td>7.03</td>
<td>7.12</td>
<td>19.07</td>
<td>15.61</td>
</tr>
<tr>
<td>7</td>
<td>P</td>
<td>13.18</td>
<td>40.16</td>
<td>7.10</td>
<td>7.25</td>
<td>19.95</td>
<td>15.73</td>
</tr>
<tr>
<td></td>
<td>MEAN</td>
<td>13.18</td>
<td>40.62</td>
<td>7.07</td>
<td>7.04</td>
<td>19.33</td>
<td>15.70</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STAND. DEVIAT.</th>
<th>Treat. x Years (T x R) in Y.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.547</td>
<td>7.48</td>
</tr>
<tr>
<td>1.025</td>
<td>5.21</td>
</tr>
<tr>
<td>0.112</td>
<td>0.107</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ALPHA</th>
<th>Treat. x Years (T x R) in Y.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.112</td>
<td>0.107</td>
</tr>
<tr>
<td>0.843</td>
<td>0.165</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COEF. OF VAR.</th>
<th>Treat. x Years (T x R) in Y.</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.8</td>
<td>18.4</td>
</tr>
<tr>
<td>7.8</td>
<td>12.8</td>
</tr>
</tbody>
</table>

- 313 -
mechanically gathered. For this reason contaminations by soil particles are practically unavoidable.

Concerning sugar beet (roots) and spring barley (grains) contents, direct drilling is almost equal to ploughing whereas shallow cultivation is lower to it.

For spring oats, direct drilling and shallow cultivation show lower yields than ploughing (about 2.5% in relative value if ploughing is 100%). Nevertheless and referring to ploughing, contents obtained for silage corn are about 1% lower in direct drilling and about 3% higher in shallow cultivation. For these plants, differences are not statistically significant (alpha > 0.05).

But analysis of variance lets show significant differences for horse bean (grains) (alpha = 0.047) and highly significant (0.001 < alpha < 0.01) for tops and leaves of sugar beet and for winter wheat.

For horse bean, direct drilling treatments show the lowest contents (~4% with regards to ploughing equal 100%). This difference can be explained by "dilution" due to high yields in direct drilling treatments (~+6%).

Regarding tops and leaves of sugar beet, direct drilling produces a clearly increase of contents (till 20% higher in relative value from ploughing) and a less higher one for shallow cultivation.

In direct drilling, tops and leaves yields are lower and in shallow cultivation a little higher than in ploughing treatment. That seems to reveal the weakness of the observation (dilution) made with regard to horse bean.

Winter wheat results show another response. As a matter of fact, lowest content appears for treatments without nitrogen supply: direct drilling (1), shallow cultivation (3) and normal ploughing (7).

The minimal value is observed in shallow cultivation for which yields are lower (~0.2%) than ploughing.

Although the differences are significant, they remain under 2.7% in relative value.

Nevertheless it is important to point out that for the twelve years that include these results, each annual analysis of variance is not significant.

Let us recall that a supplement of nitrogen manure practically has no influence on the mean yields (~0.2% for direct drilling and +0.9% for shallow cultivation).

If a synergy exists between nitrogen and phosphorus, this is very tenuous for the fields conditions of this trial and more over it doesn't appear a "dilution" effect of P2O5 when yields increase.
Potassium contents are shown in table 2. They are expressed in \( \text{K}_2\text{O} \) \%/D.M. The comparison of the coefficients of variation shows that the annual fluctuation is most higher than the one observed for \( \text{P}_2\text{O}_5 \). Only spring barley, horse bean and winter wheat contents present coefficients under 10 %. Whereas tops and leaves of sugar beet and silage corn reach value up to 18 %.

For horse bean the annual variation is lightly inferior to the variation due to the treatments (4.3 versus 4.4 %).

Generally, differences vary more or less in the same way that for \( \text{P}_2\text{O}_5 \). Although dispersion values of results is higher than these evolve in some classification disturbance. An inversion appears for silage corn for which shallow cultivation shows relative values lower (~6.5%) than ploughing (~100%) and direct drilling (~3.5%) even though for \( \text{P}_2\text{O}_5 \) they are higher to the ploughing (+3%) and to the direct drilling (+4%).

This important variation may contribute to the lack of signification of the analysis of variance.

**Bibliography**


INFLUENCE OF DIFFERENT TILLAGE ON THE EFFECT OF THE PRELIMINARY CROPS, CORN AND SUGAR BEETS, ON THE YIELD OF WINTER WHEAT.

Günter Kahnt and Ernst Kübler
Institute of Plant Production, University of Hohenheim, Federal Republic of Germany.

ABSTRACT
Analyzing the effect of previous crops, corn or sugar beets, on the following crop wheat, we often found a more important influence of the crop before previous crops in interaction with soil tillage after them, or, on the other hand, an interaction between manuring and plant protection to the plant and different soil tillage before the next crop, which was more effective than the preliminary crop itself.

The effect of preliminary crops is determined by the effect of the plants and by the effect of the measures for the growth of them, i.e. soil tillage, manuring, fertilization, plant protection, and it is influenced by the kind of soil tillage after harvesting the preliminary crop. By this way the transformation of N-fertilizer into yield only can be changed by different soil tillage. In graphic 1 it can be shown that in farm I an increasing Nitrogen-level (120 - 180 kg N/ha) has no effect on the yield of winter wheat after ploughing, but rotavating after the preliminary crop sugar beet increased from 4.2 tons to 6.0 tons at 120 kg N and from 4.4 tons to 6.6 tons at 180 kg N/ha. In farm II no difference between plough and rotavator could be found at 120 kg N, but 1.4 tons difference between ploughing and minimum cultivation was the result at 180 kg N. In farm III the difference between plough and rotavator was only 0.4 - 0.6 tons/ha.

The reason for the different yields in farm I, II and III after plough was not the preliminary crop sugar beet, but the crop rotation before (Tab.1), with a very seek rotation in farm I and a very healthy crop rotation for winter wheat in farm III. The reason for the big or small difference between the yield of winter wheat after plough or rotavator in farm I and III was the preliminary crop before sugar beets and the kind of tillage before sugar beets. In all farms the plough was used.

In farm I a very seek straw was ploughed deep into the soil before drilling the sugar beets, and in farm III straw of corn with no residues of fungi diseases. After sugar beets, these two different residues were ploughed again to the surface of the soil and came in contact with the wheat, and no chemical plant protection was able to prevent the lowering of yield after ploughing, but after rotavating, when the straw residues remained into the soil, the yield of winter wheat increased up to 1.2 tons compared to the plough at 180 kg N-level.
Tab. 1: Yield of winter wheat (t/ha) after the preliminary crop sugar beet and after ploughing or rotavating at different N-levels for wheat

<table>
<thead>
<tr>
<th>N-fertiliz. level</th>
<th>Farm I</th>
<th>Farm II</th>
<th>Farm III</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg/ha</td>
<td>plough</td>
<td>rotavat.</td>
<td>plough</td>
</tr>
<tr>
<td>N 120</td>
<td>4.2</td>
<td>6.0</td>
<td>6.1</td>
</tr>
<tr>
<td>N 140</td>
<td>4.5</td>
<td>5.8</td>
<td>6.3</td>
</tr>
<tr>
<td>N 180</td>
<td>4.4</td>
<td>6.6</td>
<td>6.4</td>
</tr>
</tbody>
</table>

diff. between plough and rotavator at 180 N

<table>
<thead>
<tr>
<th>Crop rotation</th>
<th>Farm I</th>
<th>Farm II</th>
<th>Farm III</th>
</tr>
</thead>
<tbody>
<tr>
<td>1969</td>
<td>sugar beet</td>
<td>w. rye</td>
<td>sugar beet</td>
</tr>
<tr>
<td>1970</td>
<td>w. wheat</td>
<td>w. rye</td>
<td>corn</td>
</tr>
<tr>
<td>1971</td>
<td>s. barley</td>
<td>s. wheat</td>
<td>w. wheat</td>
</tr>
<tr>
<td>1972</td>
<td>w. wheat</td>
<td>s. wheat</td>
<td>corn</td>
</tr>
<tr>
<td>Preliminary crop 1973</td>
<td>sugar beet</td>
<td>sugar beet</td>
<td>sugar beet</td>
</tr>
<tr>
<td>Test crop 1974</td>
<td>w. wheat</td>
<td>w. wheat</td>
<td>w. wheat</td>
</tr>
</tbody>
</table>

Graph 1: Yield of winter wheat

<table>
<thead>
<tr>
<th>t/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>kg N</th>
<th>Plough</th>
<th>Rotavator</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>140</td>
<td></td>
<td></td>
</tr>
<tr>
<td>160</td>
<td></td>
<td></td>
</tr>
<tr>
<td>180</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

--- plough  --- rotaator
Another experiment with 4 different preliminary crops shows, that the effect of plough or minimum tillage is very different after the 4 previous crops (graph below): a decreasing yield we got at 80 kg N-level after faba-beans, and an increasing yield at the same N-level after sugar beet and rye. So the question is, what measure is necessary for optimizing nutrients, water or oxygen for the next plant and what measure is necessary to prevent diseases from the next crop. Another question is, whether a farmer is forced to mobilize N out of the humus or the organic matter in the soil, or whether it would be better to store the humus and to use the N from the N-fertilizer. What interactions are between herbicide residues from the preliminary crop and the following crop? What interactions are there between the residues of herbicides and soil tillage, f.i. after corn? Is it necessary to let these residues at the surface of the soil for using them a second year? So we are not allowed to plough, but we have to rotavate very shallow or to use the chissel plough. Or is it necessary to put these residues in deeper layers of the soil, because we want to drill winter wheat after corn with some atrazin residues? The consequence is, the deeper we plough, the better it will be! Or is it better to thin the residues? Then we have to use a deep cultivator and not a chissel plough or a plough. Or is the aim after spraying herbicides to lower its effect by microbiological activity? Then we have to use a mulching soil tillage system with high level of organic dung and by increasing the biological activity by N-fertilizer and high pH.

In consequence of all these questions we started an experiment in 1978/1979 with the following question: What is the effect of an increasing level of chemical weed and pest control during the growth of sugar beets and corn in interaction with different manuring (green manuring, dung, straw) before and different soil tillage after harvesting these crops on the yield of winter wheat?
Remembering, that the effect of a preliminary crop may be changed if the measures before or during the growing season of the previous crop are changed, and knowing, that some crops have the same preliminary crop effect than in ancient times, like clover or alfalfa, because nothing was changed in this time, and knowing other plants like sugar beets, corn, rape or potatoes, where dung was changed into straw and fertilizer, and mechanical weed control was changed into chemical and often very different chemical weed control, we have to ask in all crop rotation experiments not only for the rotation of the plants, but much more for the special methods used for these plants.

The plan for these experiments was as follows:

1. Soil, climatic conditions and fertilization.

   Soil: silty loam (20 % clay), 1.6 % of humus, para brown earth.
   Climatic conditions: 680 mm annual rain fall, mean temperature 7.9°C.
   Fertilization: sugar beets NPK 120, 126, 140
   corn NPK 120, 126, 140
   wheat NPK 110, 126, 140

2. Crop rotation

   corn
   winter wheat
   sugar beet
   winter wheat

3. Soil tillage

   plough
   plough grubber rotavator
   plough
   plough grubber rotavator

4. Chemical plant protection (4 levels)

   1. cero
   2. once herbicide
   3. twice herbicide sugar beets
   4. twice herbicide + nematicide
   1. cero corn
   2. once herbicide corn
   3. twice herbicide corn
   4. three times herbicide

5. Organic dung

   1. cero
   2. 40 m³ liquid manure
   3. 200 dt dung
   4. green manure (rape)
   5. green manure (faba and pisum)
   6. corn straw or sugar beet leaves
   7. winter wheat straw + N-fertilizer

- 320 -
Tab. 3: 1980/81 yield of winter wheat (to/ha) after different soil tillage and increasing level of chemical plant protection to the previous crop (φ organic manure)

<table>
<thead>
<tr>
<th>a) plant protection</th>
<th>previous crop corn</th>
<th>previous crop sugar beet</th>
</tr>
</thead>
<tbody>
<tr>
<td>plough rotav. grubber</td>
<td>plough rotav. grubber</td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>5.7</td>
<td>5.8</td>
</tr>
<tr>
<td>2.</td>
<td>5.6</td>
<td>5.7</td>
</tr>
<tr>
<td>3.</td>
<td>5.8</td>
<td>5.7</td>
</tr>
<tr>
<td>4.</td>
<td>5.6</td>
<td>5.6</td>
</tr>
</tbody>
</table>

b) 1980/82 yield of winter wheat (to/ha) after different tillage to wheat and different manure to previous crop (φ plant protection measures)

<table>
<thead>
<tr>
<th>manure</th>
<th>previous crop corn</th>
<th>previous crop sugar beet</th>
</tr>
</thead>
<tbody>
<tr>
<td>plough rotav. grubber</td>
<td>plough rotav. grubber</td>
<td></td>
</tr>
<tr>
<td>1. 0</td>
<td>5.7</td>
<td>5.8</td>
</tr>
<tr>
<td>2. 4 to/ha lign.man.</td>
<td>5.6</td>
<td>5.6</td>
</tr>
<tr>
<td>3. dung (20 to/ha)</td>
<td>5.7</td>
<td>5.7</td>
</tr>
<tr>
<td>4. green man. (cruzif.)</td>
<td>5.6</td>
<td>5.7</td>
</tr>
<tr>
<td>5. green man. (legumes)</td>
<td>5.7</td>
<td>5.7</td>
</tr>
<tr>
<td>6. sugar beet leaves or corn straw</td>
<td>5.7</td>
<td>5.6</td>
</tr>
<tr>
<td>7. straw of wheat + N fert.</td>
<td>5.7</td>
<td>5.8</td>
</tr>
</tbody>
</table>

| φ | 5.7 | 5.7 | 5.8 | 5.0 | 4.7 | 4.8 |

c) 1981/1 yield of winter wheat (to/ha) after different soil tillage and increasing level of chemical plant protection to the previous crop (φ organic manure)

| previous crop corn | previous crop sugar beet |
| plough rotav. grubber | plough rotav. grubber |
| 1. | 5.4 | 5.1 | 5.0 | 5.2 | 4.9 | 5.4 |
| 2. | 5.2 | 5.2 | 5.0 | 5.1 | 4.8 | 5.3 |
| 3. | 4.9 | 4.9 | 4.3 | 5.4 | 5.2 | 5.4 |
| 4. | 5.0 | 4.8 | 4.4 | 5.4 | 5.2 | 5.3 |

| φ | 5.1 | 5.0 | 5.0/4.3 | 5.3 | 5.0 | 5.25 |

d) 1981/2 yield of winter wheat (to/ha) after different tillage to wheat and different manure to the previous crop (φ plant protection measures)

| previous crop corn | previous crop sugar beet |
| plough rotav. grubber | plough rotav. grubber |
| 1. | 4.9 | 4.8 | 4.6 | 5.1 | 4.8 | 5.2 |
| 2. | 5.2 | 5.1 | 4.7 | 5.4 | 5.1 | 5.5 |
| 3. | 5.6 | 5.3 | 5.1 | 5.5 | 5.2 | 5.6 |
| 4. | 5.2 | 5.0 | 4.7 | 5.1 | 4.8 | 5.2 |
| 5. | 5.3 | 5.0 | 4.8 | 5.3 | 5.1 | 5.4 |
| 6. | 4.9 | 4.8 | 4.5 | 5.6 | 5.1 | 5.3 |
| 7. | 4.9 | 4.8 | 4.6 | 5.2 | 4.9 | 5.3 |

| φ | 5.1 | 5.0 | 4.7 | 5.3 | 5.0 | 5.4 |
In this conference I cannot speak about all the results of all the factors we changed in this experiment, and not about the yields of sugar beet and corn after these different measures, but only about the results on the yield of wheat in 1980 and 1981 (Tab.3).

The results show in 1980, it was the first year of the experiment, that the effect of the crop is dominant about all measures, but that there is an effect of soil tillage after those crops, where harvesting destroys the soil structure more than at the other ones. No significant effect of the different plant protection measures or manuring measures to the preliminary crop could be found.

In the second year, 1981, the difference in winter wheat yield is much more influenced by the interaction between tillage, preliminary crop and plant protection or manuring measures than in 1980. The effect of dung, 200 dt/ha, is dominant (see Tab.3), and intensive plant protection and grubber lowers yield after corn more than the plough or the rotavator.

In 1982 perhaps we will have a more accumulating effect than in 1981, as can be seen in the following crop rotation plan. So we hope to inform you in 1985 some more about this and the reason of the differences in yield of wheat and/or sugar beet as well as corn.

Crop rotation from 1979 to 1985:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>wheat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>corn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>wheat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>corn</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>beets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Literature:

Kahnt, G.: Gründüngung, 1981, Ulmer Verlag
Abstract
Data from several field experiments on clay soils in Norway indicate interactions between nitrogen fertilization and soil cultivation treatments. Increasing depths of ploughing from 12 cm to 24 cm increased yields of grain only at low and medium nitrogen levels, while there was no effect of deeper ploughing than 18 cm at high N level (150 kg N per ha). Increasing ploughing depths decreased weed infestation of coach grass (Elytrigia repens L. Nevski) only up to 18 cm. There was a clear increase in coach grass cover with increasing N fertilization, but no interaction in this case. Increasing intensity of soil cultivation from 1 to 3 passes with an S-tine cultivator coupled with an increase in cultivation depth from 4 to 12 cm increased yields of grain at the lowest N level. At the highest N level the yield increase stopped with the 2 passes treatment. There was a more pronounced decrease in coach grass infestation with intensity of cultivation than with increased ploughing depth. The decrease in coach grass cover was much less from 2-3 cultivations than from 1-2. There was no significant interaction with nitrogen.

Compaction of wet soil increased the weed infestation with coach grass. The infestation with sowthistle (Sonchus arvensis L.) was stronger for wet soil cultivation than for wet soil compaction. This weed seemed to thrive in a loose, coarse cloddy soil. In another soil compaction experiment negative autumn compaction effects on yields were alleviated by higher N application while this was not achieved for spring compaction. The weed infestation with coach grass increased with increasing N-application and was absolutely highest for the spring compaction at high N level.

Early sowing of spring grain crops had a very favourable effect on yield as well as a strong negative effect on coach grass.

Introduction
Effects of soil compaction on soil and crop characteristics have been extensively treated by Barnes et al. (1971). Later, Soane et al. (1981a, 1981b) have written a comprehensive review on compaction by agricultural vehicles. The ISTRO conferences 1962, 1965, 1970, 1976 and 1979 have trea-
Interactions of soil cultivation and nitrogen fertilization

In his book "Ackerbau ohne Pflug" Kahnt (1976) stated that there is an interaction between ploughing depth and nitrogen. This interaction would imply that deep ploughing would yield higher than shallow ploughing where no nitrogen fertilizer had been applied. The optimum ploughing depth would decrease with increasing N-fertilization.

In a long term soil tillage experiment at Ås, Norway, situated at the Agricultural University of Norway 59°40'N 10°46'E, this interaction has been investigated. The experiment was started in 1939. After 1962, 3 dressings of nitrogen and 3 treatments of rotary cultivation have been added to the original 3 ploughing depths and 3 cultivation intensities. The soil is a silty clay loam with approximately 6% organic matter on top of a clay loam subsoil. Results for the years 1975, 1978 and 1979 were compiled. (The experiment was in grass 1976-1977.) Crop yields are given in table 1.

Table 1. Yield of grain, kg per hectare, in an experiment with ploughing depth and nitrogen fertilization at Ås, Norway.

<table>
<thead>
<tr>
<th>Ploughing depth</th>
<th>N, kg/ha</th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 cm</td>
<td></td>
<td>3730</td>
<td>4690</td>
<td>5120</td>
<td>4510</td>
</tr>
<tr>
<td>18 cm</td>
<td></td>
<td>4070</td>
<td>4980</td>
<td>5400</td>
<td>4810</td>
</tr>
<tr>
<td>24 cm</td>
<td></td>
<td>4200</td>
<td>5100</td>
<td>5410</td>
<td>4900</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>4000</td>
<td>4920</td>
<td>5310</td>
<td></td>
</tr>
</tbody>
</table>

An increase in ploughing depth from 18 cm to 24 cm increased the yield by 130 kg/ha at the lowest N level while the same increase in ploughing depth increased the yield by only 10 kg/ha at the highest level of nitrogen.

It is of some interest to study the interaction of ploughing depth x N on the coach grass (Elytrigia repens L., Nevski). The results are given in table 2.

Table 2. Percent ground cover by coach grass in an experiment with ploughing depth and nitrogen fertilization at Ås, Norway.

<table>
<thead>
<tr>
<th>Ploughing depth</th>
<th>N, kg/ha</th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 cm</td>
<td></td>
<td>14</td>
<td>14</td>
<td>19</td>
<td>16</td>
</tr>
<tr>
<td>18 cm</td>
<td></td>
<td>6</td>
<td>9</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>24 cm</td>
<td></td>
<td>6</td>
<td>8</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>9</td>
<td>10</td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>

There was no significant interaction in this case. The coach grass coverage has been reduced by an increase in ploughing depth from 12 to 18 cm, but there is no further decrease in the...
coach grass coverage by a further increase in ploughing depth. Further, there was no significant increase in weed population by the first increase of N application, while a further increase of N application from 100 to 150 kg/ha increased the coach grass coverage by 4%.

In the same experiment the interaction of cultivation depth and nitrogen has been investigated. The cultivation treatments were carried out with a narrow S-tine cultivator, with spacing 6 cm. The treatments were:

- A-1 cultivation to 4 cm
- B-1 " 4 " + 1 cultivation to 8 cm
- C-1 " 4 " + 1 " 8 " + 1 " 12 "

Results on yields are given in table 3.

Table 3. Yield of grain, kg/ha, in an experiment with cultivation and nitrogen fertilization at As, Norway.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N, kg/ha</th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3860</td>
<td>4160</td>
<td>4630</td>
<td>4220</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>4010</td>
<td>4810</td>
<td>5400</td>
<td>4740</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>4220</td>
<td>5140</td>
<td>5410</td>
<td>4920</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>4030</td>
<td>4700</td>
<td>5150</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It is seen that for the lowest application of nitrogen, the highest yield is obtained for the most intensive cultivation treatment, while for the highest N application, the yield is the same for both treatments B and C. On the average, the increase in cultivation intensity from one to two cultivations coupled with an increase in depth of cultivation from 4 to 8 cm has increased the yield by 520 kg grain/ha while a further increase in intensity from 2 to 3 operations coupled with an increase in depth from 8 to 12 cm, has increased the yield with only 180 kg per ha. The reason for the discrepancy in N effects between tables 1 and 3 is that only half of the cultivation treatments were included in table 3, while all were included in table 1. The treatments not included in table 3 were the rotary cultivator treatments.

The effects of intensity of cultivation and N on the coach grass cover is demonstrated in table 4.

Table 4. Percent ground cover of coach grass in an experiment with cultivation and nitrogen fertilization at As, Norway.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N, kg/ha</th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>18</td>
<td>28</td>
<td>40</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>7</td>
<td>12</td>
<td>20</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>4</td>
<td>9</td>
<td>14</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>10</td>
<td>16</td>
<td>25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
There was no significant interaction for the weed cover. It is a very clear decrease in coach grass cover from treatment A to B and a rather small effect of increasing the harrowing intensity further. For nitrogen the increasing weed problem with increasing nitrogen application is apparent. The remaining half of the cultivation experiment included the depths 4-8-12 cm of rotary cultivation (only one operation for each treatment). Here, the coach grass cover was significantly smaller, and the shallowest depth gave sufficient weed control.

Effects of soil compaction and interaction between soil compaction and nitrogen

Some results from a soil compaction experiment on loam soil at As will be discussed in the following. In table 5 yields of grain and plant cover of perennial sowthistle (Sonchus arvensis) and coach grass are given.

Table 5. Yields and weed cover in a soil compaction experiment on a loam soil at As, Norway.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yields kg/ha</th>
<th>Weeds, plants/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Cultivation, wet soil</td>
<td>2360</td>
<td>17</td>
</tr>
<tr>
<td>B Cultivation and compaction, moist soil</td>
<td>2020</td>
<td>31</td>
</tr>
<tr>
<td>C Cultivation and compaction, moist soil</td>
<td>2470</td>
<td>7</td>
</tr>
<tr>
<td>D Cultivation and compaction, moist soil</td>
<td>3670</td>
<td>6</td>
</tr>
</tbody>
</table>

Wet soil corresponded to soil moisture tension in 5 cm depth of 50 mbar or less, while moist soil corresponded to 70 to 500 mbar at this depth. At 20 cm depth the wet treatment corresponded to a soil moisture tension of less than 50 mbar and the moist treatment to 50-300 mbar. The cultivation was carried out with an S-tine cultivator as mentioned earlier, and the compaction by a tractor with 1800 kg mass, being driven wheel track by wheel track.

The results indicate somewhat different reactions by the two weeds. The sowthistle increased its coverage in the coarse, not compacted seedbed (A) while compaction in addition (B) did not have the same effect. Amount of coarse aggregates in the upper 5 cm was 61-69-49-44% for the treatments ABCD. The coach grass was promoted by a more dense soil, especially by the wet compaction. Shear strength measurements in the 0-10 cm depth gave values of 80-140-70-90 kPa for the treatments ABCD. But, the main reason for the increase in weed population is of course the lower yields of cultivated crops on plots with coarse/dense soil structure.

Another experiment with soil compaction before ploughing in autumn and before cultivation in spring resulted in a significant interaction between N and compaction for yields as demonstrated by table 6.
Table 6. Yields of grain kg/ha, in a soil compaction x nitrogen experiment on a clay loam soil at As, Norway.

<table>
<thead>
<tr>
<th>Compaction</th>
<th>Nitrogen, kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>47</td>
</tr>
<tr>
<td>A Control</td>
<td>3220 3720 3940 3630</td>
</tr>
<tr>
<td>B Spring</td>
<td>2640 2900 3210 2920</td>
</tr>
<tr>
<td>C Autumn</td>
<td>2890 3590 3930 3470</td>
</tr>
<tr>
<td>Mean</td>
<td>2920 3400 3690</td>
</tr>
</tbody>
</table>

Increasing amounts of nitrogen reduced the negative effects of autumn compaction. It is seen that the A and C yields are almost exactly the same for the highest N application. For the spring compaction, B, the difference to A increased with increasing N application. This indicates that nitrogen application did not alleviate the negative effects of soil compaction at sowing time. After the compaction treatment stopped, this negative effect of compaction in spring was maintained for two years. The coach grass coverage during these two after-effect years is given in table 7. It must be mentioned that the N-treatment continued.

Table 7. Coach grass cover in percent in soil compaction x N experiment for two years after stopping compaction treatment, As, Norway.

<table>
<thead>
<tr>
<th>Compaction treatment</th>
<th>Nitrogen, kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40</td>
</tr>
<tr>
<td>A Control</td>
<td>11 13 21 15</td>
</tr>
<tr>
<td>B Spring compaction</td>
<td>16 23 31 23</td>
</tr>
<tr>
<td>C Autumn compaction</td>
<td>8 13 19 13</td>
</tr>
<tr>
<td>Mean</td>
<td>11 16 23</td>
</tr>
</tbody>
</table>

The interaction was not significant for the coach grass cover. Increasing amounts of N increased significantly the coach grass cover for all compaction treatments. Also, the spring compacted soil had a significant higher coach grass cover than the autumn treated plots. These results indicate that when the soil is loosened and turned after the compaction, as in treatment C, increasing amounts of N may alleviate the negative yield effects of compaction, while this is not the case for spring compaction. When growth conditions are not suitable for the cultivated plants, the weed population tends to increase. It may be mentioned that during the compaction treatment period the air porosity at pH 2 was 17-10-13 volume percent for A-B-C treatments. Other results from these two compaction experiments are given in Njøs (1976).

Sowing time

Under Norwegian climatic conditions the length of the growth period is limiting for plant production. Early sowing is important for summer grain crops, such as barley, oats, wheat. An experiment on a loam soil with an organic matter content of 5-6% in the plough layer was started in 1970. Results for yields and weed cover were summarized after 10 years. Barley
Hordeum vulgare L., var Gunilla) and oats (Avena sativa L., var Mustang) were grown every second year. In table 8 are given the yields of grain and cover of coach grass.

Table 8. Yields of grain and cover of coach grass 1970-79 in an experiment with sowing time. Ploughed in autumn. As, Norway.

<table>
<thead>
<tr>
<th>Sowing time</th>
<th>Grain, kg/ha</th>
<th>Coach grass,%</th>
</tr>
</thead>
<tbody>
<tr>
<td>No cultivation</td>
<td>No cultivation</td>
<td>No cultivation</td>
</tr>
<tr>
<td>Limited bearing capacity</td>
<td>3670</td>
<td>4420</td>
</tr>
<tr>
<td>First crumbling</td>
<td>3100</td>
<td>3830</td>
</tr>
<tr>
<td>2-3 weeks after 1</td>
<td>3130</td>
<td>3920</td>
</tr>
<tr>
<td>2-4 weeks after 3</td>
<td>1680</td>
<td>2800</td>
</tr>
</tbody>
</table>

Sowing time 1 ranged from 1-20 April in 1970-79.

The cultivations for seed bed preparation were carried out by means of an S-tine cultivator with tine spacing 6 cm. The second sowing time was considered the proper time according to soil structure. But it is seen from the table that the earliest sowing although on the slightly wet side gave the highest yields and the smallest weed problem. Even without seed bed cultivation the earliest sowing resulted in reasonably high yields and low weed infestation with coach grass. Although the first sowing time may be a bit rough on the top soil the weather is normally cool and small showers may come from time to time. The top layer may be softened by night frosts. Thus as long as the first sowing time is in the very cool period with air temperatures during daytime generally 0-10°C and soil temperatures in the 5 cm depth around 0-5°C there is much less influence of soil structure on the emergence than in a warmer, drier period at a later state. Often, more than 3 weeks may pass before the grain is emerging. Still the yields come out higher from this treatment than from any other, and the weed control (perennial weeds) is good. It has been observed in soil compaction on grassland that increased number of silage cuts and increased soil compaction tend to decrease grass silage yields and increase the population of coach grass and dandelion (Taraxacum officinale).

Reference


1981b. Compaction by agricultural vehicles; A review. II. Compaction under tyres and other running gear. Soil & Tillage Research 1:373-400.
SPRING SEEDBED CONDITIONS FOR SILAGE CORN ON SANDY SOILS IN THE NETHERLANDS

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Abstract

It was attempted to determine the various influences of a range of soil moisture contents, bulk densities and penetration resistances, as a function of both soil moisture and bulk density, on the imbibition process, time from planting to 50% emergence, ratio of emerged seedlings to planted seeds and dry matter yield of corn in a sandy soil. Field and laboratory experiments showed that the imbibition process was independent of the bulk density around the seed, that increasing soil penetration resistance beside and under the seed affected adversely early growth characteristics after germination, and that an optimal range of bulk densities could be indicated for compacting a late spring plowed sandy soil prior to planting.

INTRODUCTION

In the Netherlands the acreage of silage corn has increased rapidly during the last decade up to 20% of the total arable area in 1980. High market prices for fodder, new high yielding varieties, adapted to short growing season, and the necessity to get rid of large amounts of liquid manure, stimulated this growth. Since the farmer wants to spread his liquid manure as long as possible, land for silage corn is often ploughed shortly before planting in late spring, leaving no time for natural settling of the soil. As spreading of manure involves traffic with heavy equipment on the land, the compacted soil is loosened to depths of 35 to 40 cm prior to planting. Deep loosening just before planting requires artificial settling of the soil by furrow packers, rollers or driving in closed passes over the field (2). This is thought to improve moisture availability by capillary transport, by a reduced resistance of moisture flow and a better seed-moisture contact during
germination. In an effort to update Extension Service recommendations for spring tillage and seed-bed preparation for silage corn on sandy soils, field and laboratory experiments were carried out. The effect of soil compaction on soil moisture and on soil bulk density was determined by measuring soil penetration resistance, emergence, DM yield and corn seed imbibition. In the following a summary is presented, giving the general outline of the experiments and a discussion based on part of the results obtained.

RESULTS AND DISCUSSION

I. Two-year field experiment

The field experiment carried out over two seasons (1979, 1980) dealt with the response of silage corn to three ploughing times with natural and artificial settling of the ploughed layers in a sandy soil. Detailed description and results can be found elsewhere (3, 5). Let us consider the moment that the seed is placed in a soil environment with different soil physical properties, irrespective of how those seedbed conditions were obtained prior to planting. In Table I field data are arranged in groups of similar bulk densities with their corresponding soil moisture contents and soil penetration resistances. Weather conditions for the month of May and plant responses are also given.

In the wet spring of 1979 best seedling stand was obtained with seeds planted in a soil environment having a relatively high soil moisture content and a penetrometer resistance below 1.0 MPa. Compacting the soil around the seed, by driving over the seed-row, to a bulk density of more than 1600 kg.m$^{-3}$ delayed time for 50% seedling emergence by 14 days and reduced the ratio of emerged seedlings to planted seeds seriously, resulting in a reduction of final dry matter yield.

In the dry spring of 1980, soil bulk density of the root-bed of about 1450 kg.m$^{-3}$ was associated with a somewhat better soil moisture supply than that of 1300 kg.m$^{-3}$, though emerged seedling ratio was generally low, probably as a result of low soil moisture content resulting in high soil penetration resistances. Highest dry matter yield fell by 7% compared to that of 1979.

Field data indicated at an increased penetration resistance of the soil around the seed, caused either by high soil bulk density and/or by low soil moisture content, could likely be a significant factor to delay seeding emergence and reduce seedling emergence ratio to planted seeds. A more definite answer concerning those relationships was obtained by a laboratory experiment.
Table I  Soil properties at 5 cm depth at planting time, and plant response in the 2-year field experiment

<table>
<thead>
<tr>
<th>Year</th>
<th>Weather</th>
<th>Average soil temp. at 5 cm (May)</th>
<th>Seed depth, cm</th>
<th>Bulk density, kg.m(^{-3})</th>
<th>Soil moisture, % v/v</th>
<th>Penetrometer resistance at 5-10 cm, MPa</th>
<th>Ratio* emerged seedlings to planted seeds</th>
<th>Relative** DM yield, (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>Wet</td>
<td>11.6°C</td>
<td>5</td>
<td>1610</td>
<td>24.3</td>
<td>1.5</td>
<td>0.55</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>Wet</td>
<td>ca 5</td>
<td>1630</td>
<td>24.5</td>
<td>1.3</td>
<td>0.58</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wet</td>
<td>ca 5</td>
<td>1650</td>
<td>25.3</td>
<td>1.6</td>
<td>0.62</td>
<td>82</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dry</td>
<td>11.1°C</td>
<td>1280</td>
<td>20.7</td>
<td>0.6</td>
<td>0.87</td>
<td>96</td>
<td></td>
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<tr>
<td></td>
<td>Dry</td>
<td>ca 5</td>
<td>1310</td>
<td>22.4</td>
<td>0.7</td>
<td>0.81</td>
<td>99</td>
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</tr>
<tr>
<td></td>
<td>Dry</td>
<td>ca 5</td>
<td>1360</td>
<td>22.0</td>
<td>0.9</td>
<td>0.82</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td>ca 5</td>
<td>1440</td>
<td>14.1</td>
<td>1.7</td>
<td>0.72</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td>ca 5</td>
<td>1450</td>
<td>14.4</td>
<td>1.8</td>
<td>0.73</td>
<td>94</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td>ca 5</td>
<td>1450</td>
<td>14.0</td>
<td>2.0</td>
<td>0.73</td>
<td>91</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td>1320</td>
<td>12.2</td>
<td>0.9</td>
<td>0.68</td>
<td>97</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td>5</td>
<td>1320</td>
<td>12.2</td>
<td>1.1</td>
<td>0.60</td>
<td>91</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1980</td>
<td>1340</td>
<td>12.8</td>
<td>1.1</td>
<td>0.68</td>
<td>94</td>
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<td></td>
</tr>
</tbody>
</table>

*1979 planted seed density 9.9 seeds · m\(^{-2}\) = 1.00
1980 planted seed density 7.4 seeds · m\(^{-2}\) = 1.00

**1979 dry matter yield of 1150 g·m\(^{-2}\) = 100%
1980 dry matter yield of 1060 g·m\(^{-2}\) = 100%
II. Seedling emergence laboratory experiment

This follow-up laboratory experiment dealt with the effect of soil penetration resistance, as a function of bulk density and soil moisture content, on seedling emergence and early growth of corn on a sandy soil. A varied depth of planting was an additional factor to be introduced. A detailed description and results can be found elsewhere (4).

Moist sandy soil was compacted to bulk densities of 1200, 1300, 1400 and 1500 kg.m\(^{-3}\). Final soil moisture content for one serie was 25% v/v, with a soil matric potential of about -0.10 bar; for the second serie 15% v/v, with a moisture matric potential of about -0.50 bar. Corn seeds were placed in planting holes, backfilled with non-compacted soil. The relationship between penetration resistance and bulk density for the moisture contents was curvilinear, as shown in Fig. 1.

![Relationship between penetration resistance and bulk density for two soil moisture contents (% v/v).](image)

Fig. 1. Relationship between penetration resistance and bulk density for two soil moisture contents (% v/v).
Time lapse from planting to 50% seedling emergence, ratio of emerged seedlings to planted seeds and the dry matter yield, approximately 10 days after planting, as related to the penetration resistance of the soil under and beside the planting hole, are given in Table II.

Planting at depths of 2, 3.5 and 5 cm did not appear to influence the plant responses measured. The time lapse from planting to 50% seedling emergence increased linearly with an increase in penetration resistance of the soil beside and under the seed. The ratio of emerged seedlings to planted seeds, however, decreased linearly. Both plant responses interacted, only weakly, with soil moisture content. As a consequence of the influence of soil conditions on plant characteristics, increasing penetration resistance was also associated with a reduction in the dry matter yield of the seedlings, suggesting that the roots encountered increasing difficulties in penetrating the soil and in supplying the necessary moisture for early growth of the emerged seedlings. Dry matter yield response lines to penetration resistance for the two moisture contents were at different levels. Furthermore, it could be concluded that the critical limit for penetration resistance of the soil at planting depth seemed to be situated at about 0.8 to 1.0 MPa. With higher penetration resistances the ratio of emerged seedlings to planted seeds becomes unacceptably low in practice. From the relationship between bulk density and penetration resistance for two soil moisture regimes (Fig. 1), it follows that bulk density, by compacting the soil prior to planting, should not exceed 1450 kg.m\(^{-3}\) at 25% v/v moisture and 1350 kg.m\(^{-3}\) at 15% v/v moisture. This also warrants an air-filled pore space larger than 20%. It should be noted that this result applies to non-evaporative experimental conditions.

III. Imbibition of water by corn seeds laboratory experiment

From the experiment described in section II, it was not possible to establish the proportion of time taken for planted seeds, to reach 50% emergence that could be attributed to imbibition. Therefore an experiment was set up in such a way that seed batches in sandy soil, compacted to three bulk densities and three moisture regimes, could be sampled periodically to determine the increase in seed moisture by imbibition and volume of the seeds. A parallel experiment with seeds in saturated filter paper was carried out. Detailed description and results can be found elsewhere (1). The results showed that compacting this sandy soil around the corn seeds from a bulk density of 900 kg.m\(^{-3}\) to 1310 kg.m\(^{-3}\), did not significantly influence the rate of imbibition, at any
<table>
<thead>
<tr>
<th>Soil moisture (% v/v)</th>
<th>Penetration resistance (MPa)</th>
<th>Penetration resistance (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>0.20 0.61 1.07 1.73</td>
<td>0.09 0.26 0.52 1.12</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Seedling response**

1. Time from planting to 50% seedling emergence (hr.)
   - 15: 130 155 208 258
   - 25: 117 124 135 164

2. Ratio emerged seedlings to planted seeds
   - 0.97 0.92 0.73 0.58
   - 0.92 0.90 0.89 0.77

3. Dry matter yield ca 10 days after planting, (g.m⁻²)
   - 15.0 12.1 6.6 2.3
   - 17.4 17.7 16.2 10.1
given soil water potential. This raises the question as to the necessity of using pressure wheels, connected to the corn planter, on weakly aggregated sandy soils.

The time taken for the seeds to reach a seed water content of 40%, based on oven dry weight at 70°C, is given in Table III. At this seed water content corn seeds start to germinate. Imbibition of seeds in contact with saturated filter paper was terminated after 6 hours, whereas in a wet soil with a 15% to 22% v/v soil moisture content (-0.15 bar) seeds needed 13 hours imbibition time. In relative dry soil with 10% to 14% v/v soil moisture content (-1.20 bar) imbibition time was 17 hours. These imbibition times for the seeds in the two moisture regimes account for about 10% of the overall time lapse from planting to 50% seedling emergence, as can be deduced from Table II. Seed volume increase caused by swelling of the corn seeds during imbibition, was found to be linearly correlated to seed moisture content. Swelling of the seed may anyway enhance better contact between the seed-coat and the surrounding soil particles, especially when lacking at the start. Further inspection of the data of imbibition and soil moisture properties, suggested that the water flux into the seed, being caused by a large moisture matric potential gradient between seed- and soil moisture, was limited in the first place by the low permeability of the seed coat as could be shown in the case of seeds in contact with saturated filter paper. A proceeding reduction in soil water film- seed coat contact area for seeds in soil from a -0.15 to -1.20 bar soil moisture potential further restricted water flux into the seed. Moisture flux in the bulk soil in the examined range of soil moisture potentials was found to be several orders of magnitude greater than the water flux into the seeds.

CONCLUSIONS

From the laboratory experiments with a sandy soil, it was found that the imbibition time of corn seeds could not be shortened by compacting the soil around the seeds from a bulk density of 900 kg.m⁻³ to 1310 kg.m⁻³ under relative wet as well as under dry soil moisture conditions. The main restrictions controlling water movement into the seeds is the low permeability of the seed coat and the contact area between soil-water films and the seed coat. Time lapse for imbibition of corn seeds was about 10% of that from planting to 50% emergence of the seedlings.

Increased soil penetration resistance beside and under the planted corn seeds increased time from planting to 50% emergence and reduced the ratio of emerged
Table III. Seed water content (% by oven dry weight at 70°C) after various periods of imbibition related to external conditions. (Data averaged for bulk densities of soil).

<table>
<thead>
<tr>
<th>Time of imbibition (hrs.)</th>
<th>External water potential (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ca 0.00 (saturated filter paper)</td>
</tr>
<tr>
<td></td>
<td>21.4</td>
</tr>
<tr>
<td></td>
<td>24.1</td>
</tr>
<tr>
<td></td>
<td>32.8</td>
</tr>
<tr>
<td></td>
<td>32.2</td>
</tr>
<tr>
<td></td>
<td>39.5*</td>
</tr>
<tr>
<td></td>
<td>33.9</td>
</tr>
<tr>
<td></td>
<td>44.6*</td>
</tr>
<tr>
<td></td>
<td>44.4*</td>
</tr>
</tbody>
</table>

* Seeds germinated at 40% seed water content by oven dry weight at 70°C seedlings to planted seeds in a linear fashion. Soil moisture interaction was small. Dry matter yield of seedlings of about 10 days after planting was clearly reduced with increasing soil penetration resistance, but now available soil moisture determined level of the response curve. A critical limit for penetration resistance of about 0.8 to 1.0 MPa at planting depth could be defined. Laboratory experiments were carried out under non-evaporative conditions. From the field experiments it could be deduced that under the unpredictable weather conditions in spring of the Netherlands, compacting the plowed layer prior to planting to a bulk density within a range of 1300 to 1450 kg.m\(^{-3}\) seems the safest way to obtain the best seedling emergence and early seedling growth as well under wet as dry soil moisture conditions after planting. This bulk density range corresponds to a penetration resistance measured in the field of 0.8 to 1.9 MPa at planting depth, dependent on the soil moisture content at the time of measurement. Planting corn at a depth in the range of 2.5 to 5.0 cm did not affect results in the field and the laboratory experiments.

REFERENCES


6. TILLAGE IN DRY CLIMATIC CONDITIONS AND TILLAGE IN CONNECTION WITH IRRIGATION
IRRIGATION WITH BRACKISH WATER UNDER DESERT CONDITIONS
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*Regional Council - Ramat Negev, Israel

Abstract

The presentation describes the work which is being carried out at the Ramat Negev Experimental Station in the central Negev. The objective of this work is to develop new technologies allowing the use of the local brackish ground water in agriculture. Salt concentration in this water ranges from 2,300 to 5,000 parts per million.

The most critical stages in plant development under brackish-water irrigation are germination and establishment in the field. Practical methods that ensure good germination have been developed by us. They include sowing inside shallow furrows, mulching of the seed rows, and continuous leaching of the upper soil layers during germination. The drip method is especially adapted for use with brackish water irrigation for the following reasons: (a) it establishes a well leached zone under the drippers in which most of the roots develop; b) it permits daily application of water, thus water and salt stress are kept at a minimum.

Physiological studies during the growth cycle of a crop yields valuable information on factors important for production under saline-water irrigation, i.e. salt-sensitive stages, water status of the plants under salinity stress, and the possibility of the crop to adapt to salty environment. All these are instruments for devising appropriate agromanagement policies for the crop under study.
EFFECT OF TILLAGE DEPTH, WITH AND WITHOUT SUBSOILING, AND DIFFERENT LEVELS OF NITROGEN FERTILIZATION IN IRRIGATION ON THE YIELD AND QUALITY OF SUGARBEET GROWN ON THE SOILS OF HEAVY TEXTURE

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Institute of Field and Vegetable Crops,
Novi Sad;
Ratko Rozić, B.Sc.,
IPF Kikinda, Yugoslavia

ABSTRACT

In the period 1979-1981 we examined the effect of tillage depth, including subsoiling, and nitrogen fertilization on the yield and quality of sugarbeet grown on clayey soils with and without irrigation. It was concluded that a deeper tillage did not bring yield increases, especially in irrigation.

The increases in the levels of nitrogen fertilizer increased the yields but gradually reduced the percentage of sugar.

Irrigation had the highest effect on sugarbeet yields. The average increase for all variants was 6.3 t/ha or 9.1%.

Shallow tillage emphasized the effect of irrigation. Neither tillage depth nor irrigation affected the percentage of sugar.

INTRODUCTION

Sugarbeet requires light and well-structured soils due to its morphological characteristics. However, being an important raw material for the refining of sugar, sugarbeet is grown not only on loamy soils of favorable structure but also on heavy soils. This also stands for the province of Vojvodina.

We examined different tillage depths in combination with different levels of nitrogen fertilization and irrigation in order to determine optimum conditions for obtaining high and profitable yields of sugarbeet grown on the soils of heavy
texture. Results of this investigation are reported in this paper.

METHOD

The investigation was conducted in Vojvodina, the north-eastern part of Yugoslavia, on calcareous hydromorphic black soil of heavy texture.

Wheat was regularly the preceding crop to sugar beet. The tillage and fertilization with one half of the fertilizer were performed in October or November. The second half of the fertilizer was applied during planting. The investigation included the following variants:

a) Tillage depth:
- plowing at 20 cm,
- plowing at 30 cm,
- plowing at 40 cm,
- plowing at 20 cm and subsoiling at 45 cm,
- plowing at 30 cm and subsoiling at 45 cm,
- disk harrowing at 15 cm and subsoiling at 45 cm.

b) Fertilization:
1. $P_{90} K_{60} N_{80}$ kg/ha of pure nutrients,
2. $P_{90} K_{60} N_{120}$ kg/ha of pure nutrients,
3. $P_{90} K_{60} N_{160}$ kg/ha of pure nutrients.

c) Irrigation:
- with irrigation,
- without irrigation.

The irrigation practice included sprinkling performed at 65-70% FWC.

The irrigation followed the next pattern:
1979 - 50 mm on June 15, 60 mm on July 25;
1980 - 60 mm on July 24, 60 mm on August 11, 50 mm on September 10;
1981 - 60 mm on July 26, 60 mm on August 24.

We examined the sugar beet variety Monopur which was planted at the row-to-row distance of 50 cm, plant-to-plant distance of 6-7 cm and thinned after the emergence at 20 cm. The crop was protected against diseases and pests by conventional methods.
RESULTS AND DISCUSSION

The yields of sugarbeet varied from year to year in dependence of weather conditions, primarily the rainfall and its distribution during the vegetative season.

The amount and distribution of rainfall differed not only from year to year but also from month to month. The total rainfalls in the test years were 470, 541, and 614 mm. The long-term average for this region is 550 mm. The rainfalls for the vegetative seasons were 286, 282, and 338 mm, similar or somewhat higher than the long-term average. The consequence was that the yields were relatively high even without irrigation. The water shortage to the amount required by sugarbeet, which, according to Dragočić (1979), is 550 mm for this region, was supplied after the above irrigation schedule.

Tab. 1 - Effect of tillage depth, nitrogen fertilization, and irrigation on root yield (t/ha), average for 1979-1981

<table>
<thead>
<tr>
<th>In irrigation</th>
<th>Tillage depth</th>
<th>N fertilization</th>
<th>20 cm</th>
<th>30 cm</th>
<th>40 cm</th>
<th>P</th>
<th>30 cm+</th>
<th>P</th>
<th>T+P</th>
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<tr>
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<td></td>
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</tr>
<tr>
<td>N80</td>
<td></td>
<td></td>
<td>73,8</td>
<td>73,5</td>
<td>72,1</td>
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<td>72,5</td>
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<tr>
<td>N120</td>
<td></td>
<td></td>
<td>75,0</td>
<td>76,6</td>
<td>73,4</td>
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<tr>
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<td></td>
<td>80,3</td>
<td>77,2</td>
<td>78,7</td>
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</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td>76,4</td>
<td>75,8</td>
<td>74,8</td>
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<td>75,2</td>
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<td>Without irr.</td>
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<td>66,4</td>
<td>68,3</td>
<td>67,9</td>
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<td>71,2</td>
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<td>N120</td>
<td></td>
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<td>69,5</td>
<td>72,5</td>
<td>66,1</td>
<td>70,1</td>
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<td>Effect of irr.</td>
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<td>8,4</td>
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<td>Average for tillage</td>
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<td>72,2</td>
<td>73,0</td>
<td>72,6</td>
<td>71,3</td>
<td>72,5</td>
<td>70,5</td>
<td></td>
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<tr>
<td>Average for fert.</td>
<td></td>
<td></td>
<td>N80-69,9, N120-72,4, N160-73,8</td>
<td></td>
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</table>

Till. depth | N fert. | Irr. | Interaction
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>3,1</td>
<td>2,2</td>
<td>1,9</td>
</tr>
<tr>
<td>10%</td>
<td>4,1</td>
<td>2,9</td>
<td>2,4</td>
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</table>

P = subsoiling; T = disk harrowing.
Deep tillage, including subsoiling, did not bring significant yield increases. The tillage at 30 cm brought the highest average yield (73.0 t/ha), the harrowing combined with subsoiling the lowest (70.5 t/ha), but the difference was not significant at 5%. Deep tillage was more effective without irrigation. Subsoiling was ineffective in combination with either tillage or disk harrowing.

The reasons for small effects of deep tillage were that the test plots were tilled at 30 cm in the previous years and the trial was not stationary but the plots were rotated annually. In a similar trial with corn but the same soil type, Dragović (1979a) found that the tillage deeper than 25 cm increased the yields while the tillage below 35 cm had a negative effect. Similarly, Lebed et al. (1981) found that the tillage at 40-42 cm brought a lower yield than the tillage at 30 cm.

Increased doses of nitrogen brought certain yield increases. Each 40 kg/ha N more increased the yields by 2.5 and 1.4 t/ha, i.e., by square regression. There were no clearly defined interactions between the intensity of fertilization and deep tillage either with or without irrigation. However, earlier studies of Dragović (1967) indicated that the irrigation practice emphasized the effects of increased doses of nitrogen.

Irrigation brought the largest yield increases. The effect of irrigation varied from year to year but it was invariably in positive correlation with the number of irrigations performed and irrigation rate. The largest difference between the irrigated and the non-irrigated variant was found in 1980 when we performed three irrigations adding 170 mm of water - 9.1 t/ha or 15.6%. The smallest difference was found in 1981 when we performed two irrigations with 120 mm of water - 2.4 t/ha or 3.3%. In an earlier study conducted in the same region and on the same soil type, Dragović (1979) found that irrigation brought a four-year average increase of 5.2 t/ha or 9%.

The contents of sugar varied from 15.1 to 16.8%. Tillage depth did not affect this character although a tendency of increase was observed with the deepening of the tillage without irrigation, same as with the yields of roots.

The content of sugar was in a significantly negative correlation with the doses of nitrogen applied. The differences
between the variants $N_{80}$ and $N_{120}$ were significant at 5%, between $N_{80}$ and $N_{160}$ at 1%. These results confirm earlier results of Dragović (1976a).

Tab. 2 - Percentage of sugar depending on tillage depth, fertilization, and irrigation, average for 1979-1981

| In irrigation | Tillage depth | 2o cm | 3o cm | 4o cm | 2o cm+ | 3o cm+ | T+P | Average
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N fertilization</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$N_{80}$</td>
<td></td>
<td>16.5</td>
<td>16.0</td>
<td>16.3</td>
<td>16.2</td>
<td>16.3</td>
<td>16.3</td>
<td>16.2</td>
</tr>
<tr>
<td>$N_{120}$</td>
<td></td>
<td>15.6</td>
<td>15.6</td>
<td>16.3</td>
<td>16.0</td>
<td>15.4</td>
<td>15.7</td>
<td>15.8</td>
</tr>
<tr>
<td>$N_{160}$</td>
<td></td>
<td>15.3</td>
<td>15.5</td>
<td>16.2</td>
<td>15.7</td>
<td>15.1</td>
<td>15.6</td>
<td>15.6</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>15.8</td>
<td>15.7</td>
<td>16.3</td>
<td>16.0</td>
<td>15.6</td>
<td>15.8</td>
<td>15.9</td>
</tr>
<tr>
<td>Without irr.</td>
<td>$N_{80}$</td>
<td>16.0</td>
<td>16.5</td>
<td>16.3</td>
<td>16.8</td>
<td>16.4</td>
<td>16.7</td>
<td>16.4</td>
</tr>
<tr>
<td></td>
<td>$N_{120}$</td>
<td>15.8</td>
<td>16.2</td>
<td>16.6</td>
<td>16.0</td>
<td>16.2</td>
<td>15.9</td>
<td>16.1</td>
</tr>
<tr>
<td></td>
<td>$N_{160}$</td>
<td>15.8</td>
<td>15.7</td>
<td>16.2</td>
<td>15.4</td>
<td>16.2</td>
<td>15.8</td>
<td>15.8</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>15.9</td>
<td>16.1</td>
<td>16.4</td>
<td>16.1</td>
<td>16.3</td>
<td>16.1</td>
<td>16.1</td>
</tr>
<tr>
<td>Effect of irr.</td>
<td>Average</td>
<td>-0.1</td>
<td>-0.4</td>
<td>-0.1</td>
<td>-0.7</td>
<td>-0.3</td>
<td>-0.2</td>
<td></td>
</tr>
<tr>
<td>Average for tillage</td>
<td></td>
<td>15.8</td>
<td>16.0</td>
<td>16.3</td>
<td>16.0</td>
<td>15.9</td>
<td>16.0</td>
<td></td>
</tr>
<tr>
<td>Average for fert.</td>
<td>$N_{80}$-16.3,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$N_{120}$-16.0,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$N_{160}$-15.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

P = subsoiling; T = disk harrowing.

Irrigation brought a non-significant reduction in the percentage of sugar-by 0.2%. The effect of irrigation on sugar content depended in this region on the weather conditions during the vegetative season. It was found that the percentage of sugar was higher in irrigation than without irrigation in years with a higher temperature sum. These results confirmed earlier findings of Dragović (1976, 1976a). On the other hand, some authors stated that irrigation reduced the content of sugar (Dorco, 1968; Šipoš et al., 1972; etc.).
LITERATURE CITED


Dragović, S., Vučić, N.: Comparative studies of various methods in determination of water supply timing to sugar beet. 39 th Winter Congress Brisel, 1976b.


EFFECT OF TILLAGE DEPTH, FERTILIZATION, AND IRRIGATION ON THE YIELD OF ROOT AND SUGAR OF SUGARBEET

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Faculty of Agriculture, Institute of Field and Vegetable Crops, Novi Sad, Yugoslavia

ABSTRACT

A stationary field experiment was conducted on medium loamy soil on the effect of tillage depth, fertilization, and irrigation on the yield and quality of sugarbeet. The experiment lasted from 1964 to 1977. This paper reviews the results obtained in the last three years (1975-1977).

Fertilization had the highest effect on sugarbeet yield. The plots unfertilized for 11 consecutive years rendered 50% lower yields, on the average for the last three years, in relation to the fertilized variants.

The depth of tillage affected positively the yield. Compared with the tillage at 15 cm, the cultivation at 25 and 35 cm brought yield increases by 3.6 and 8.5%, respectively, in irrigation and 1.8 and 4.6%, respectively, without irrigation.

Irrigation brought significant yield increases: in combination with fertilization and deeper tillage, it brought about 10% higher yields.

The effect of the examined factors on the percentage of sugar was not as pronounced as with root yield. The percentage of sugar increased slightly with deeper tillage, decreased after manuring, but remained on the same level in irrigation.
INTRODUCTION

The province of Vojvodina, located in the northeast of Yugoslavia, is an important sugarbeet-growing region on account of its favorable soil and climatic conditions. The hectarage under this crop expands from year to year.

Although the yields of sugarbeet are generally high there, they vary in dependence of weather conditions, primarily on the amount and distribution of rainfall during the vegetative season.

The technology of sugarbeet production has been studied long. The prevailing practice includes nowadays intensive cultural practices. However, the introduction of new varieties imposes the need of permanent investigations of the basic problems of sugarbeet production, primarily the depth of tillage and the intensity of fertilization. These problems were the subject of numerous papers among which the most important ones are those written by Todorović (1957), Drezgić (1958), Mušac et al. (1971), Stanačev (1969), etc.

This paper discusses a part of the results of a complex long-term trial established with the aim of determining the optimum depth of tillage and its interactions with fertilization and irrigation.

METHOD

A stationary trial with a five-crop rotation was established in 1964. This paper reviews the results for sugarbeet in last three years of the trial (1975-1977) including the following variants:

Tillage depth: 15, 25, and 35 cm.
Fertilization: a) control (unfertilized)
   b) N_{100}P_{90}K_{60} kg/ha of pure nutrients
   c) N_{100}P_{90}K_{60} kg/ha + 40 t/ha of manure
Irrigation: - irrigated
           - non-irrigated.
The preceeding crop was winter wheat. The examined sugar-beet variety was Novi Sad poli Zuca. Cultural practices and crop protection were performed according to the experiment's program. Irrigations according to soil moisture were performed at 70% FC. The number of irrigations and irrigation rates depended on the amount and distribution of rainfall. In 1975, there was one irrigation with 60 mm, on August 7; in 1976, there were two irrigations with 60 mm, on July 11 and 22; in 1977, there was one irrigation with 60 mm, on July 17.

WEATHER CONDITIONS DURING THE TRIAL

The weather conditions during the trial were on the level of the long-term average or better. In 1975 and 1977, the rainfalls were 690 and 681 mm, respectively, or 90 and 81 mm more than the long-term average of 600 mm. In 1976, the rainfall was 577 mm or 23 mm less than the long-term average.

The distribution of rainfall during the trial was favorable. The vegetative periods had 466, 423, and 391 mm of rain, i.e., 69%, 74%, and 57% of the total annual rainfall. However, the distribution of rainfall per month of the vegetative season varied from year to year. The water shortage in relation to the requirements of sugarbeet in this region were, according to Dragović (1976), 150 mm in July and 128 mm in August. Thus, the shortage was not large and only one or two irrigation were required, as stated before.

The average annual air temperatures in 1975, 1976, and 1977 were 11.4, 10.9, and 12.0°C, respectively. There were no large differences from the long-term average (10.9°C), but the temperatures in some months of the vegetative season were higher. In 1976, the mean monthly temperature for August was 17.6°C; in 1977, it was 20.1°C. The temperatures for the other months were similar to the long-term averages.
RESULTS

Table 2 shows three-year average results of sugarbeet yields affected by tillage depth, fertilization, and irrigation.

Deeper tillage brought yield increases with and without irrigation. Still higher increases were obtained with irrigation and also without fertilization.

The results obtained in the three-year period were similar to the results from the preceding 10 years of the trial (Drezgić et al., 1972), confirming the fact that sugarbeet requires deep tillage.

<table>
<thead>
<tr>
<th>Irrigation</th>
<th>Tillage depth</th>
<th>Non-irr.</th>
<th>N100P90K60</th>
<th>N100P90K60 + manure</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated</td>
<td>15</td>
<td>27,2</td>
<td>54,9</td>
<td>58,6</td>
<td>46,9</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>29,5</td>
<td>57,3</td>
<td>59,1</td>
<td>48,6</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>32,9</td>
<td>59,0</td>
<td>60,8</td>
<td>50,9</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>29,6</td>
<td>56,8</td>
<td>59,3</td>
<td>48,5</td>
</tr>
<tr>
<td>Non-irrigated</td>
<td>15</td>
<td>28,5</td>
<td>52,7</td>
<td>54,5</td>
<td>45,2</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>29,4</td>
<td>52,9</td>
<td>55,6</td>
<td>46,0</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>31,8</td>
<td>54,1</td>
<td>56,1</td>
<td>47,3</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>29,6</td>
<td>53,2</td>
<td>55,3</td>
<td>46,0</td>
</tr>
</tbody>
</table>

Positive effect of deeper tillage on corn yield was also confirmed by this trial (Drezgić et al., 1972).

The fertilization with mineral fertilizers alone and in combination with manure had the highest effect on sugarbeet yield in this trial as well as in numerous previous experiments conducted in the country and abroad.

Mineral fertilization brought the average yield increase of 92.5-100% in irrigation and 80-87% without irrigation. The manuring brought additional increases of 2.5 t/ha in irrigation and 2.1 t/ha without irrigation, which makes 10%.

The effect of irrigation varied from year to year, depending directly on the amount and distribution of rainfall. The average increase for the whole trial was 2.5 t/ha. However, the
irrigation brought insignificant increases in the unfertilized variants while in the fertilized ones the increases were 3.6 and 4.0 t/ha, respectively, or 10.7%.

Numerous authors found interactions between fertilization and irrigation. Petinov (1966) stated that irrigation improves the efficiency on nutrient uptake. Baljabo et al. (1969) pointed out that fertilization and irrigation are the most important factors of land use. Kuzma (1972) stated that fertilization increased significantly the effect of irrigation.

The previous results of this trial (1964-1972) indicated the increases in sugarbeet yields after irrigation by 8.0 and 11.6% (Drezgic et al., 1972). In other experiments, the increases were 4.1-6.8 t/ha (Dragović, 1977) and 4.6-6.9 t/ha (Živković, 1973).

The effect of the experimental variants on the content of sugar was not as pronounced as it was with the yield of roots. There were no regularities in the effect of tillage depth although there was a general trend of increase in sugar content with deeper tillage.

Tab. 3 - Effect of the depth of tillage, fertilization, and irrigation on the percentage and yield of sugar (1975-1977 average)

<table>
<thead>
<tr>
<th>Irrigation depth</th>
<th>Tillage</th>
<th>% of sugar</th>
<th>Yield of sugar t/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>b</td>
<td>c</td>
</tr>
<tr>
<td>Irrigated</td>
<td>15</td>
<td>14.1</td>
<td>14.7</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>14.8</td>
<td>14.9</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>14.7</td>
<td>15.0</td>
</tr>
<tr>
<td>Average</td>
<td>14.9</td>
<td>14.9</td>
<td>14.2</td>
</tr>
<tr>
<td>Non-irrigated</td>
<td>15</td>
<td>14.4</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>14.4</td>
<td>14.6</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>14.9</td>
<td>15.1</td>
</tr>
<tr>
<td>Average</td>
<td>14.6</td>
<td>14.9</td>
<td>14.0</td>
</tr>
</tbody>
</table>

Mineral fertilization increased the percentage of sugar, especially without irrigation, in relation to the unfertilized variants. The manuring reduced the percentage of sugar in relation to both, the variants of mineral fertilization and the unfertilized variants. The fertilized variants and the variants of deeper tillage increased the yields of sugar on account on the increases in root yield, not in sugar percentage.

2. Dragović S.: Irrigation of sufar beet on chernozem at different nutrient levels.


Dryland Tillage Methods and Implements in Turkey
G. Kocacioglu, T. Haradin

Abstract
The fall treatments in the Central Anatolia don't show any significant effects on wheat yield. In the spring tillage treatments, the moldboard plow gives the best results. The different summer treatments do not change the yield much, but sweep-harrow combination seemed to be better on a practical basis.

Introduction
Wheat has always been the most important crop in Turkey in terms of both acreage and production. Because of its adaptation to dryland conditions, it will continue to be the most important crop as far as its occupation area and domestic needs are concerned.

Central Anatolia has a continental climate with a hot and dry summers and cold and wet winters. Its mean annual precipitation is about 400 mm and annual evaporation is 1300 mm. Its soil mainly fall into brown soil group which covers a large area in the Central Anatolia. Soil structure is granular and subsoil structure is block or prismatic. Down to the 60 cm depth the soil texture is generally clay and silt-clay and subsoil texture is clay-loam and sandy-clay.

<table>
<thead>
<tr>
<th>Soil depth</th>
<th>sand</th>
<th>silt</th>
<th>clay</th>
<th>texture</th>
<th>pH</th>
<th>organic material</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-10</td>
<td>30.2</td>
<td>30.0</td>
<td>39.8</td>
<td>CL</td>
<td>7.40</td>
<td>2.27</td>
</tr>
<tr>
<td>10-30</td>
<td>27.9</td>
<td>26.7</td>
<td>45.4</td>
<td>c</td>
<td>7.28</td>
<td>2.12</td>
</tr>
<tr>
<td>30-60</td>
<td>25.2</td>
<td>26.7</td>
<td>45.4</td>
<td>c</td>
<td>7.35</td>
<td>1.51</td>
</tr>
</tbody>
</table>

Prof. In the Department of Agricultural Engineering, Faculty of Agriculture, Ege University, Izmir, Turkey.

Assoc. Prof. In the Department of Mechanical Engineering, Faculty of Machinery, Ege University, Izmir, Turkey.
Because of the high clay content of the soil, cultivation is difficult. Especially in the Spring the soil is heavy and is not tilted easily, therefore it requires high draft force. When rainfall is insufficient to permit annual cropping, as in Anatolia, a system is applied to keep the land free of crop and weeds for the fallow period and called fallow system. This period runs from the time of harvest through a full year to the time of seeding the next fall (approximately 15 months). The purpose of this fallow system is to accumulate moisture in the root zone for the subsequent crop on alternate years.

Mechanization of agriculture has shown an immense progress in these low rainfall areas in the last 25 years. In relation with the increase in the number of tractors and plows, the wheat area jumped from 4.5 million hectares up to 8.7 million ha and the fallow area from 5.5 million ha to 9 million ha.

Tillage operations, necessary for weed control and moisture storage, help to produce a desirable seedbed. In order to determine the most suitable tillage equipments in wheat-fallow agriculture, extensively carried out in Central and South-West Anatolia of Turkey, several different experiments have been conducted.

According to the experiments conducted in the Central Anatolia by several research institutions the following verifications can be summarized.

**Fall Tillage Treatment**

In the experiments Moldboard plow (18-22 cm depth) Chisel (18-20 cm) and No-tillage have been carried out on different plots.

**Fig. 1.** The average (Fall Tillage Treatment) yields over the years 1972 to 1976 (Kg/dec)
The fall treatments don't show any significant effects on wheat yields. If the subsoiler is used for 4-6 years period, it can be useful for this particular region.

**Spring Tillage Treatment**

In the spring treatments, the moldboard plow gives the best results. Hence it is the best equipment to kill the weed, water conservation and the infiltration of the soil.

The data indicated that moldboard plow plots consistently produced slightly higher yields than the other implements. When the soil conditions are not good for cultivation, the harrow could be attached behind the moldboard.

![Diagram](image)

**Fig. 2.** The average (Spring Tillage Treatments) yields over the years 1972 to 1976 (Kg/dec)

These results are in good agreement with the results of other investigators under the same conditions. When we compare the equipment with each other, it is observed that offset disc, changed the texture of the soil and pulverized it. Due to the wind and water erosion, if these types of equipment are used the yields will be reduced.

In the spring treatment sweep has not been successful for weed control due to the risoms of the weeds.

**Summer Tillage Treatment**

In the Central Anatolia, generally hot and dry weather comes after the spring. To prevent the evaporation on the soil, summer tillage is important.
When one prepares 10 cm mulch on the field, one can hold the water in the soil and weed control and seedbed preparation become easy.

The long period experiments show that sweep harrow combination is the best summer tillage treatment. This combined treatment is economical than the others. Rod weeder also gives good results when the dry soil conditions exist. Lastly chemical treatment is the most expensive application among the three treatments.

Timing is very important in preparing a good seedbed in the heavy clay soil in Turkey. If this soil is tilled earlier, and has some moisture in the soil profile, the tillage implements will break down these large clods and a good seedbed and mulch will be formed.

Adaptive research trials were conducted on several farmer's fields in the Central Anatolia. The results indicated that it is possible to increase wheat production substantially by the application of the improved techniques, in this regions.

Fig. 3. The comparison of the farmers and improved tillage techniques in respect of yields on Central Anatolia.
Fig. 4. The comparison of the Farmers and improved tillage techniques in respect of yields over the years.

The comparisons showed that the wheat yields from adaptive research trials were 79% more than wheat yields in adjacent farmer's fields.

Literature


Abstract

In an experimental field, soil water status results from previous years under traditional management, for table olive trees, are compared with those from a new no-tillage fertigation system in a plot with 108 12-year old trees.

INTRODUCTION

Olive trees orchards in Southern Spain, as in most regions of the Mediterranean area, have been receiving not sufficient care till now. In recent years, this situation is changing rapidly, due to the high cost of fertilizers and labour, particularly in the case of table olive fields in which hand work is much involved in harvesting. In these cases intensive irrigated agriculture is a necessity.

Many methods of irrigation have been applied to olive trees orchards, either to improve natural soil water reserve in winter to overcome later extremely dry periods or as the main water supply in summer. One of the most appropriate methods for this type of plant is trickle (drip) irrigation.
Bresler et al. (1971) and Bar-Yosef and Sheikholeslami (1976) have studied in extent the distribution of water and ions in the soil and Manor (1981) has given practical advice on it.

This paper deals with soil physical data from an experiment in which a young olive grove previously managed in a traditional way has been transformed by applying fertigation to the plot.

MATERIAL and METHODS

Experimental site

Experiments have been carried out in an olive tree field of approx 0.5 Ha, including 108 12-year old trees at a normal planting distance of 7x7 m. The plot is surrounded by the general orchard of similar nature.

Main soil physical characteristics are summarized in table 1 and figs. 1, 2. The soil is classified as sandy clay loam. It is deep and well drained.

Climate is typical Mediterranean, with humid mild winters and very hot dry summers.

Tillage and management

All sites have received during the experiment and previously the same respective tillage, irrigation and fertilization, allowance having been given to plant distance in certain cases.

During previous years tillage consisted on plowing the soil, alongside between trees, to a depth of 20 cm, and reducing weeds to a minimum by the application of a weed-keeler at convenient intervals.

Fertilization consisted on the application of 2 Kg per tree of 12:12:24, in November and 0.5 Kg per tree of urea, in March, distributed on a circular area between 20 and 100 cm, around the tree trunk.
Table 1. Soil physical characteristics.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Coarse sand</th>
<th>Fine sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Bulk density</th>
<th>Hydraulic conduct.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20 cm</td>
<td>22.5%</td>
<td>39.5%</td>
<td>17.5</td>
<td>20.0</td>
<td>1.42 g/cm³</td>
<td>4.1 cm/h</td>
</tr>
<tr>
<td>20-40 cm</td>
<td>23.0%</td>
<td>40.5%</td>
<td>16.5</td>
<td>20.0</td>
<td>1.61 g/cm³</td>
<td>4.0 cm/h</td>
</tr>
<tr>
<td>40-60 cm</td>
<td>20.5%</td>
<td>40.0%</td>
<td>16.0</td>
<td>23.5</td>
<td>1.53 g/cm³</td>
<td>3.0 cm/h</td>
</tr>
<tr>
<td>60-80 cm</td>
<td>17.5%</td>
<td>40.5%</td>
<td>17.5</td>
<td>24.0</td>
<td>1.46 g/cm³</td>
<td>3.1 cm/h</td>
</tr>
<tr>
<td>80-100 cm</td>
<td>23.0%</td>
<td>38.0%</td>
<td>16.0</td>
<td>23.0</td>
<td>1.48 g/cm³</td>
<td>0.9 cm/h</td>
</tr>
</tbody>
</table>

Fig. 1. Soil pF curves.

Fig. 2. Differential porosity.

Fig. 3. Water balance.
In transformed plots, tillage has consisted on the application of a light scarifier once a year.

The fertigation water contained the following units:

\[ 1.0 \text{ N}, 0.05 \text{ P}_2\text{O}_5, 0.5 \text{ K}, 0.1 \text{ S}, 0.08 \text{ Mg} \text{ and } 0.005 \text{ Fe.} \]

Considering the average application of 4,500 l. per tree, it could be estimated a convenient dilution.

Irrigation schedule was planned based on the prevailing environmental conditions, and total water application being equivalent to approx 0.5 ETP. This value was derived from evaporation data in a class A pan and measurements of soil water content and tension at various depths in appropriate moments.

To follow water movement, a neutron probe and a series of tensiometers were used, taking into account the scope and implications of this method (Dau-det et Vachaud, 1977) and the contribution of the root system (Taylor and Kepler, 1978).

In transformed plots, needkeeler treatments have to be done more frequent and intensively than in previous years.

RESULTS

General estimates of water balance for the experimental period and previous years can be observed in fig. 3, in which the mean value from a normal precipitation and evapotranspiration is also included.

The variation of soil water content for different soil strata for the period 1979-80, taken as an example for previous years, is given in fig. 4.

In non-fertigated plots, water depletion patterns, during the dry summer period, includes two main parts, as can be observed in fig. 5. In the first one, from the beginning of water depletion till approx. middle of July (depending on the year particular climate), a large substration occurs in the top layers of the soil profile, decreasing gradually with depth. In the second part, lasting till the end of the drying cycle, if irrigation is not suffi-
Fig. 4. Water content at various depths.

Fig. 5. Contribution of each layer (%) to total water depletion: I First period, II 2nd period.

Fig. 6. Water content profiles in non-irrigated (left) and irrigated (right) plots: 1 initial, 2 at the end of period I, 3 at the end of period II.
cient, as it is usually the case under traditional management, the trees sub-
stract water progressively from deeper layers, still more humid than the top
layers, thus counterbalancing, to a certain extent, the total water depletion.

In fertigated plots, water movement may be substantially represented by
the pattern given in fig. 6. Plants are therefore in a water stress-free si-
tuation. On the other hand, fertilization is achieved in a most convenient
way, i.e., by supplying nutrients of lower concentration but during longer pe-
riods of application. This may result in a more even wetness of the soil at
the root zone.

CONCLUSIONS

The system combining minimum tillage with fertigation seems to be a promi-
sing method for young intensive olive trees plantations in modern agriculture
for the Mediterranean area.

Besides the routine check of keeping the water network distribution in
good operating conditions, tillage is practically reduced to the application
of a weed-killer at convenient moments, on and around the soil surface areas
wet by the drippers.

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"EFFECT OF SOIL PHYSICAL CONDITIONS ON CEREAL GROWTH IN S.W. SPAIN"

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ABSTRACT

This experiment was conducted to determine the influence of soil hydrophy-
sical characteristics on the growth and development of a wheat crop culti-
vated under conventional tillage practices in S.W. Spain. The experimental
period was coincident with very arid climatic conditions. Differences in soil
physical properties between the first 40 cm of soil profile and the underneath
layers were detected and attributed to tillage method. No system had its
maximum development at the upper zone, and the final grain yield attained
was considered as optimum for our region.

INTRODUCTION
For several decades a great deal of work have been carried out in order to study the influence of technical management of soil and climatic conditions on some soil physical properties, especially structure status and development, water retention and redistribution and their relations with crops growth. The latter have been studied in detail by Hill and Blewins (1973), Blewins et al. (1971), Eilers (1973) and Goss et al. (1978), among others, in the particular case of the growth of cereal plants.

It is well known that the relationships between soil physical properties, soil management and the development of a crop depend strongly upon soil type. In SW Spain a very large surface of its agricultural land is devoted to winter cereal, mostly wheat, growing normally under different kinds of soils. This fact makes that those relations vary largely in our conditions which have been in addition unusually arid in the last two years.

In this paper we try to quantify the foregoing influence of soil physical properties on the development of a wheat crop cultivated in a soil traditionally dedicated to cereals under conventional tilling practices and very arid climatic conditions. We will try to see also if under these given situations, the soil is able to hold the necessary amount of water for the normal growth of the plants.

MATERIALS AND METHODS

The study was conducted from November 1980 to June 1981 at the National Institute for Agronomic Research Farm (INIA) in Seville (37° 30' N) SW Spain. Yert, a wheat variety was cultivated on a "clay loam" Alfisol developed on Pleistocene sediments with an Ap horizon 30 cm deep. The surface of the experimental area is about one hectare and was subjected just before wheat sowing time to the following tillage practices: burying the stubble from the preceding crop (corn) with a turn-wrest plough to a depth of 40 cm, and making it again but in a perpendicular direction; then the latest work to plow twice with a disc harrow to a depth of 20 cm.
Prior to planting (January 18, 81) 54 Kg N/Ha, 192 Kg P/Ha and 54 Kg K/Ha fertilizer was applied and worked into the soil. A basal dressing of 115 and 130 Kg N/Ha was supplied one and two months later respectively.

Soil samples were taken before sowing in order to analyze its physical properties in the lab, following routine methods used in our Center. Plant height, root growth and development, and soil moisture profile evolutions, determined by gravimetric method, were recorded along the plants life cycle. Cylinder method (Böhm, 1979) was used in root system characterization, valuating root density according to Marsh (1971) procedure. Rainfall and air temperatures were recorded at experimental site as well.

CLIMATE

The experimental station is located in a zone with a typical Mediterranean climate, having moderately humid winters and dry and hot summers. The mean air temperatures varies from 10 °C in January to 25°5 °C in August. The mean annual precipitation reaches 550 mm, distributed mostly between November and March, although there are some years with very low precipitation values like 1980-81. The potential evapotranspiration rate is about 900 mm.

RESULTS AND DISCUSSION

Soil analysis results made after the foregoing tillage practices are given in Table 1. Soil texture values show that in the surface (0 - 20 cm) there is a good equilibrium between fractions, whereas below 20 cm there is a progressive increasing of the fraction less than 0.002 mm. Bulk density (Db) increases with depth, being the difference between 0 - 10 and 10 - 20 cm layers the most significative. These facts make evident that although the tillage practices were given to a depth of 40 cm, only in the top surface of the soil (0 - 10 cm) the effects were more evident.

The hydraulic conductivity (Ks) values measured under saturated conditions
are in accordance with textural and structural soil characteristics, already discussed, the linear extensibility coefficient (COLE) value shows that swelling-shrinkage process is only moderate. Data for individual sampled points within the plot were not significantly different, so the soil can be considered as uniform along the experimental plot.

Water retention curves (Fig. 1) showed a similar trend in each depth analyzed, increasing water holding capacity with depth until 20 cm, and having a more uniform relation in deeper points. According to these results, the amount of available water ranged from 0.10 to 0.14 cm^3 cm^{-3}. This volume represents an optimum for the cultivated soils in our region and agrees with the results reported by Moreno et al. (1981).

It is important to say that the experimental period was coincident with very arid climate conditions (140 mm of total rainfall from December 1980 to July 1981). As far as soil moisture profile evolution is concerned, we can separate two different situations as shown in Fig. 2: in the first, the top 40 cm of soil profile are most of the time between field capacity and wilting point, but closer to the latter; the second situation corresponds to the soil profile to a depth below 40 cm and shows a water content value near to wilting point or even lower, which is understandable taking under consideration the increasing of dry content with depth, and the difficulty for water displacement from pores underneath the plowed zone and deeper than 40 cm. These facts are similar to those reported by Boss et al. (1970).

When comparing moisture profile evolutions and rainfall distribution, one can see in Fig. 2 as the initial profile (dated at 23-XII-80) sampled after the mild autumn precipitation (1980 was also a very dry year with only 300 mm of rain) changes toward the situation reached at 22-I-81 where the soil available water is higher in the first 40 cm, being below this depth always lower than the in wilting point. The light rain fallen in February does not imply that in a short period of time, the mean soil water content decreases below wilting point as shows profile 2-III-81.
Table 1

Some physical properties of soil

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Particle size (mm)</th>
<th>Dp</th>
<th>Db</th>
<th>Ks</th>
<th>QUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>0.2-0.02</td>
<td>39.5</td>
<td>18.0</td>
<td>34.5</td>
<td>1.33</td>
</tr>
<tr>
<td>10-20</td>
<td>0.02-0.002</td>
<td>38.5</td>
<td>19.0</td>
<td>34.5</td>
<td>1.50</td>
</tr>
<tr>
<td>20-40</td>
<td>0.002</td>
<td>33.5</td>
<td>19.5</td>
<td>42.0</td>
<td>1.54</td>
</tr>
<tr>
<td>40-50</td>
<td></td>
<td>24.5</td>
<td>21.0</td>
<td>50.0</td>
<td>1.55</td>
</tr>
</tbody>
</table>

Fig. 1  pH-curves for soil at different depths

Fig. 2  Evolution of water content profiles

Fig. 3  Distribution of rainfall profiles
Water extraction by plants in the first growth stage contributes in a considerable way to the mentioned soil desiccation process. Afterwards, the soil water content increases due to sprinkler irrigation (13-III-81) that supplied 35 mm of water and precipitations. Plant water extraction continues increasing and the final soil water is going to be lower again (see situations dated 1-IV-81 and 10-V-81 in Fig. 7).

It is interesting to point out that during the experimental period we recorded a very high volume of 200 mm, which is a very high volume when comparing with normal years.

The evolution of plant height and root density is given in Fig. 4, that shows as more than 50% of the root system is located in the first 15 cm of depth, which agree with soil bulk density values listed in Table 1. The regression coefficient values between these two variables were -0.9887, -0.9729 and -0.9942 for the three growth stages shown in Fig. 4 respectively, making the...
dent that there is an increasing of soil mechanical impedance with depth. As a result of the tillage practice and soil disecration, a soil compaction phenomenon was observed after harvest time, increasing soil bulk density to 1,50 g.cm$^{-3}$.

According to the foregoing comments we can conclude that 1°) the conventional tillage practices and the small amount of water supplied by irrigation and rainfall were considered appropriate to reach a good final yield of 4000 Kg/Ha optimum for our region, and 2°) the soil physical conditions allowed that mostly of the root system developed in the first 20 cm of depth.

ACKNOWLEDGMENT

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LITERATURE CITED


EFFECT ON CALCAREOUS IRREGATED SOIL CHEMICAL PROPERTIES OF SUGARCANE PERMANENCE TIME AFTER TILLAGE

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ABSTRACT

An irrigated calcareous soil was tilled in peruvian sugarcane conventional form, that means, two disk harrowings (at 20 and 30 cm depth, respectively) coarse grading, two subsolings (at 65 and 85 cm depth), fine grading, and furrowing. A portion of experimental field was planted with H32-8560 cultivar and 3 cuttings of 18 months each in average were obtained. Another, was not initially planted for making it after and obtaining 2 cuttings of the same cultivar. The same procedure was followed in another portion and 1 cutting was obtained. The rest of the field was not planted with sugarcane. At the end of the last harvesting, soil was disk plowed at 30 cm depth and furrowed. Before planting sugar cane cultivar H57-5174 soil chemical characteristics determinations were made.

Results shows that soil nutrients are more concentrated in surface layer, because peruvian sugarcane conventional tillage does not cause inversion of the soil by ploughing. That sugarcane permanence time after tillage does not influence soil chemical condition. Monoculture of sugarcane produces a gradually impoverishment of K in the soil. And, that tillage effects on soil nutrients or chemical properties are made manifest only if there is tillage influence on soil physical conditions.

INTRODUCTION

In the last years minimum tillage techniques have been strong developed (Barker and Wünsche, 1977; Cannel et al., 1978; Gowman et al., 1978). Minimum tillage has been developed also in sugarcane (Hadlow and Millard,
although some authors state that tillage is necessary for reducing soil compaction effects. Compaction is produced in clayed soils, high moisturized and principally as a consequence of heavy harvesting machines utilisation (Fernandes et al., 1981; Georges, 1980; Maud, 1960; Ricaud 1977; Yang, 1977; Trouse and Humbert, 1961; Hadlow and Killard, 1977).

Lack of rains and poor development of drip or sprinkling irrigation in peruvian sugarcane makes zero tillage impossible to do, because furrowing for conducting water is necessary. Moreover, elimination of sprouted canes of precedent cutting is a problem because they do only after first irrigation with scarce water. Being the last problem resolved, the possibility that conventional tillage (which includes subsoiling) was not the most convenient system was stated.

Although improvement of soil physical conditions by conventional tillage, and its permanence, is questioned in peruvian sugarcane conditions, changes in soil chemical properties are totally unknown.

MATERIALS AND METHODS

Experimental soil is alluvial, middle textured, of high exchange capacity, alkaline, calcareous, poor in total nitrogen and organic matter, medium to well provided in P and K. Experimental field was prepared in peruvian sugarcane conventional form (Morales, 1975), with the slight variations for Casa Grande (Zanatti, 1974), that means two disk harrowings (at 20 and 30 cm depth, respectively), coarse grading, two subsoilings (at 65 and 85 cm depth), fine grading, and furrowing. A portion of experimental field was planted with H32-8560 cultivar and 3 cuttings of 18 months each in average were obtained. Another was not initially planted for making it after and obtaining 2 cuttings of the same cultivar. The same procedure was followed in another portion and 1 cutting was obtained. The rest of the field was not planted with sugarcane. At the end of the last harvesting, minimum tillage was applied in land preparation, consisting in disk plowing at 30 cm depth and furrowing. Treatments were therefore: 1) Conventional tillage; 2) Conventional and 1 sugarcane cutting; 3) Conventional and 2 cuttings; 4) Conventional and 3 cuttings.

Samplings were made at 2 depths in 2 locations per experimental plot. If Ap1 horizon was thick enough, it was subdivided into two (Ap1 and Ap2) for samplings and observations; is for that reason that Ap2 horizon has normally very few observations. Disturbed samples for structure stability
measures and physical and chemical characteristics determination were taken too. In present paper, results obtained with soil chemical analysis will be discussed.

RESULTS AND DISCUSSION

It can be seen in table 1 that soils are non saline and have a pH uniformly distributed with depth. Also that Organic Matter, Total and Available N, C/N ratio, and interchangeable cations, decrease with depth, which is expected, because peruvian sugarcane tillage does not cause inversion of the soil by ploughing. Variance analysis did not show significant differences for any characteristic before mentioned, which is in contraposition with Baeumer and Bakermans (1973) who found that minimum tillage increases the total organic matter of the soils; but is in agreement with Ellis and Howe (1980) who did not find significant influence of variations in the degree of soil disturbance before planting over calcium content, pH or organic matter. These results indicate that sugarcane permanence time after tillage does not influence soil chemical conditions, and this is probably due to the close relation between physical and chemical properties with regard to tillage effects on soils (Parish, 1971; Kemper et al., 1971; Rowse and Stone, 1980). In the same soil Pinna et al. (1983) found that sugarcane per
manence time after tillage does not influence soil physical characteristics in a permanent way.

In Fig. 1 it is showed that $\text{CaCO}_3$ decreases significantly with cane permanence after tillage. We do not know the explanation of this behaviour, but we do not think that it is due to sugarcane roots effect on soil physical or chemical properties; it could be possible that $\text{CO}_2$ produced by abundant roots, dissolved $\text{CaCO}_3$ making it easier to be leached.

![Calcium Carbonate](image1)

![Interchangeable Potassium](image2)

![Available Phosphorus](image3)

Fig. 1. Calcium carbonate, interchangeable potassium and available phosphorus measures for Ap1, Ap2 and C horizons. Variance analysis is indicated by: $\times \times$ highly significant differences between treatments; $\times$ significant differences; NO, no differences.

Calcium carbonate, interchangeable K, and available P contents are lesser in C horizon than in Ap1 (according with Baeumer and Bakermans, 1973; and Ellis and Howse, 1980), confirming that if soil is not inversed by ploughing, nutrients are more concentrated in surface layers (Ellis and Howse, 1980).

Interchangeable K decreases highly significantly with sugarcane permanence after tillage in Ap1 and C horizons, do not being statistical differences for Ap2 layer (Fig. 1). Like for $\text{CaCO}_3$, we do not believe that this is due to sugarcane effects on soil physical conditions and, as a consequence, on soil chemical properties, because if there was, this influence should be the contrary (Baeumer and Bakermans, 1973). Rather, it is possible that soil K decrement is due to its absorption by sugarcane, which is
a crop that requires high amounts of K for normal production (Humbert, 1968), in peruvian sugarcane soils K fertilizers applications are not made, because they are well provided in this element, and well furnished by irrigation water (Pinna and Valdivia, 1977), but results of this experiment shows that monoculture of sugarcane produces a gradually impoverishment of K in the soil.

Fig. 1, shows significant differences of available P for Ap1 layer, but do not for Ap2 and C. It can be seen that in surface horizon sugarcane time permanence after tillage did not influence soil phosphorus during 2 cuttings, for reducing its contents after. This is in disagreement with Baeumer and Bakermans (1973) and Ellis and Howse (1980) results. This phenomenon has not any logic, and it is certainly due to soil variability, which is made manifest by the fact that there are no significant differences in the other layers, and by the high variation coefficients (59.73, 146.69 and 74.83% for Ap1, Ap2 and C horizons, respectively).

From the discussion of Fig. 1, it can be concluded, that CaCO3, K and P variation are not due to direct tillage effects, or structural modifications by sugarcane roots after tillage; confirming that tillage effects on soil nutrients or chemical properties are present only if there is tillage influence on soil physical conditions (Kemper et al., 1971; Parish, 1971).

CONCLUSIONS

(1) Soil nutrients are more concentrated in surface layers, because peruvian sugarcane conventional tillage does not cause inversion of the soil by ploughing. (2) Sugarcane permanence time after tillage does not influence soil chemical condition. (3) Monoculture of sugarcane produces a gradually impoverishment of K in the soil. (4) Tillage effects on soil nutrients or chemical properties are made manifest only if there is tillage influence on soil physical conditions.

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7. TILLAGE IN RELATION TO ECONOMICS AND ENERGY CONSUMPTION
THE SHARE OF CULTIVATION IN THE ENERGY BALANCE OF THE PRODUCTION TECHNOLOGY OF MAIZE AND WHEAT

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N. Poushkarov Institute of Soil Science and Yield Prediction, Bulgaria

ABSTRACT

It is reported that as a result of the replacement of the technology based on restorable sources of energy by a technology based on non-restorable ones greater amount of energy is expended per unit grain production. This increase is mainly at the expense of energy consumed in fertilizer production since the energy outlay for field operations including soil tillage is reduced.

In studying the balance of energy consumed in crop production it is very difficult to determine which activities should be taken into account when calculating energy expenditure. It is also difficult to assign the same physical energy value to products with different consumption energy values. It is impossible to organize an up-to-date production of maize and wheat without expending energy on the extraction of ore and its processing into tractors and other machines or without expending energy on oil production and oil processing or excluding transportation and other means of communication or even intellectual activities such as science, education, etc. In the long run the whole variety of human activities, directly or indirectly, in the year of their performance or in the following years affect the basic production of every society, i.e. the production of food. It can be assumed, therefore, that the energy expenditure of society is the energy expenditure in agriculture. Globally, this assumption can be acceptable, if, of course, the energy expenditure for military purposes is excluded, since this expenditure cannot be justified as necessary to man and for the development of productive forces.

Society is interested to know the energy balance in the different branches of production, even in some subbranches, technologies and technological operations. In the evaluation of the energy balance of the production
of maize and wheat only the energy expended in the field and in the transportation of products to and from the farmyard is taken into account. The energy expenditure for the production of machines and tools for field operations and for the transportation in general is not included, since it is not possible to determine its total share for a given year or in the volume of work carried out for the production of these two crops.

In making the energy balance statistical data have been used (5,6,9), while the operations and materials for which no published data exist have been evaluated according to the adopted norms (4,7,8).

The data (Table 1) indicate that in the course of 30 years the sources of energy for carrying out field operations and for supplying materials needed in the organization of maize and wheat production have been completely changed. This has made it possible to reduce the energy expenditure for soil cultivation and for performing all field operations involved in the production of unit grain both absolutely and relatively. When the energy expended on the production of fertilizers and preparations is included, the unit grain production of both crops obtained with a technology based on exploitation of internal combustion engines and chemicalization turns out to need a doubled amount of energy. This tendency cannot but give rise to concern for many reasons, one of them being the soaring prices of energy sources and the prospect of their being exhausted. In 1978 the power supply on a national scale measured some 7 times the supply in 1939, but the supply from restorable sources was only doubled, mainly through increasing crop production. Over the same period energy consumption in agriculture was increased by some 34% but the share of non-restorable energy sources was increased about 250 times, and that of the restorable ones decreased more than 5 times.

Many studies carried out abroad (15, 16, 17, 18, 19, 20) and in this country (2,3,10,11,12) indicate that it is possible to decrease the number of cultivations or to merge them together with other field operations. There is a possibility to replace plowing of wheat by its disking, and entirely or in part to abandon pressowing and vegetation cultivation and to introduce weed control through herbicides application instead. In many cases deep plowing can be replaced by shallow or periodic plowing (13,14) or completely excluded. Even the entire abandoning of cultivation in the production of the two crops will not significantly affect energy expenditure per unit production.
At the present stage this is not a realistic task, and, as studies show, it is even disadvantageous under many ecological and economic conditions (3,13,14). There are possibilities to considerably increase productivity and to decrease energy outlay in other operations related to cultivation, harvesting and transportation of the crop. Neither in this field is it possible to achieve results which could reverse the tendency of increasing the total energy consumption per unit production.

About 60% for wheat and 70% for maize of the total energy outlay per unit production (without the energy contributed by seeds these figures are 80% and 72%, respectively) are expended on mineral fertilizers. At the present stage without mineral fertilizer application it is not possible to increase plant production. It is known that the annual effectiveness of a unit N fertilizer is 50% on the average, considerable part being lost with the surface or soil runoff or in a gaseous state(1).

Through considerably decreasing energy expended on producing fertilizers, N fertilizers in particular, and through raising the annual effectiveness in the formation of the yield of maize and wheat the tendency of increasing energy consumption per unit grain production can be checked. There are two other opportunities to do this biologically, using the methods of genetics. The first one is to create soil or symbiotic nitrogen-fixing bacteria similar to those found on leguminous crops. The second possibility is to create varieties which, at the present rate of energy consumption per unit area, could use not less than 1.0 - 1.5% PAR in the production of wheat grain and maize grain. The varieties existing at present can utilize only 0.31% to 0.35% PAR for grain production. In that way the most rapid for the time being reduction in energy expenditure per unit grain can be achieved. The economies of all countries are interested in solving this problem.
### Energy Expenditure for Wheat and Maize per 100,000 tons Grain (GJ)

<table>
<thead>
<tr>
<th>Field operations and materials</th>
<th>For Wheat</th>
<th>For Maize</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1939</td>
<td>1978</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>Restored*</td>
</tr>
<tr>
<td>1. E (cultivations)</td>
<td>62.40</td>
<td>61.88</td>
</tr>
<tr>
<td>2. Spraying herbicides</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3. E (all field operations)</td>
<td>128.35</td>
<td>127.73</td>
</tr>
<tr>
<td>4. Seeds</td>
<td>221.74</td>
<td>221.74</td>
</tr>
<tr>
<td>5. Fertilizers</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6. Herbicides</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>E</td>
<td>350.09</td>
<td>349.47</td>
</tr>
<tr>
<td>E (- seeds)</td>
<td>128.35</td>
<td>127.73</td>
</tr>
</tbody>
</table>

* Workers, draught animals, firewood, charcoal, electrical energy from hydroelectric power stations

** Coal, oil, oil products, electrical energy from thermo-electric power stations and atomic energy power stations
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THE POSSIBILITIES FOR APPLICATION OF DIFFERENT TOOLS 
IN THE TILLING OF HEAVY SOILS

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Abstract
With comparative conducting of primary tillage in course of 6 years using mouldboard plough, chisel plough and heavy discharrow it was estimated that chisel plough insures about 50% and discharrow about 40% more of crumbled soil under 2 cm diameter in the seedbed layer up to 10 cm of depth. The surface levelness was also more favourable, the looseness of soil was similar but mouldboard plough realised the "ploughing in" of plant trash and weeds 4-5 time more succesfully. After chisel plough the yields were similar or little higher (87,4-116,6 %), working effect was 2 time bigger with 30% less of fuel consumption and 50% smaller soil resistance.

INTRODUCTION
According to foreign experiences with application of chisel plough for primary tillage it was possible to acheive the savings of 50% of worktime and 30% of fuel (3,4,5). More light types of machines (grubber) are able to "ploughing in" short cut and well distributed plant residue (3,5) and their construction makes possible to combine tools for tillage and even for sowing in one passage (1,2,5).

This possibilities were proved in our circumstances with the chisel ploughs Jumbo Buster, Vicon with 7 and 9 inclined shanks,
Lemind RZ 203 with 7 upright shanks and narrow shovels but with side wings and discharrows INT 600 OJ, J. Deere 330 and Drava OLT with discdiameter 56-64 cm and 6,5-3,7 m of working width.

MAIN RESULTS OF INVESTIGATION

THE EFFECT OF SOIL CRUMBLING

The analyse of surface layer of soil to depth till 10 cm after application of different tools for primary tillage showed in all years and conditions better loosing effect tilling with chisel plough and discharrow than with mouldboard plough (Tab.1).

Table 1

CRUMBLINESS OF SOIL IN SURFACE LAYER TO 10 cm
applying mouldboard plough, chisel plough and heavy discharrow

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>Participation of soil fractions in % of total weight regarding to crumbliness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- 2 cm</td>
</tr>
<tr>
<td>1976-1981</td>
<td>p c d</td>
</tr>
<tr>
<td>1979</td>
<td>l h i</td>
</tr>
<tr>
<td>1980</td>
<td>o i s</td>
</tr>
<tr>
<td>1981</td>
<td>u s c</td>
</tr>
<tr>
<td>1982</td>
<td>g e h</td>
</tr>
<tr>
<td>1983</td>
<td>h l</td>
</tr>
<tr>
<td>Average</td>
<td>27.3 64.8 89.9 6.6 8.7 7.2 16.4 26.5 4.3 49.7 0 3.4</td>
</tr>
<tr>
<td></td>
<td>49.3 55.4 49.4 7.5 7.0 9.2 16.0 7.3 18.7 27.2 30.3 22.7</td>
</tr>
<tr>
<td></td>
<td>20.9 41.2 41.2 3.8 4.4 9.5 14.5 12.7 27.2 60.8 45.0 22.1</td>
</tr>
<tr>
<td></td>
<td>34.0 65.6 52.6 8.5 8.6 7.2 26.2 15.9 22.5 31.3 9.9 17.7</td>
</tr>
<tr>
<td></td>
<td>27.8 36.1 31.2 5.0 5.7 10.6 23.3 16.1 24.7 43.9 42.1 33.5</td>
</tr>
<tr>
<td></td>
<td>66.7 75.2 - 6.4 5.8 - 24.1 13.7 - 2.8 5.3 -</td>
</tr>
<tr>
<td>Average</td>
<td>37.3 55.8 52.9 6.3 6.7 7.8 20.1 15.4 19.5 35.9 22.1 19.9</td>
</tr>
<tr>
<td>After equal pressing cultivation ++</td>
<td>73.9 84.8 75.2 11.5 8.0 4.6 11.8 7.2 18.1 2.9 0 1.5</td>
</tr>
</tbody>
</table>

+ normal, middle heavy, very heavy; ++ after sunflower lighter discharrow (2x), Brillion, crumble-cultivator

The most minute fraction of soil texture with the stoutness less than 2 cm diameter amounted after mouldboard plough in average 37.3% from total weight of the soil sample (1/6 m²), but after chisel plough this minute fraction amounted in average 55.8% and after heavy discharrow 52.9%. The fraction of the small
clods 2 - 4 cm was similar after all three tools but a little more after chisel plough and heavy discharrow i.e. 6,3 - 7,8 %.

After mouldboard plough it was estimated 20,1 % of clods 4 - 10 cm and 35,9 % of clods bigger than 10 cm but on the contrary after chisel plough was 15,4 respectively 22,1 % and after discharrow was 19,5 resp. 19,9 %. According to that it was noticed after discharrow, specially on more heavy soil and higher moisture, broader appearance of small clods (7,8 %) and diminution of amount of stout clods 19,9 %.

Intensity of crumbling in deeper layer 10 - 20 cm was more favourable and by mouldboard plough and differences in crumbliness were smaller. The moisture diminished the crumbling effect of chisel plough.

LEVELNESS OF SURFACE LAYER OF SOIL

The levelness of surface layer of soil was less varying after primary tillage with chisel plough than after mouldboard plough specially if ploughing heavy soil in very wet or dry condition. From data in Tab. 2 is apparent that the unlevelness before primary tillage in sense of depression and altitude in relation to one middle level "O" was in average 4,1 cm.

Table 2

LEVELNESS OF SOIL SURFACE

Deviation from middle "O" level in cm

<table>
<thead>
<tr>
<th>TOOLS</th>
<th>min.</th>
<th>max.</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>before tilling</td>
<td>0,1</td>
<td>18,5</td>
<td>4,1 (2,9- 5,8)</td>
</tr>
<tr>
<td>after tilling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mouldboard plough</td>
<td>0,2</td>
<td>44,1</td>
<td>10,1 (5,8-15,4)</td>
</tr>
<tr>
<td>chisel plough</td>
<td>0,4</td>
<td>39,0</td>
<td>7,8 (5,6-11,9)</td>
</tr>
<tr>
<td>heavy discharrow</td>
<td>0,5</td>
<td>19,8</td>
<td>5,6 (4,9- 6,0)</td>
</tr>
</tbody>
</table>

The mean unlevelness amounted after mouldboard plough 10,1 cm, after chisel plough 7,8 cm and after heavy discharrow 5,6 cm. Following the tillage on more wet (mouldboard plough) or more dry (chisel plough) soils the unlevelness was striking with 44,1 respectively 39,0 cm but in such cases the frequency of greatest deviation was much more rare after chisel plough what is invigorated with av. values.
COMPRESSIBILITY (LOOSENESS) OF SOIL

The reached looseness of soil after carrying out the primary tillage was controlled measuring the resistance of soil to penetrate with penetrometer point. Expressed as compactibility it amounted before primary tillage in average 43,4 daN (29,4 - 72,9) and after primary tillage it was as presented in Tab. 3.

Table 3

COMPRESSIBILITY OF SOIL AFTER PRIMARY TILLAGE WITH DIFFERENT TOOLS

<table>
<thead>
<tr>
<th>TOOLS</th>
<th>Mean values in daN for particular depth layer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 - 10 cm</td>
</tr>
<tr>
<td>Mouldboard plough</td>
<td>3,4(1,9-4,9)</td>
</tr>
<tr>
<td>Chisel plough</td>
<td>3,7(2,8-5,1)</td>
</tr>
<tr>
<td>Heavy discharrow</td>
<td>2,8(1,2-4,5)</td>
</tr>
</tbody>
</table>

The surface layer was the most loose after the usage of discharrow but its effect was limited on the small depth. The penetrometer pierced the most easily through the soil tilled with mouldboard plough because of uniformity of depth (after chisel plough ridged bottom under stirred layer of soil) and air space which the mouldboard plough leaves. However, the differences in resistances of soil are very small and looseness as altitudiness too are after tilling with chisel plough greater because of better crumbliness.

BURYING OF PLANT TRASH UNDER SOIL SURFACE

Efficiency of burying the trash tilling with different tools is expressed in Tab. 4 with % of that part which remains on surface and in layer of 0 - 10 and 10 - 20 cm of depth.

The most successfully "ploughing in" the trash is reached with mouldboard plough leaving 11,11 to 26,3 % of trash mass on the surface. After chisel plough it was remained 37,2 - 79,1 % and after discharrow 47,3 - 57,3 %.

In the shallow layer 0 - 10 cm the difference between the mouldboard plough and chisel plough is diminished, because the mouldboard plough burys the biggest part of trash on bottom of furrow and chisel plough achieves to bury only a small part of trash into the deeper layer (10 - 20 cm).

The heavy discharrow "packs" the considerable part of trash into
Table 4

EFFECT OF BURYING THE PLANT RESIDUE IN SOIL

<table>
<thead>
<tr>
<th>Condition of field before tilling</th>
<th>ESTIMATED MASS OF PLANT RESIDUE BEFORE % OF INITIAL MASS IN DEPTHLAYERS after tilling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BEFORE TILLING ON SURFACE KG/ha</td>
</tr>
<tr>
<td></td>
<td>plo-</td>
</tr>
<tr>
<td>Scattered straw</td>
<td>5.639</td>
</tr>
<tr>
<td>Cutted straw</td>
<td>5.257</td>
</tr>
<tr>
<td>Balled straw</td>
<td>3.598</td>
</tr>
<tr>
<td>Discharrowed stub</td>
<td>3.424</td>
</tr>
<tr>
<td>Discharrowed beet</td>
<td>23.796</td>
</tr>
<tr>
<td>Discharrowed s.fl</td>
<td>4.308</td>
</tr>
<tr>
<td>After presowing cultivation</td>
<td>4.308</td>
</tr>
</tbody>
</table>

1-behind combine, 2-high mowed, 3-stubble with straw, 4-leaves and tops of sugar beet, 5-stems of sunflower. 2x disc, +after sunflower: primary tillage, disc, Brillion, crumble cultivator

shallower layer 0 - 10 cm, but more important is that it cuts und crumbles the plant residue and so rather large part of trash is latter in soil not possible to determinate specially when the tilling with discharrow is repeated.

DEVELOPMENT OF CROPS AND YIELDS

The influence of the manner of tillage on development of crops was expressed specially at sprouting of wheats. It was faster and more intensive after tilling with heavy discharrow (22.2 % sprouted plants 14 days after sowing) and chisel plough (8.4 %) because of better crumbled soil in surface than after mouldboard plough (1.3 %).

Table 5

RELATIONS OF YIELDS IN % AFTER DIFFERENT PRIMARY TILLAGE

<table>
<thead>
<tr>
<th>CROP</th>
<th>TOOLS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mouldboard plough</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CROP</th>
<th>TOOLS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mouldboard plough</td>
</tr>
<tr>
<td>wheats</td>
<td>100</td>
</tr>
<tr>
<td>maize</td>
<td>100</td>
</tr>
<tr>
<td>sunflower</td>
<td>100</td>
</tr>
<tr>
<td>sugar beet</td>
<td>100</td>
</tr>
</tbody>
</table>

On controlled parcels the yields of particular crops after ch...
sel plough were varying from 89,7-116,6% in relation to yield after mouldboard plough what indicates about possibility of favourable influence of chisel plough.

OUTPUT AND CONSUMPTION OF WORK AND FUEL

From average results in Tab.6 is possible to see that because of increased working width and speed the output of chisel plough is twice bigger than that of mouldboard plough. The specific resistance and fuel consumption are in the same time 51 resp. 31 % lower.

Table 6

<table>
<thead>
<tr>
<th>WORK EFFECTS AND FUEL CONSUMPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Mould-board plough</td>
</tr>
<tr>
<td>chisel plough</td>
</tr>
<tr>
<td>heavy discharrow</td>
</tr>
<tr>
<td>Soil moisture %</td>
</tr>
<tr>
<td>Working depth cm</td>
</tr>
<tr>
<td>Working width m</td>
</tr>
<tr>
<td>Working speed km/h</td>
</tr>
<tr>
<td>Profil section cm²</td>
</tr>
<tr>
<td>Draught tot. daN</td>
</tr>
<tr>
<td>Sp. resistance daN/cm</td>
</tr>
<tr>
<td>Output(0,8) ha/h</td>
</tr>
<tr>
<td>Work consump. h/ha</td>
</tr>
<tr>
<td>Fuel &quot; kg/ha</td>
</tr>
</tbody>
</table>

In application of heavy discharrow, if the circumstances permit, the output is four time more favourable than with mouldboard plough.

However, it is necessary to point out that the output of chisel plough is not satisfactory, if the plant residue cause interruption in work and choking. Therefore, the applied constructions of chisel plough with vertical clearance till 600 mm at working depth to 40 cm do not satisfy and the vertical clearance needed to be about 700 mm.

Literature

THE 9th CONFERENCE OF THE INTERNATIONAL SOIL TILLAGE RESEARCH ORGANIZATION,
ISTRO, SOCIALISTIC FEDERAL REPUBLIC OF YUGOSLAVIA, Osijek 1982.

THE BASIS OF TRACTOR POWER SELECTION FOR PRIMARY TILLAGE
Dr BRIAN D WITNEY, EDINBURGH SCHOOL OF AGRICULTURE, U.K.

Summary and conclusions
The arbitrary selection of soil work days based on a unique but intangible value does not correctly simulate the managerial response of revising the criterion of a work day to accommodate adverse soil and weather conditions. The identification of the effect of different soil moisture content levels on the work rate of various tractor/plough combinations provides a more flexible assessment of soil workability and represents a major advance on existing machinery planning procedures. It has been achieved by relating traction and plough draught to cone index as a soil strength parameter which is soil moisture dependent. Incorporating a soil moisture simulation model, this study shows the feasibility of a comprehensive computer programme for the selection of economically viable tractor plough combinations for a given climate and soil type within a machinery, labour and timeliness penalty cost framework.

Introduction
Tractor power on an arable farm is governed by the heavy draught work on soil tillage. The mass of the tractor and implement and the chosen process of cultivating the soil interact with the soil type to determine not only the traction available but also the draught required. Whilst the influence of the type and moisture content of the soil on its strength is widely recognised, greater attention has been focused on improving the accuracy of predicting soil and meteorological data than on the practical application of such models to evaluate the variation in the strength of agricultural top soils and its influence on tractor operations in the field.

In practice, the effectiveness of a mechanisation policy is determined by the management skill in matching the work output of the power and machinery system to the time available at an acceptable level of fixed and operating costs. The annual cost surcharge of any over investment in tractors and machines is balanced against the timeliness penalties of an inadequate production system. Timeliness penalties reflect the additional time required to complete operations in excess of the soil work days actually available in any particular period of the year. To a degree, the farmer compensates for the inadequacies of the machinery system and for the vagaries of the weather by adjusting the definition of a soil work day to suit the advanced or belated state of pro-
gress in the field. For farm machinery planning, soil work days selected at the discretion of the farmer have less to offer than those circumscribed by known boundary conditions of soil moisture level which have a predictable impact on traction and soil workability.

![Flow chart for mechanisation systems analysis](image)

**FIGURE 1.** Flow chart for mechanisation systems analysis, with missing links shown dotted.

From an examination of the factors influencing the cost components of a mechanisation system for primary tillage, the key issue in an effective machinery selection procedure lies in closing the loop between techniques for assessing soil moisture content, soil strength and work days (Figure 1). In practical terms, the wettest conditions for soil working are limited by high tractor wheelslip and low tractive efficiency which incurs high operating costs for reduced rates of work. If drier soil conditions are considered advisable, the machinery system operates more effectively but there is less working time available. Finally, progressing to the driest end of the soil moisture scale, plough draught becomes excessive and the probability of obtaining a period with these parched conditions are negligible so that unrealistically high power and machinery costs or excessive timeliness penalties are incurred.

**Soil moisture model**

The soil water balance equation for predicting the moisture status of unsaturated topsoils in a homogeneous soil profile located on a non sloping area is:

\[ m = m_p + P - R - D - E \]

where: \( m, m_p \) = soil moisture status on the present and previous days (mm), and \( P, R, D, E \) = precipitation, run off, drainage and evapotranspiration (mm/day).
This equation which is fully described elsewhere (Witney et al., 1982) incorporates two main advances. Firstly, the simulation model for predicting soil moisture status is cumulative and error compensating whenever the soil reaches saturation. Secondly, drainage rate is related to the hydraulic conductivity of the soil between saturation and field capacity.

Soil moisture status has been predicted for three soil types - Darvel, a sandy loam; Macmerry, a medium loam and Winton, a heavy loam - and compared with experimental data. For ten investigations with a total of 820 data points, spanning periods of up to a year, correlation coefficients range from 0.990 to 0.999.

Modelling tractor plough performance

Soil moisture content can be related to plough draught and traction by means of cone index as an indication of soil strength (Eradat Oskoui & Witney, 1982):

\[ CI = 450.5 \ MC^{-2} + 0.019 \ \gamma \]

where: \( CI \) = soil cone index (MPa)
\( MC \) = soil moisture content (% w/w)
\( \gamma \) = soil specific weight (kN/m³).

Despite the simplification of adopting a single equation for three soil types, the empirical relation explained 97.70 per cent of the experimental data.

The draught load of a mouldboard plough is a combination of the quasi static soil shearing resistance and a dynamic component increasing with the square of the velocity and influenced by the lateral directional angle of the mouldboard end:

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

where: \( Z \) = specific plough draught (kN/m²),
\( v \) = plough forward velocity (m/s),
\( g \) = gravitational constant (m/s²),
\( \theta \) = lateral direction angle of the mouldboard end (deg)
and \( K_1 \) and \( K_2 \) = empirical draught coefficients.

Regression analysis of NIAE experimental data gave the values of the draught coefficients as \( K_1 = 50 \) and \( K_2 = 9.66 \).

In a recent test programme, again on three soil types, correlation coefficients between measured and predicted values of plough draught were 0.93 and 0.96 using the values of the cone indices measured at median plough depth and predicted, respectively (Eradat Oskoui et al., 1982).

In a comprehensive analysis of tractor performance, Dwyer et al. (1974) have already established the relations between the main traction parameters and the tyre mobility number. For given values of the wheelslip, the coefficient of
traction (pull/load), the coefficient of rolling resistance (towing force/load) and the tractive efficiency are all simple functions of the tyre mobility number. Consequently, drawbar power can be matched to plough draught and speed requirements.

**Work day probabilities**

A procedure has been adopted to calculate the number of workdays at different levels of soil moisture content or workability criteria for various probability levels of occurrence over a 10 year period (Table 1). If field capacity is chosen as the criterion of a work day during the same period on the same soil in place of that for Table 1, no tillage work could be undertaken.

**TABLE 1.** Work days available in late January and February on Macmerry soil series with a soil moisture content not exceeding 105% of field capacity.

<table>
<thead>
<tr>
<th>% Probability</th>
<th>Week No 4</th>
<th>Week No 5</th>
<th>Week No 6</th>
<th>Week No 7</th>
<th>Week No 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>90</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>80</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>

**Timeliness Penalties**

The timeliness cost is taken as the value of the yield loss due to late completion of the sowing or planting operation. It was found that the curvilinear response of yield to sowing date was in the form of a quadratic equation:

\[ Y = C_1 t^2 + C_2 t + C_3 \]

where: \( Y \) = crop yield sown at time, \( t \)
and \( C_1, C_2, C_3 = \) coefficients

By integrating the yield function with respect to time over the sowing period, the optimum average yield can be calculated and the loss through a delayed starting date obtained.

**Power and Machinery Costs**

The final part of the analysis is the calculation of tractor and machinery costs using the routine developed by Audsley and Wheeler (1978) to obtain the present annual cost of the equipment from the actual cost flow.

The new list price of two wheel drive tractors and conventional ploughs were found to be linear functions of power rating and number of furrows, respectively, both with correlation coefficients of 0.90 (Eradat Oskouei, K., 1981). The resale values and repair costs are calculated as a percentage of these list prices, fuel cost is related through the specific fuel consumption to
power demand and the labour cost is assumed to be that portion of the operators' annual remuneration spent on the tillage operation.

**Mechanisation Systems Analysis**

An evaluation of the tractor power level and plough size for 400 ha of continuous winter cereals on a single soil type was selected to test the viability of the machinery selection procedure. Ploughing was assumed to start at the beginning of week 33, week 1 being the first week of January and the target completion date was week 42, thereafter timeliness penalties were increasingly applied. By introducing a series of filters to eliminate mismatched tractor/implement combinations, six different tractor/implement/speed/soil workability/probability permutation out of 1800 were obtained with three different power levels of 48, 64 and 91 kW (Table 2).

The extra power of the largest tractor was most effectively used with a smaller plough at a higher speed than with the medium powered tractor, whilst the smallest tractor could only manage the smaller plough at the lower speed. Working to the more stringent workability criterion of 105% of field capacity, none of the tractor implement combinations could complete the work on time, even for 9 years out of 10 and the smallest tractor incurred severe timeliness penalties. Allowing some working on wetter soils, the largest tractor completed the work on time and was the cheapest system overall, regardless of whether the proportional labour charge is included or treated as a whole farm expenditure.

Following the successful operation of the analytical procedures, further work is in progress to develop the full potential of the machinery selection programme for whole farm machinery planning with a range of crops, tractor units and field operations.

**References**


Eradat Oskoui, K. and Witney, B.D., 1982. The determination of plough draught - I prediction from soil and meteorological data with cone index as the soil strength parameter. J. Terramechanics. (Under editorial scrutiny.)

Eradat Oskoui, K., Rackham, D.H. and Witney, B.D., 1982. The determination of plough draught - II the measurement and prediction of plough draught for two mouldboard shapes in three soil series. J. Terramechanics. (Under editorial scrutiny.)

## Table 2
Feasible Tractor-Implement Combinations for a 400 Ha Farm

Operation starting at Week 33 and expected to finish at Week 42

### Plough Operating at 80% Field Efficiency

<table>
<thead>
<tr>
<th>UNIT COMBINATION NUMBER</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
</table>

### Tractor Specification

<table>
<thead>
<tr>
<th>POWER</th>
<th>KW</th>
<th>91</th>
<th>91</th>
<th>64</th>
<th>64</th>
<th>48</th>
<th>48</th>
</tr>
</thead>
<tbody>
<tr>
<td>WEIGHT</td>
<td>KN</td>
<td>32</td>
<td>32</td>
<td>32</td>
<td>32</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>TRACTIVE EFFICIENCY</td>
<td>%</td>
<td>72</td>
<td>72</td>
<td>72</td>
<td>72</td>
<td>72</td>
<td>72</td>
</tr>
<tr>
<td>THEORETICAL PULL</td>
<td>KN</td>
<td>34.4</td>
<td>34.4</td>
<td>34.4</td>
<td>34.4</td>
<td>25.8</td>
<td>25.8</td>
</tr>
<tr>
<td>ACTUAL PULL</td>
<td>KN</td>
<td>24.8</td>
<td>24.8</td>
<td>24.8</td>
<td>24.8</td>
<td>18.7</td>
<td>18.6</td>
</tr>
<tr>
<td>SLIP</td>
<td>%</td>
<td>10</td>
<td>11</td>
<td>10</td>
<td>11</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>TYRE SIZE</td>
<td>18.4-38</td>
<td>18.4-38</td>
<td>18.4-38</td>
<td>18.4-38</td>
<td>18.4-34</td>
<td>18.4-34</td>
<td></td>
</tr>
</tbody>
</table>

### Plough Specification

| PLOUGH DRAUGHT | KN | 17.7 | 17.1 | 20.2 | 19.5 | 15.2 | 14.6 |
| NUMBER OF PLOUGH BODIES | 3 | 3 | 3 | 4 | 3 | 3 |
| DEPTH OF CUT | M | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| WIDTH OF CUT | M | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 |
| WORK RATE | HA/H | 0.75 | 0.75 | 0.70 | 0.70 | 0.82 | 0.82 |
| LATERAL DIRECTIONAL ANGLE | RAD. | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 |

### Soil Specification

| WORKABILITY CRITERION | % FC | 105 | 110 | 105 | 110 | 105 | 110 |
| MOISTURE CONTENT | %M | 30.08 | 31.51 | 30.08 | 31.51 | 30.08 | 31.51 |
| CONE INDEX | KPA | 858 | 820 | 858 | 820 | 858 | 820 |
| SPECIFIC WEIGHT | KPA/CM | 12.05 | 12.05 | 12.05 | 12.05 | 12.05 | 12.05 |
| FIELD CAPACITY | MM | 110.00 | 110.00 | 110.00 | 110.00 | 110.00 | 110.00 |

### Operating Conditions

| PROBABILITY LEVEL | % | 90 | 100 | 90 | 100 | 90 | 100 |
| TRAVEL SPEED | M/S | 2.64 | 2.64 | 1.85 | 1.85 | 1.85 | 1.85 |
| FINISHING WEEK NUMBER | 43 | 42 | 43 | 43 | 48 | 46 |
| NUMBER OF PENALTY WEEKS | 1 | 0 | 1 | 1 | 6 | 4 |

### Cost of Operation Pounds Sterling

| COST OF OPERATION | POUNDS STERLING | 1023 | 1023 | 1420 | 1420 | 1023 | 1023 |
| TRACTOR PURCHASE PRICE | 10857 | 10857 | 7743 | 7743 | 5698 | 5698 |
| PRESENT ANNUAL COST OF TRACTOR | 893 | 893 | 677 | 677 | 669 | 669 |
| PRESENT ANNUAL COST OF PLOUGH | 611 | 611 | 650 | 650 | 611 | 611 |
| FUEL COST | 828 | 828 | 629 | 629 | 625 | 625 |
| LABOUR COST | 1328 | 1328 | 1423 | 1423 | 1898 | 1898 |
| TIMELINESS PENALTY | 553 | 0 | 553 | 553 | 24902 | 10846 |
| TOTAL COST OF THE SYSTEM | 4213 | 3660 | 3932 | 3932 | 23705 | 14649 |
8. TILLAGE AND ITS INFLUENCE ON THE PHYSICAL, CHEMICAL AND BIOLOGICAL PROPERTIES OF SOIL
THE CHARACTERISATION OF PORES IN PLOUGHED AND DIRECT DRILLED SOILS IN SCOTLAND.
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Abstract

Methods are described to characterise soil pores in tillage experiments from measurements on soil cores. The methods help in the assessment of soil suitability for direct drilling. The measurements are of water release characteristics, macroporosities, total porosities, air permeabilities, relative diffusivities and the dimensions of tube models. The methods are illustrated by a selection of results from six field experiments in south-east Scotland.

Introduction

The porosity of direct drilled soils is generally less than in ploughed soils mainly because the volume of macropores (> 0.025 mm radius) is also less (Ball, 1981b). More detailed studies of cores of undisturbed soil have shown that measurements of relative diffusivity and air permeability, in addition to air-filled porosity and water release characteristics, allow other pore characteristics to be calculated either as an index of pore continuity and tortuosity (Ball, 1981a) or by modelling the pores as tubes of known number and dimensions (Ball, 1981b).

Accordingly, we characterised the pore space of six soils of contrasting texture after ploughing and direct drilling using the above methods.

Materials and Methods

Measurements were made in seven soils in six field experiments in south-east Scotland. Textures and particle size distributions are in Fig. 1.
Fig. 1. Size distributions of particles and pores at 10 to 60 mm depth just after sowing and, for pores only, at 100 to 150 mm in mid-season. A typical standard error for the total porosities is 1.4 and for the individual pore size ranges is 1.3. P and D refer to ploughed and direct drilled treatments.

Each soil was in a cultivation experiment which included the treatments considered here, namely direct drilling into undisturbed stubble and conventional cereal establishment by ploughing to 200 to 250 mm, secondary cultivation and conventional sowing.

Cores of undisturbed soil, 50 mm high and 37 mm in radius were taken either shortly after sowing at 10 to 60 mm depth or
in mid-season at 100-150 mm. Between 1 and 4 cores were taken from the 3 to 8 replications of each treatment. Samples were equilibrated at a selected range of water potentials between saturation and -1500 kPa.

The water release characteristics of those samples which were tested to -1500 kPa resembled a curve of the form

\[\theta = \theta_r + ((\theta_s - \theta_r)/(1 + (P/P_1)^u))\]

where \(P\) = matric potential (kPa), \(\theta\) = volumetric water content and \(\theta_s, \theta_r, P_1\) and \(u\) are constants. The four constants summarise the water characteristic and allow comparison between treatments and soils. This equation was fitted to the data for those samples tested to -1500 kPa matric potential.

Relative diffusivity and air permeability were measured in core samples using the method of Ball et al. (1981). The radius, tortuosity and number per unit area of uniform radius tubes representing the continuous pores were calculated using the method of Ball (1981b) from relative diffusivity, air permeability and air-filled porosity for samples where these three properties were measured. In addition, an index of pore continuity and tortuosity, \(c\), was calculated by dividing relative diffusivity by air-filled porosity (Ball, 1981a).

Results

The pore size distributions are summarised in Fig. 1. The fractions of soil volume drained between potentials of 0 and -1 kPa, between -1 and -6 kPa and between -6 kPa and oven dryness are taken to correspond to the volumes of pores > 0.15 mm, between 0.15 and 0.025 mm and <0.025 mm equivalent radius respectively. The total porosities and volumes of macropores in ploughed soils, particularly in the 0.15-0.025 mm range, exceeded those in direct drilled soils.

Water release characteristics for soils from Carberry at 10 to 60 mm depth and for soils at Carberry and Gullane at 50 to 100 mm are in Fig. 2. At 100 to 150 mm depth, at a given potential, water content did not differ significantly between treatments so that overall means are given in Fig. 2B. The fitted curves and the four curve parameters are included in Fig. 2. The curves fit the data better at the lower depth. \(\theta_s\) is the water content at saturation and \(\theta_r\).
is the residual water content corresponding to some potential between -1500 kPa and air dryness. $P_1$ is the matric potential at which half of the pores between $\theta_s$ and $\theta_r$ is drained. $u$ is related to the slope of the central portion of the curve and is proportional to the uniformity of the radii of the pores. $u$ is greater for the more uniform and coarser textured sandy loam found at Gullane than for the Carberry soil.

The treatment mean air permeabilities and their corresponding air-filled porosities and matric potentials are summarised for all the sites of measurement in Fig. 3.

Relative diffusivity was measured as well as air permeability and air-filled porosity (Table 1) in two soils of differing texture. Each property was smaller in the direct drilled soil, particularly in the sandy clay loam. The index of pore continuity and tortuosity and the radius, tortuosity and number of equivalent tubes are in Table 1.
Fig. 3. The relationship between air permeability and air-filled porosity for different soils. KEY: • = direct drilled, o = ploughed, SL = sandy loam and SCL = sandy clay loam from South-East Scotland. ZL = silty loam and CL = clay loam from South England, included for comparison. Numbers are the matric potentials to which the samples were equilibrated (kPa). P is field matric potential.

Table 1 Relative diffusivity, air permeability and pore characteristics in soil at 10 to 60 mm depth at field water content after crop emergence. P and D refer to ploughed and direct drilled treatments.

<table>
<thead>
<tr>
<th>Site and field texture (USDA)</th>
<th>Air-filled diffusivity, %</th>
<th>Relative Air permeability, cm²</th>
<th>Tortuous tubes model</th>
<th>Radius, tortuosity, Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>C, D₀ × 10⁻⁵ cm²</td>
<td></td>
<td>Per cm²</td>
</tr>
<tr>
<td>Carberry, P</td>
<td>29.3</td>
<td>0.0825</td>
<td>5.69</td>
<td>0.28</td>
</tr>
<tr>
<td>Sandy Loam</td>
<td>23.1</td>
<td>0.0365</td>
<td>1.52</td>
<td>0.16</td>
</tr>
<tr>
<td>South Road, Sandy Clay Loam</td>
<td>23.8</td>
<td>0.0448</td>
<td>1.32</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>8.9</td>
<td>0.0097</td>
<td>1.07</td>
<td>0.11</td>
</tr>
</tbody>
</table>

- 400 -
Discussion

Two of the soils, the sandy clay loams, are classified as unsuitable for direct drilling (Cannell et al., 1978). In these the total porosities and macroporosities, particularly those between 0.15 and 0.025 mm radius (Fig. 1), tend to be smaller after direct drilling at 10 to 60 mm depth. The curves fitted to the water release data also revealed treatment differences at this depth at Carberry. $P_i$ was smaller after direct drilling, indicating an increase in pores containing water readily available to roots. The direct drilled soils in the plot of air permeability vs. air-filled porosity (Fig. 3) tend to be nearer the origin and be more scattered than the ploughed soils. Variations in air permeability at a given air-filled porosity reflect mainly the differences in the radii of the largest soil pores (Ball, 1981b).

Relative diffusivities and air-filled porosities (Table 1) differed more between treatments in the sandy clay loam than in the sandy loam. This sharp contrast is also shown by the model pores in the direct drilled soil being wider, more tortuous and much fewer and hence indicating a less suitable rooting medium than in the ploughed soil.

Conclusion

The methods allow a comprehensive description of soil pores related to compaction, drainage and the suitability for crop rooting and reveal differences between direct drilled and ploughed soils which influence their suitability for direct drilling.

References


SOIL STRUCTURE IN MODERN AGRICULTURE

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Abstract
A number of changes have taken place in agriculture in the last 10-20 years; more mechanization, a narrower crop rotation, and an increased use of chemicals. At first sight these changes must have a considerable, usually unfavourable, effect on soil structure. The results of annual investigations into soil structure confirm that indication.

Therefore, a study was made of the effect of various factors involved in modern farming on soil structure. The conclusion was that the decline in soil structure is not caused by a change in crop rotation or by the use of chemicals, but is mainly the result of more compaction due to the use of heavier equipment and insufficient restoration of the compacted soil through soil tillage.

Introduction
A number of changes have taken place in agriculture in the last 10 to 20 years. At first sight, these changes must have a considerable, usually unfavourable, effect on soil structure. The fact that soil compaction and deterioration of soil structure have often been a topic of discussion in recent years also points into that direction. The results of annual investigations into the structure of the top layer of farm fields and experimental fields confirm this indication, as is illustrated in fig. 1. It not only shows that structure varies from year to year due to weather conditions, but also that structure has been deteriorating during the last 10 years.

It was therefore decided to study how soil structure is affected by the various factors involved in modern farming and to search for means to prevent deterioration of soil structure.
Changes in agriculture

The most striking development in agriculture is mechanisation, characterized by an increase in number and weight of implements. This change has been promoted by an increase in farm size and by high costs of labour. It resulted in new systems and new cropping techniques which make heavier demands both on the soil and on the management skills of the farmer.

Another change, especially in The Netherlands, is narrowing of the rotations. The number of crops decreased and the area under potatoes, sugar beet and corn increased. It is conceivable that this results in a reduced return of organic residues to the soil and more compaction as a consequence of the use of heavier machines under more unfavourable conditions, e.g. at harvest.

A third development is the increased use of chemicals like fertilizers, herbicides, and pesticides, and a decrease in organic matter supply. This development leads to a reduction in soil tillage and possibly to interference with the biological activity in the soil.

Measurement of the effects

Some of the effects are studied on experimental fields, for example those of heavy machines, fumigation, crop rotation, and organic manuring. The behaviour of soil structure of the top layer and the density of the subsoil in the course of time are measured on fields of commercial farms.
Soil structure is evaluated by a visual score and by determination of bulk density, pore space, air content and oxygen diffusion rate. Workability is characterized also by a visual score.

Compaction by machines

Driving a tractor a varying number of times over a sandy soil under different moisture conditions gave results as shown in fig. 2. As expected, an effect of number of runs and of moisture content was found. The conclusion reported in this study was that on sandy soils having a moisture tension of more than 125 cm, driving a tractor will give little harmful compaction. In actual farm practice, however, machines are often used under more unfavourable conditions and then the soil is strongly compacted. If compaction occurs in spring before the start of the growing season, plant growth will be impeded. During harvest in late summer, strong compaction of clayey soils is found (fig. 3). The greater part of the field is occupied by tracks in which soil structure is very poor. In most years, subsequent soil tillage will undo this damage and thus the compaction will not be injurious.

An important question is to what depth compaction takes place. It is generally thought that the subsoil will be compacted by using heavy machines. However, on sandy and clayey soils we did not find an increase in density of the subsoil (fig. 4).

Effect of crop rotation

Twenty years of different crop rotations did not result in differences in organic matter content and workability in spring. Only small differences in actual soil structure were produced. With a larger proportion of sugar beet and potatoes in the rotation, soil structure deteriorated somewhat (table 1).
Visual rating of soil structure after harvest
- between tracks
- in tracks

Mean soil structure before harvest
Mean soil structure after harvest
Mean soil structure in tracks

Fig. 3. Effect of driving with heavy machinery - during harvest - on the actual soil structure.

Bulk density, g/100 cm³

A = Situation 15 years ago
moderate mechanization
B = Situation now
heavy mechanization

Fig. 4. Effect of mechanization on the density of the topsoil and of the subsoil.

In the Netherlands, the proportion of potatoes and sugar beet in the rotation rose from 27% to 43% in the last 20 years and, according to table 1, this will result in a soil structure deterioration of about 0.1 unit on the visual score scale.
Table 1. Influence of crop rotation on organic matter content, workability, and actual soil structure.

<table>
<thead>
<tr>
<th>Number of years with potatoes and sugar beet in six years</th>
<th>Organic matter content</th>
<th>Workability</th>
<th>Actual Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Visual score</td>
<td>Plasticity</td>
</tr>
<tr>
<td>0</td>
<td>3.04</td>
<td>5.0</td>
<td>28</td>
</tr>
<tr>
<td>1</td>
<td>3.00</td>
<td>5.1</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>3.05</td>
<td>5.1</td>
<td>31</td>
</tr>
<tr>
<td>3</td>
<td>3.04</td>
<td>5.1</td>
<td>29</td>
</tr>
<tr>
<td>4</td>
<td>3.01</td>
<td>5.1</td>
<td>32</td>
</tr>
</tbody>
</table>

Effect of chemicals

Chemicals like fertilizers and pesticides promote growth and increase yields. In general, this also means that larger amounts of organic residues are added to the soil.

Use of herbicides instead of mechanical weed control entails missing the effect of soil tillage. Especially after harvest, stubble plowing may be important in restoring the compacted soil.

Fumigation is not damaging to soil structure. This conclusion was reached in a study conducted on a sandy soil which was fumigated annually and on a clay soil that received a single treatment.

Organic matter content of the soil

It was expected that a number of factors in modern agriculture would cause a reduction in organic matter content of the soil. This is not the case, however, judging from the results of routine analyses in certain regions of The Netherlands (table 2).

Table 2. Soil organic matter contents in two regions.

<table>
<thead>
<tr>
<th>% particles &lt;16μm</th>
<th>Wieringermeer</th>
<th>Northern part of Groningen</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>'41-'47</td>
<td>'50-'61</td>
</tr>
<tr>
<td>10</td>
<td>1.71</td>
<td>1.65</td>
</tr>
<tr>
<td>20</td>
<td>2.24</td>
<td>2.22</td>
</tr>
<tr>
<td>30</td>
<td>2.73</td>
<td>2.78</td>
</tr>
</tbody>
</table>
Evidently the amount of organic matter added to arable land was not lowered by the change in crop rotation or by substitution of fertilizers for organic manure. Another explanation may be that decomposition of the organic material is slowed down due to poorer aeration of the soil.

Factors responsible for soil structure deterioration

It was pointed out in the preceding that soil structure deterioration in The Netherlands, which occurs mainly in the top layer, is not caused by a decrease in organic matter content or by a more intensive use of chemicals; a minor contributing factor is a change in crop rotation. Thus, other factors like mechanization and soil tillage must be responsible for the decline in soil structure.

What happens in actual farm practice? Nowadays, during harvest, the soil is compacted more than it was a number of years ago. So more intensive soil tillage is needed to restore soil structure. But that is usually not done, for the following reasons: the season is too far advanced, lack of time, high cost of labour and energy, or the presence of a green manure crop. Usually the soil is autumn-plowed without a prior stubble tillage operation. Then, restoration of soil structure is incomplete, because only the top layer of 8-10 cm is brought into a good condition due to freezing and thawing and seedbed preparation, but the deeper layers are left untouched. The result is that we get a good, friable top layer and a cloddy, poorly aerated 10-25 cm layer.

How do we maintain good soil structure?

In the first place it is very important to keep the soil in a good condition with respect to drainage and lime status. Research has shown that, in general, it is economically justified to do so.

In the second place the farmer should try to prevent compaction as much as possible, but if he does not succeed, he should try to restore soil structure through more intensive soil tillage. To make this possible, potatoes and sugar beet should not be harvested too late, and seedbed preparation in spring should be done only when the soil is dry enough, so not too early. That is easy to say, but in every-day farm practice these measures are less obvious, because there are some disadvantages: yields may be somewhat lower, there may be problems with storage of sugar beet and industrial potatoes prior to delivery to the factory, organization of the work may be more difficult and more expensive, and labour and fuel costs may be higher.
In view of the changed situation in agriculture and the changed ratio between yield and costs of production, a lower quality norm for soil structure may have to be accepted. This point needs more attention in the near future.
Abstract

Characterization of water flow through soils with macropores requires special techniques because these soils are not isotropic and homogeneous as required by flow theory. The techniques should preferably be rapid and inexpensive to allow multiple applications in the field. Three selected techniques, which were recently developed, are discussed. They measure: (i) the vertical and horizontal $K_{\text{sat}}$ in a gypsum covered cube of soil which is carved out in situ (the cube method); (ii) the $K_{\text{unsat}}$ near saturation down to pressure heads of about -15 cm by determining fluxes through a series of crusts and the associated negative pressure heads below the crusts (the crust test) and (iii) short-circuiting, which is preferential movement of free water along vertical macropores in unsaturated soil, by applying sprinkling irrigation to large, undisturbed cores.
Introduction

There have been major developments in soil physics during the last ten years as is evident when reviewing articles in the various soil science journals. Mathematical descriptions of transport processes have been perfected and the availability of computers has allowed widespread use of simulation techniques. More emphasis is being placed on characterization of soils in the field, including studies on variability. In this context there is a growing consensus that it is more profitable to have many measurements at different locations, using rapid and inexpensive procedures, than to have only a few measurements using sophisticated and expensive techniques.

In addition, the realization that many swelling soils in the field with continuous macropores, do not behave according to flow theory, has had some practical consequences in terms of the development of new methods for describing flow processes in such soils.

This paper will present a review of some new, inexpensive methods for characterizing flow through swelling soils with continuous macropores, as developed at the Netherlands Soil Survey Institute.

Methods

Three methods will be discussed briefly by describing the procedures involved and by suggesting the context in which the methods should be applied. The first two methods deal with saturated and very wet soil and the last one is used in dry soil. Reference will be made to more detailed publications, (e.g. Bouma, 1981).

The cube method for measuring $K_{sat}$

Measurement of $K_{sat}$ in clayey soils with large natural aggregates ("peds") offers problems: (i) smearing of the walls of bore-holes may yield unrealistically low $K_{sat}$ values for the auger-hole method, which are, in any case, an undefined mixture of $K_{sat}$ (hor) and $K_{sat}$ (vert); (ii) small samples give poor results because of unrepresentative large-pore continuity patterns (e.g. Bouma, 1980), and (iii) water movement occurs only along some pores which occupy less than 1% by volume (Bouma et al., 1979). These pores can be easily disturbed by compaction which may occur when sampling cylinders are pushed into the soil.

The cube method (Bouma and Dekker, 1981) avoids these problems and uses a cube of soil (25 cm x 25 cm x 25 cm) which is carved out in situ and encased in gypsum on four vertical walls (Fig. 1). First, the $K_{sat}$ (vert) is measured by determining the flux leaving the cube while a shallow head is maintained on top. Next, the cube is turned 90°. The open surfaces are closed with gypsum
and the new upper and lower surfaces are exposed. Again, a $K_{sat}$ is measured which now represents the $K_{sat}$ (hor) of the soil in situ.

![Diagram of cube method for measuring $K_{sat}$ (vert) and $K_{sat}$ (hor).]

Fig. 1 The cube method for measuring $K_{sat}$ (vert) and $K_{sat}$ (hor).

The crust test for measuring $K$ near saturation

Non steady-state methods, which are widely used to measure $K_{unsat}$, are not suitable to obtain $K$ values near saturation in all soils, in the range $h = 0$ cm to, say, $h = 15$ cm. These values are particularly relevant for describing flow of water in clay soils with continuous macropores. In these soils there is a strong drop of $K$ upon desaturation due to emptying of the macropores (Bouma, 1982). Again, very large samples are needed to obtain representative results. The cube method can be extended to provide $K_{unsat}$ data near saturation. This procedure represents a version of the crust test (Bouma et al., 1971, Bouma and Denning, 1972; Baker, 1977). A tensiometer is placed about 2 cm below the surface of infiltration, which is covered by a series of crusts, composed of mixtures of sand and quick-setting cement (Fig. 2) (Bouma et al., 1982). Earlier, the crust test used gypsum but this may dissolve too rapidly. Dry sand and cement are thoroughly mixed, water is applied and a paste is formed which is applied as a 0.5 to 1 cm thick crust on top of the cube. The crust, which has perfect contact with the underlying soil due to the application method, hardens within 15 minutes. Light crusts (5 to 10% of cement by volume) induce pressure heads ($h$) near saturation and relatively high fluxes. Heavier crusts (20% cement and up) induce lower $h$ values and fluxes. These fluxes, when steady, are equal to $K_{unsat}$ at the...
Fig. 2 The crust test for measuring $K_{\text{unsat}}$ near saturation.

measured subcrust h value. Of course, subcrust h values can never be lower than equilibrium values dictated by the height of the cube. Fluxes are measured as outflow rates from the cube (Fig. 2B). Cylinders with soil can be used too and inflow rates can be measured rather than outflow rates by using cylinder-infiltrometers with a mariotte device (Bouma, 1977) (Fig. 2A).

Measurement of short-circuiting

Irrigation of dry, cracked clay soils offers problems because much of the applied water may rapidly disappear to the subsoil, following vertical cracks of root- and worm-channels which are continuous up to the soil surface. As a consequence, the bulk of the soil between the cracks is hardly wetted or leached (relevant in saline soils) and surface applied fertilizers and pesticides may rapidly move beyond rooting depth. Downward movement of "free" water along the walls of continuous macropores in unsaturated soil has been called short-circuiting (Bouma and Dekker, 1978, Bouma and de Laat, 1981). Short-circuiting can be measured by using large undisturbed cores of surface soil with a height that is equal to rooting depth (Bouma et al., 1981) (Fig. 3). For Dutch Conditions in heavy clay soils, cylinders are used with a height and diameter of 20 cm. These cores include the soil surface with grass, which is closely cropped. The cores are placed in the path of a spraying gun in the
field which is commonly used for sprinkling irrigation. In general, sprinkling conditions should correspond with local practices.

The mass of the soil-filled cylinder is determined before and after sprinkling and the stove-dry mass is measured at the end, thus allowing calculation of physical constants such as bulk density and moisture contents. Sprinkling intensities and duration should be measured independently. The volume of water that leaves the column is measured as a function of time, thus allowing an estimate of short-circuiting which can be expressed as a percentage of the applied quantity of water. Many measurements can be made in a short time and the effects of using different sprinkling rates of different durations can be easily evaluated. Thus, irrigation efficiencies can be improved because movement of water beyond the root-zone often represents a loss of precious irrigation water and surface applied chemicals.

**Fig. 3** Measurement of short-circuiting in a large core of undisturbed surface soil.

**LITERATURE CITED**


THE RESULTS OF SO FAR INVESTIGATIONS OF SOME ORGANIC AND INORGANIC CONDITIONERS OF SOIL PROPERTIES

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Agricultural and Processing Plant Osijek2

ABSTRACT

The paper presents the results of 3-year greenhouse experiments of the application of organic (bitumen emulsion and polyacrilamide) and inorganic (glotal and tripher) conditioners, i.e., their effect on the yields of spring oats, winter wheat and soybean, and on some important physical, chemical and microbiological properties of the soil. Investigations were started in 1979 and have been carried out on three different soil types: amphigley, vertic, mineral, amphigley, vertic, hemic and pseudogley, dystric, of sloping terrains. Simultaneous field experiment have been set up on several soil types, with important field crops but their results are not presented in this paper due to limited space.

INTRODUCTION

The achievements of the application of conditioners in other countries give the investigation of their efficacy in our ecological conditions a special scientific and practical importance, particularly because of the prevalence of heavy soils of unstable structure, rich in silt. In addition, unfavourable weather conditions frequently prevailing at the time of the main agricultural practices make it necessary to look for solutions, especially for arable areas under intensive cultivation. The situation is increasingly getting worse by the use of heavy machinery which causes trampling and compacting of the soil. As there is very scarce circulation of organic matter in the soil, due to the practiced systems of crop production, hardly including any soil improving crops or application of organic fertilizers, the sought for solutions should also be aimed at achieving a good functioning of the soil for intensive exploitation.


The investigations involved two conditioners from the group of organic (bitumen emulsion and polyacrilamide) and two from the group of inorganic conditioners (glotal and tripher). According to the current state of science in this field the application of the mentioned conditioners looks very promising for agricultural practice. By applying conditioners to heavy, vertic soils an attempt is made to reduce the adverse effects of swelling and shrinking on the other physical and mechanical properties of the
soil. In pseudogley it is aimed, among others, at improving the aggregate stability, thus preventing the formation of the crust in seedbed. The preparations were obtained from two foreign manufacturers (bitumen emulsion and polyacrilamide from Belgium, and glotal and tripher from Italy).

INVESTIGATION METHOD

The trials were started in the spring of 1979 and have been carried out in the greenhouse, in Micherlich pots, on two varieties of amphigley, mineral vertic and humic vertic, and on pseudogley, dystric. The experimental treatments are presented in Table 1, together with the achieved yields of oats, wheat and soybean. Bitumen emulsion and polyacrilamide, to which glyoxal is added, are applied each year to the surface layer in solution: bitumen emulsion 25 and 50 g, and polyacrilamide 20 and 30 g per m² respectively. These quantities are calculated according to the area of the pot. The doses of glotal and tripher are calculated on the basis of 2.5, 5.0 and 10.0 % in relation to soil weight, in accordance with the instructions given by the manufacturers of conditioners. The application of calcium carbonate follows the same procedure. Other experimental practices are the usual ones, including also fertilization, which is adjusted to the test crop.

The changes in the physical, chemical and microbiological soil complex are also recorded in the trials. These analyses are performed by standard laboratory methods, including also stereomicroscopic study of soil samples by means of the electronic scanner microscope. The statistical data processing is carried out by the analysis of variance.

RESULTS AND DISCUSSION

a) Effects of soil conditioners on the yield of test crops

The discussion of the results achieved in the trials refers first to the yield of spring oats. The results of the analysis of variance show a significant effect of the conditioner application on the grain yields on both varieties of amphigley (Table 1). However, on amphigley, vertic, mineral, significantly higher yield of oat grain, in comparison with the check treatment, was obtained only at medium and high doses of tripher; while there is no significant yield drop below the check in any treatment. This may point to the advantage of ferric conditioners, primarily tripher.

On amphigley, vertic, humic, no effect of bitumen emulsion on the yield of oat grain was recorded, while the high dose of polyacrilamide had a significant effect in comparison with the check. A slightly more expressed trend of yield increase appears in medium and high tripher doses, but without reaching significance.

As regards the grain yield of winter wheat, the analysis of variance shows significant differences between trial treatments on all three soil types, with very marked significance between some treatments. On amphigley, vertic, mineral, all treatments with conditioners rendered higher yields than the check. With the exception of the lower dose of bitumen emulsion, the yields in all other treatments are highly significant in relation to the check, which points to a good response of wheat to conditioner application.

The yields of winter wheat grain achieved on amphigley, vertic, humic, are slightly different from the yields obtained on amphigley, vertic, mineral, which, is, among others, reflected in the degree of significance.
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Dose</th>
<th>Soil type</th>
<th></th>
<th></th>
<th></th>
<th></th>
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<th></th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Amphigley mine-</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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Organic conditioners had considerably less effect than the inorganic ones. Moreover, it is almost a rule that increased doses of inorganic conditioners bring about a yield increase.

The effect of conditioners on the grain yield of winter wheat grown on dystric pseudogley is almost diametrically opposite to that of both varieties of amphigley. For a good effect of inorganic conditioners it is essential that the soil should not be acid, and it is desirable that it should be humic, neither of which conditions is satisfied by pseudogley. There was no positive effect not only of inorganic but also of organic conditioners. The latter can be partly explained by the initial soil treatment. It should be kept in mind that pseudogley is a soil of very low productivity, marked soil acidity, low saturation with bases, low cation exchange capacity, very poor biogeny, deficient in available nutrients, etc. The conditions for plant nutrition are likely to deteriorate due to the application of inorganic conditioners. This is confirmed by the drop in wheat yield parallel to the increased doses of glotal and tripher. This points to the conclusion that there was a negative response of wheat to the application of these conditioners which depended on the applied doses. It seemed useful to extend the investigations to an acid oligotrophic soil, for it gave valuable results for further investigation trends. Therefore, in the following year, graded doses of conditioners were included into the trials, together with graded doses of calcium, the aim of which was to eliminate the adverse chemical properties of pseudogley through liming.

The analysis of variance of the yield of soybean, the third test
crop in the trials, grown on amphigley, vertic, mineral, and on pseudogley, dystric, shows the presence of a significant effect, which was completely absent on amphigley, vertic, humic. On amphigley, vertic, mineral, the effect of discrete treatments varied considerably in comparison with the check. Tripher had the most stable effect, while the effect of glotal was negative. As this was not the case of spring oats and winter wheat, there seem to be sufficient elements to corroborate the statement that the specific response of a crop is an important factor in assessing the effect of a conditioner. It should be pointed out that in case of amphigley, vertic, humic, the experiment was not significant. A relative advantage over the check was achieved by the higher dose of polyacrilamide, and high doses of glotal and tripher.

The investigation results relating to dystric pseudogley differ from the results of both varieties of amphigley. However, in case of this soil type the experiment is highly significant. Out of a relatively big number of treatments in the trial there was not a single case of significantly higher yield than that of the check. There are even treatments significantly worse than the check. Our attention is concentrated on the treatments with glotal and tripher with calcium, in view of the mentioned assumption that the main cause of the negative effects of these conditioners may be the acidity of pseudogley, that is deficiency of available calcium. The results achieved this year to a certain extent justify this opinion, for soybean yields show an increase parallel to increased doses of calcium in the treatments of glotal and tripher with calcium. It is just this yield increase that shows that not even the applied calcium doses sufficed to eliminate the adverse properties of pseudogley. However, theoretically, they justify its application. This all points to the conclusion that the excessive acidity of the soil is the essence of the problem, not excluding other unfavourable chemical properties of pseudogley. In such a medium, ferric conditioners seem to have negative effect on the chemical properties of the soil. Tripher should, nevertheless, be differentiated from glotal, for its use seems to be prospective for acid soils.

b) Effects of soil conditioners on some physical and chemical properties of the soil

In the last three years investigations were carried out with the objective of identifying and evaluating the changes in the soil due to the application of structure stabilizers. Graph 1 shows the changes in the soil reaction, bulk density and volume contraction according to the data for 1979/80. The data are discussed in further text.

The presentation of the paper will be accompanied by a few slides taken during the growing season of discrete crops and the micromorphological study by the electronic scanner microscope. The phenomenon of the crust was studied separately, as well as the good effect of bitumen emulsion in the initial development stage of soybean, which prevented the formation of the crust on the surface of pseudogley. Further on, it was established that polyacrilamide and bitumen emulsion connect, or completely cover, the surface of aggregates by means of thready or chain formations. Glotal and tripher bring about flocculation of colloidal particles, thus exerting a favourable effect on the formation of microstructural aggregates.

In trials without liming a logical drop of pH was recorded, parallel to increasing doses of mineral conditioners, glotal and tripher (Graph 1). At the highest grades of glotal and tripher there is a considerable rise of hydrolytic acidity, while the sum of replaceable alkalis is reduced especially the degree of cation exchange capacity saturation with bases.
The mentioned negative changes are more easily tolerated by heavy hydromorphic soils (amphigley), owing to their better buffering capacity and generally more favourable chemical properties. Conservely, in texturally lighter and dystric surface horizons of pseudogley the cation exchange capacity gets almost completely destroyed, which induced us to try setting up trials combined with liming.

The application of liming in pseudogley brought the expected rise of pH, depending on different grades of discrete inorganic soil conditioners. In the first year, however, no positive effect of liming was determined with regard to the physical properties of pseudogley.

It also deserves mentioning that at the higher grades of mineral
conditioners there was a stronger fixation of phosphorus fertilizers applied to the soil, notably in case of glotal.

In case of bulk density and volume contraction, no significant changes were determined, which could be with certainty ascribed to soil conditioners (Graph 1).

The other investigation results relating to heavy hydromorphic soils and higher grades of organic and inorganic conditioners point to a certain decrease of moisture retention at 1/3 bars. Related to this is the fact that these soils now have somewhat more favourable relation between the water holding capacity and the lower limit of plasticity, for the plasticity limits have not changed significantly under the influence of soil conditioners. Even at the highest glotal grade a greater stability of microaggregates in the water was recorded in pseudogley.

c) Effects of soil conditioners on some microbiological properties of the soil

Graphs 2, 3 and 4 present the results of microbiological investigations, i.e. the proportion of aerobic symbiotic nitrogen fixing bacteria, and Graphs 5 and 6 the proportion of species Azotobacter chroococcum, which may be taken as indicators of the good soil condition.
The results point out to the conclusion that the soil structure conditioners in most cases effected an increase in the proportion of aerobic nitrogen fixing bacteria in amphigle: mineral, whereas in amphigle, humic, they brought about a slightly lower proportion of this physiological group of microorganisms in comparison with the check. On dystric pseudogley, in the course of the first year of conditioner application (test crop wheat), there was a drop in the proportion of this group of microorganisms in all treatments with conditioners, whereas in the second year (test crop soybean) a certain positive effect of conditioners was observed.

The proportion of species Azotobacter chroococcum varied in dependence on the soil type and on the soil structure conditioners used in the trial. It should be pointed out that the application of tripher caused a depressive effect on the proportion of Azotobacter chroococcum, which was more expressive on amphigle, humic, in relation to the check treatment. The presence of A. chroococcum was not recorded in dystric pseudogley in the first investigation year, and in the second year this microorganism was recorded only if organic conditioners were applied. This will have to be re-checked in further investigations.

CONCLUSIONS

1. The soil conditioners tested manifested a positive effect on the yields of oats, wheat and soybean in most cases in the trials set up on both varieties of amphigle. As a rule, inorganic conditioners had an advantage over the organic ones. On dystric pseudogley, however, there was a negative effect, particularly of inorganic conditioners, which was to a certain extent alleviated by the application of calcium carbonate.

2. The applied conditioners displayed different behaviour in connection with some physical and chemical properties of the soil, depending on the soil type. Thus, in addition to the prevailing positive effects also some negative changes occurred. This primarily applies to dystric pseudogley and inorganic conditioners.

3. Under the influence of the applied conditioners there were certain changes in the proportion of aerobic nitrogen fixing bacteria, in which the effect of the soil type is evident. The proportion of Azotobacter chroococcum varied in dependence on the soil type and the conditioner applied.

4. The investigations of soil conditioners are continuing, both in greenhouse and in field experiments, on important field crops grown on three different soil types. The field experiments have also rendered valuable results of 3-year investigations in which a distinctly positive effect was achieved by inorganic conditioners based on iron. They are not presented in this paper due to limited space.

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OXYGEN DIFFUSION AND REDOX POTENTIAL AS INFLUENCED BY CRUST FORMATION IN A CLAY SOIL.

F. Callebaut¹, M.K. Magunda², D. Gabriels³ and M. De Boodt¹

(1) Laboratory of Soil Physics, Faculty of Agricultural Sciences, State University Ghent (Belgium)
(2) Namulonge Research Station, (Uganda)
(3) National Science Research Funds, Brussels (Belgium)

Abstract

The effects of crust formation on oxygen diffusion, redox potential and sugar beet emergence are reported for a tropical clay soil. Crusts, formed by use of a rainfall simulator, resulted in poor emergence, the oxygen diffusion remained low. The gaseous diffusion was depending on a very large extent on the soil water content and aeration porosity. Conditioning the soil with a polyacrylamide solution, a soil stabilizer, prevented crust formation and resulted in a favourable sugar beet emergence and oxygen diffusion. Addition of calcium peroxide, an oxygen supplier, had identical favourable effects on gaseous diffusion. Redox potentials did not reflect the oxygen fluctuations effectively.

Introduction

The roots of most plants grow normally only if the soil environment is reasonably well aerated. Soil aeration is related to the volume fraction, the continuity and the stability of air-filled pores. The stability of the soil structure, especially the openness of the large pores at the top layer during wet periods is one of the most important factors determining soil aeration. The whole root system can be paralysed if the aeration is blocked by a slaked and water saturated top layer; this during a warm period when oxygen consumption is high. A dry crust has enough pore space for gas diffusion. Russell (1973) points out that even if the formed crust is only a few millimeters thick, it will prevent the shoots of germinating seeds from emerging.

The present study aims to investigate: (1) the effect of soil crust formation on oxygen diffusion, redox potential and sugar beet germination in a clay soil highly sensitive to slaking, (2) the application of a polyacrylamide spray in order to protect the soil surface against the beating action of raindrops and (3) the use of calcium peroxide as an oxygen supplier.
Materials and methods.

A clay soil from an Ap horizon was used with the following textural composition: 40% sand (> 50 μm), 13% silt (2-50 μm) and 47% clay (0-2 μm) and with 3.28% organic matter, 0.4% CaCO₃ and 5.8% Fe.

Plastic containers (14 cm by 14 cm and 16 cm deep) with fritted bottoms were filled with air-dry soil aggregates (0.5-5.0 mm) on top of a sand layer of 2 cm thickness, to a bulk density of 1.35 g/cm³. Three different treatments were carried out: (1) control, (2) a surface application of a polyacrylamide (PAM) solution at a rate of 20 g/m² (for aggregate stability determinations the soil was incorporated with PAM at a rate of 2% on dry soil weight) and (3) a calcium peroxide (CaO₂) incorporation in the upper 3 cm layer at a rate of 0.5% (on dry soil weight). Each treatment was replicated twice. Sugar beet seeds were planted at one centimeter depth in each container. The soil was wetted by capillary rise to a soil water potential of -7 cm. On days 4, 7 and 11 after planting, the samples were subjected to a simulated rainfall with an intensity of 42 mm/h for a period of 10 minutes.

Redox potentials and oxygen diffusion rates were measured at 1 cm depth before and four hours after each simulated rainfall, using micro platinum electrodes and a Ag/AgCl reference electrode (Lemon and Erickson, 1952; F. Callebaut et al, 1981, 1982). The water status was monitored by means of mercury tensiometers. This experiment was carried out in a controlled environment (t = 22-24 °C; R_h = 50% ± 10%).

A second experiment was carried out in order to determine the relation between the oxygen diffusion coefficient (D_o) and the aeration porosity (ε). Soil samples (0.5-5.0 mm, bulk density 1.35 g/cm³) were mulched with polyacrylamide at a rate of 20 g/m², wetted by capillary rise and then subjected to a simulated rainfall (42 mm/hr during 10 minutes). The oxygen diffusion coefficients in rings were measured according to the method of Bakker and Hidding (1970).

Results and discussion.

Depending on the stability of the soil aggregates the seedbed will resist the intensive rainfall. The aggregate stability was determined according to the wet sieving method of De Leenheer and De Boodt (1967). The instability index was calculated from the difference between the mean weight diameter of the dry aggregate distribution and the mean weight diameter of the water stable aggregate distribution. The smaller this index, the more stable the aggregates.
The results are presented in Table 1. Treatment with PAM at a rate of 2% increased markedly the stability of the soil. Conditioning with CaO₂ at a rate of 0.5% however did not improve the aggregate stability.

The oxygen diffusion rate (ODR) at 1 cm depth for the two different treatments are reported in Figure 1. The values of the ODR are the averages of 6 readings (3 electrodes per duplicate). Stolzy and Letey (1964) observed that plant root development will be inhibited at an ODR less than $20 \times 10^{-8}$ g·cm⁻²·min⁻¹. An ODR value of at least $40 \times 10^{-8}$ g·cm⁻²·min⁻¹ was required for good emergence. In our experiments favourable effects of stabilization with PAM and CaO₂ fertilization on oxygen diffusion can be observed. Throughout the germination period the ODR remained above $40 \times 10^{-8}$ g·cm⁻²·min⁻¹ for PAM and CaO₂ treated soil. Surface crusting was observed after the second simulated rainfall on untreated as well as on soil samples treated with CaO₂. The effect of a crust on gas diffusion is reflected through the low ODR of the untreated soil. Higher ODR values in CaO₂ treated soil are recorded, due to the release of oxygen. On a sandy loam soil however Callebaut et al (1981) observed that CaO₂, besides being an oxygen supplier, stabilizes the surface soil clods at a rate of 0.25-0.5%. They also measured a lower instability index with the loam treated soil (CaO₂ 0.5% treatment I.I.: 1.037 compared to the untreated: 2.34). The fluctuations of the ODR during the experiment can be ascribed to the wetting (rainfall) and drying periods (between two rainfalls).

Gas diffusion can also be expressed as the ratio $D_e/D_a$ with $D_e$ being the coefficient of diffusion in the soil and $D_a$ being the coefficient of diffusion of the same gas in air at the same temperature and pressure. Figure 2 shows...
the high correlation between the oxygen diffusion coefficient and the aeration porosity. At an $\varepsilon$ of 0.08, $D_\varepsilon$ of the stabilized soil is about 1.41 times this of the crusted soil. At an $\varepsilon$ of 0.20 the factor is 1.93.

The evolution of the redox potential at 1 cm depth during the germination period is illustrated in figure 3. Oxidation-reduction potentials tend to decrease with pH. The pH was measured at the beginning and at the end of the experiment. There were no remarkable changes in pH during the experimental period. CaO$_2$ treated soils exhibited a pH of 7.2 while PAM treated and untreated soils maintained a pH of about 6.2. When adjusting the redox potential values to pH 7, all observations are almost identical to those of the CaO$_2$ treated soil (Stolzy and Flühler, 1978). Redox potential measurement does not reflect the soil aeration status when still some oxygen is present in the soil environment.

Sugar beet seedling emergence is shown in figure 4. Emergence was poor on the untreated soil. Low oxygen diffusion rates were recorded (figure 1).
At the end of the experiment, all surface soil was removed and the germination was checked. In the untreated plots almost 57% of the germinated seeds failed to break through the crust. Callebaut (1981) stated that low oxygen diffusion could be sufficient for germination but not for emergence through the crust.

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Characterization of the effects of cultural treatments (half ploughing, normal ploughing and direct drilling) on soil mechanics using the penetrometer (cone index).

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Abstract

The study is conducted to evaluate the mechanical resistance offered by the soil (silt loam) to a penetrometer (cone index) for the following tillage treatments: 1) Normal ploughing to 30 ± 5 cm depth.
2) Half ploughing to 15 ± 5 cm depth.
3) Direct drilling (no tillage).

Measurements were taken five times at different state of water content. Although the measurements with the penetrometer depend highly on the moisture content of the soil, this instrument responds positively to an increase in soil density. When the soil water content is lower than the soil moisture at field capacity, the penetrometer has a good capability to evaluate soil compaction.

Measurements show:
- A significantly higher resistance (alpha < 0.05) than other treatments, at 10-15 cm depth for direct drilling.
- A higher resistance (statistically not significant) at 20-25 cm for half ploughing.
- Soil's behaviour under normal ploughing depends on the moisture content of the soil. In Augustus 1980 (low moisture content: Pw 16-20 %), the horizon 30-35 cm depth, under normal ploughing shows a significantly higher resistance (alpha < 0.05). In April 1980 and November 1980 (high moisture content: Pw 21-25 %), the same horizon doesn't offer a higher resistance.
- One of the effects of normal ploughing included in mixed treatments is a higher water content between 10 to 30 cm in wet conditions for the mixed treatments than for the basic treatments corresponding. Subsequently, cone resistances are lower.

- 429 -
In 1967, the "Station de Phytotechnie" has settled an experimental design to study the incidence of soil work techniques on yield of several crops (sugar beet, oat, barley, corn, wheat) (FRANKINET et al., 1979).

Three basic treatments are used:
- normal ploughing: 30 ± 5 cm depth
- half ploughing: 15 ± 5 cm depth
- direct drilling.

These options being defined, two variables are susceptible to be studied:
- on one hand, preliminary experiments having shown the interest of an additional nitrogen manuring when the soil work depth was reduced, this variable has been kept;
- on the other hand, it has been interesting to study one time per rotation the effect of normal ploughing on certain plots treated by shallow ploughing or by direct drilling (mixed treatments).

From these elements, seven treatments have been defined and can be shortly described as follows:
- Treatment 1 - Permanent direct drilling with normal nitrogen manuring (SD).
- Treatment 2 - Permanent direct drilling with a nitrogen manuring supplement (SD N).
- Treatment 3 - Permanent shallow ploughing with normal nitrogen manuring identical to the treatment 1 (D).
- Treatment 4 - Permanent shallow ploughing with a nitrogen manuring supplement (D n), this supplement being generally equal to the half of the one applied to treatment 2 (n = N/2).
- Treatment 5 - Direct drilling with nitrogen supplement during three consecutive years, the fourth year being with normal ploughing and manuring (3 SD N + L).
- Treatment 6 - Shallow ploughing with nitrogen supplement during three consecutive years, normal ploughing and manuring during the fourth year (3 D n + L).
- Treatment 7 - Permanent normal ploughing, normal nitrogen manuring (L).

This trial has been established in a 7,5 ha field which has been devised in four parcels. Each parcel was subdivided in four blocks or replications including each of the seven treatments.

This scheme corresponds to the statistical design of complete randomised blocks. These experiments are conducted on a Hesbaye loess soil, which is deep, fresh and fertile.
A more detailed description of the cultural operations and manurings really applied and a complete analysis of results since 1967 to 1977 is reviewed by FRANKINET et al. (1979).

Different studies are carried out on the same experiment field and concerning the present problem: influence of tillage treatments on geotechnical characteristics of the soil (CORDIER, 1978; CORDIER et al., 1979; CORDIER, 1981 a et b).

In a preceding study (CORDIER et al., 1979), we conclude to the interest of the use of a penetrometer to evaluate soil's compaction following tillage treatments.

2) Equipment and methods

Cone resistances are measured with a penetrometer, hydraulically driven (constant rate : 100 mm/s) and mounted on a tractor. The penetrometer screwed to a load cell (quartz), has a cone with apex angle of 30° and a diameter of 2,027 cm (Norma ASAE R.313.1). Displacement to 70 cm depth (potentiometer) and force (load cell - force transducer) are recorded, together, on a magnetic tape. 

Gravimetric water content and specific weight (dry bulk density) are determined on soil samples, immediately collected to adjacent probed soil between 5 to 45 cm depth with 5 cm steps.

More details of the equipment are reviewed by CORDIER et al. (1979) and CORDIER (1981 b).

The experimental design consists of a split plot (DAGNELIE, 1981) with tillage (T) as whole plot treatments arranged in four randomized blocks, and positions (P) as subplots treatments. For each treatment (T), measurements (cone resistance, dry bulk density, and water content) are done in two positions (P) in each block.

Experimental design is summarized in Table 1.

<table>
<thead>
<tr>
<th>Sources of variation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>7</td>
</tr>
<tr>
<td>Position</td>
<td>2</td>
</tr>
<tr>
<td>Block</td>
<td>4</td>
</tr>
</tbody>
</table>

For each depth (cone resistance 2,5 to 2,5 cm, gravimetric water content and dry bulk density 5 to 5 cm), differences between treatments are statistically tested by split-plot analysis and test of Newman and Keuls (Alpha = 0,05).
3) Results and discussion

Measurements were taken five times: in June 1979, September 1979, April 1980, August 1980, and November 1980. Water contents corresponding at each testing series are different.

3.1. Dry bulk density (g/cm³)

For the five series of measurements:
- the horizon (5-15 cm) shows significant higher bulk density under direct drilling. Under normal ploughing, between 15 and 25 cm depths, bulk density is significantly lower than under other treatments;
- we register the lack of significant differences under 25 cm depth.

3.2. Gravimetric water content (% Ww soil)

As a general rule, water content is higher in the horizon 15-30 cm under normal ploughing, while we register lower water content in the horizon 5-15 cm under direct drilling.

For the horizon 0-5 cm depth, different authors (FRANKINET, 1977; RAGHAVAN et al., 1979; SOANE et al., 1970) conclude to an increase of water content under direct drilling. This increase of water content is in relation with the large quantity of organic matter (mulch) in this zone.

For the mixed treatments, the higher water content registered in the horizon 15-30 cm should be a residual effect of the last normal ploughing operated during winter 1977.

3.3. Cone resistances

Figure 1 shows cone resistance values for the seven treatments measured in August 1980. Figure 2 summarized values obtained in November 1980. These two figures illustrate the whole results obtained by the five measurements periods. In general and independently to water content of the soil, for all the tests:
- cone resistance is significantly higher in the horizon 15-17 cm, under direct drilling conditions;
- results under half ploughing show a maximum resistance in the horizon 20-25 cm. In this layer differences between half ploughing and others treatments are not statistically significant;
- between 0 and 15 cm, resistances are practically equal for half ploughings and normal ploughing. From 15 to 30 cm soil loosening effects due to the plough appears evidently, differences are significant comparing with others treatments (0.005 < alpha < 0.05).
Resistance Penetration (daN)

Fig. 1 - Resistances curves registered in Augustus 1980.

Fig. 2 - Resistances curves registered in November 1980.
Nevertheless, in some case soil water content during measurements can hide or display differences. It is true, for normal ploughing, under 30 cm depth when water content is lower than water content at field capacity (θ w/w at Pf = 2). In this case, cone resistances (fig. 1, Augustus 1980) are significantly higher than other treatments. On the other hand, when water content is high (near saturation), differences between cone resistances under each treatment are not statistically significant (fig. 2, November 1980).

For the first three measurement's series (June 1979, September 1979, April 1980), the mixed treatments (5 and 6) show resistance's curves intermediate between curves of basic treatments corresponding (2 and 4) and curves of normal ploughing (7). In Augustus 1980 (fig. 1) (Pw < 20 %), cone resistance of mixed treatments and of basic treatments corresponding are almost equal. We should say that an equilibrium state of the soil's resistance has been reached after two years of direct drilling or half ploughing. The last normal ploughing has been done in winter 1977. But in November 1980 (fig. 2), (two months later : Pw > 20 %), cone resistances of mixed treatments are lower than cone resistances of basic treatments between 10 to 30 cm. In the same time, we register for mixed treatments, higher water content than for basic treatments corresponding. The decrease of cone resistance can be due to the increase of water content, this increase of water content should be an effect of the last normal ploughing operated two years before.

4) Bibliography


The influence of soil moisture at the moment of cultivation on work effects of active implements.

Henryk Domżaļ, Mieczysław Palikot, Anna Słowińska-Jurkiewicz
Academy of Agriculture Lublin Poland

Abstract

The investigations concerned clodiness, density, porosity, as well as water and air capacity of loam and loess soil, cultivated with a plough and active implements under a variety of moisture conditions. It was found that most profitable agrophysical effects, within a wide range of moisture values, may be obtained in the case of soil cultivated by means of a plough-miller.

Introduction

In order to decrease machinery traffic on soil and the time consuming cultivation activities, as well as to improve the effects of crumling and mixing, the following active implements have been introduced into agricultural research and practice: plough-miller, rotary tiller and active harrow /2, 4, 5/.

As is well known now, the quality of plough work depends, among other things, on soil moisture and the best effects are obtained at a well-defined level of water capacity in soil, which is termed the optimum cultivation humidity /1, 3/. Therefore, it is interesting to ascertain to what extent the agrophysical effects of active implements are dependent on soil moisture. It is equally important to find out whether the use of these implements will result in good cultivation conditions of soil within a wide range of soil moisture.
Methods

The investigation was carried out on two soil types typical of the Lublin region:

- brown soil formed from medium heavy loam geologically nonuniform, on marl. Matter of post-glacial origin is often mixed with particles of carbonate rocks. In the arable layer it contains 36% of fractions $\leq 0.02$ mm and 14% of fractions $\leq 0.002$ mm, as well as 1.83% of humus. The value of water capacity at pH 2.5 ranges normally within 20.0-25.0%, plasticity limit equals 17.40%, liquidity limit - 28.90% and plastic index - 11.50%. These soils may be found in complexes with shallow eroded chalk rendzina.

- brown soil formed from loess. In the arable layer this soil contains 30% of fractions $\leq 0.02$ mm, 12% of fractions $\leq 0.002$ mm and 1.70% of humus. Water capacity at pH 2.5 ranges normally within 26.0-31.0%. Plasticity limit equals 24.40%, liquidity limit - 28.20% and plastic index is 3.80%.

The experimental cultivation was carried out with a plough, plough-miller and rotary tiller at 6 different levels of soil moisture; within 16-30% and 18-21%, for loam and loess soil, respectively.

Immediately after ploughing the following factors were estimated:
1. Clodiness - as percentage of clod surface $\geq 5$ cm.
2. Soil density, pore space, water and air capacity in probes taken 10 times and stored in cylinders of 100 cm$^3$. Water capacity was determined on ceramic plates in a pressure chamber, according to Richards.
3. Consistency limits, granulometric composition and humus content - according to generally accepted methods.

Results

Clodiness. Active implements used in cultivation of both types of soil leave it well crumbled and levelled. Clodiness after plough-miller and rotary tiller cultivation was markedly smaller than after ploughing, even at an unfavourable moisture level.
The differences in the degree of clodiness were more pronounced in the case of loam soil than in the case of loess. However, it was observed that at a very high level of cohesive moisture in loam soil, the rotary tiller cut the soil into "pieces" which were left uncrumbled on the surface of the field. On the other hand, when humidity level of loess soil was too low, the use of rotary tiller resulted in excessive crumbling and pulverization.

Density and pore space. Changes in density and pore space depending on soil moisture after plough and plough-miller cultivation were similar, the only difference being that a higher value of mellowness was invariably obtained as a result of plough-miller cultivation. The highest values of mellowness, for the two implements mentioned above, were obtained at an average soil humidity level, calculated for the whole experiment.

Fig. 1. The physical properties of soils after tillage
In the case of rotary tiller cultivation of loam soil, greatest mellowness was achieved at the lowest and highest level of humidity.

If one were to evaluate, on the basis of mellowness effect, the usefulness of the two active implements in cultivation under unfavourable conditions, then it would turn out that better results, with reference to ploughing, may be obtained in the case of plough-miller cultivation. This is so because satisfactory mellowness of soil is then less dependent on soil humidity [fig.1].

![Fig.1. The physical properties of soils after tillage](image)

### Water capacity

Loam soil cultivation did not result in increased water capacity, irrespective of the humidity level at which cultivation was carried out.

Loess soil cultivation did increase water capacity, particularly at the average level of humidity, but negligibly also at a high and low humidity value.

The differences resulting from the kind of implement used
are negligible for both types of soil [fig.2].

Air capacity. The use of each of the implements tested resulted in increased air capacity of soil of both types, independently of the humidity level at the moment of cultivation. In the case of loess soil, cultivation by means of active implements yielded greater increase in air capacity than plough cultivation. In the case of loam soil, the increase of air capacity was most spectacular after plough-miller cultivation [fig.2].

Needless to say, the effects described above neither exhaust the list of problems connected with the use of active implements, nor do they provide full explanation for the particular problem raised in our investigation.

In our view these preliminary results point to the need and purposefulness of undertaking such investigations.

Future design research on active implements may decrease their energy consumption. This could enable taking greater advantage of these implements, due to their good preparation of soil.

Literature
The possibility of utilizing the results of density and water-air soil properties for performing some cultivation activities.

Henryk Domżał
Academy of Agriculture Lublin Poland

Abstract

This is an attempt to employ the results of investigations concerning physical properties of soil in deciding whether it is possible to use simplified methods of cultivation, and if it is necessary to perform certain cultivation activities. The method which is proposed here consists in estimating the physical condition of soil after harvesting. This is based on field results of density determination and on the correlative model of water-air soil properties related to density, worked out for a given type of soil.

Results and discussion

The investigations of physical properties of soil which have been carried out for several years have aimed at defining the optimum and critical values for these properties. The most frequently used indicators of the physical condition of soil are the following: density, pore space, penetration resistance \[3, 5, 6, 8, 9\]. Although quite a lot has been said already with reference to this topic and density in particular, still we are far from being able to answer the question how to cultivate soil in order to obtain its optimum condition. It is as relevant do specify below what density values soil characteristics get so unfavourable that cultivation becomes necessary, if only for this particular reason alone. This problem is extremely significant with reference to the possibility of introducing simplified cultivation or zero tillage.
a variety of soil-climatic conditions. It proved possible to arrive at a relatively simple method of determining such relationships, one could probably avoid or minimize the time-consuming cultivation experiments and in this way the results of soil physical properties determination would find wider application in practice.

As one attempts to utilize the results of investigations concerning the physical characteristics of soil in estimating the prospects for simplified cultivation, or the necessity of performing certain cultivation activities, the following, by now well-known, conditioning factors should be considered and accounted for:

1. Simplified cultivation or zero tillage was successful when the soil was characterized by good physical properties, including its structure which prevented the soil from self-condensation and deterioration of the water-air properties [2, 7]. This does not hold for cases when the soil is strongly endangered by water or air erosion, since then those factors impose a different system of cultivation.

2. Soil density expressed in g/cm³ may be related to soils of a given kind, or even exclusively to a certain complex of soils characterized by similar properties. For instance, the optimum and critical density values estimated for brown loess soils will be inadequate as criteria for humus chernozem formed from loess.

3. In the case of subsided soil, a new system of pores, ducts, cracks and crevices forms itself, particularly in consequence of zero tillage performed for several subsequent years. Due to these, gas exchange is possible even at a fairly high value of density. That is to say, the same density, when effected by compacting loose, freshly ploughed soil, may lead to physical conditions worse than those resulting from the natural process of subsidence [1].

However, the idea that the results of investigations concerning the physical characteristics of soil may be used in order to judge the need of performing certain cultivation acti-
vities, or the possibility of introducing simplified cultivation—this idea then is so tempting and promising that it should not be discarded without trying to verify it.

Having this objective in view, we made use of the data and results of field and laboratory experiments carried out for a number of years.

The data consisted of estimates concerning the physical properties of the arable layer, carried out on probes taken from fields cultivated for various plants. At the same time probes of varying density were prepared in the laboratory. Density diversification was enforced by mechanical compaction of freshly collected damp soil contained in cylinders. Water and air capacity values were determined for such probes, at several different water tension values ranging within 1.0-2.7 pF.

The results which were thus gathered were presented graphically, with the properties under investigation shown as depending on soil density. A variety of such a presentation is given as fig. 1.

The estimation is performed, for the particular species of plants, on the basis of the optimum and critical values of physical properties, especially air capacity, as described in the literature.

As an example one may consider the results obtained for the brown soil formed from loess. In years of normal rain-fall distribution, density after harvesting reached about 1.40 g/cm³. At the level approximating field water capacity of pF 2.0-2.5, air capacity was about 10%. That is to say, even at field water capacity, the soil is not devoid of air pores. Such density should not, therefore, limit the yields of plants following in crop rotation, provided that these are corn plants.

In years characterized by great rain-falls, density at harvesting time is about 1.50 g/cm³. At this density level air capacity for field water capacity equals only a few per cent. This may then bring about lower yields. Therefore, cultivation of such soil seems indispensable.
The results of the field experiment which is being carried out now seem to corroborate these conclusions cf. "The changes of the soil physical ...". In the damp year 1960 density of loess soil, even after pulse crop cultivations, ranged within 1.40-1.50 g/cm³. Winter wheat yields were also markedly lower, although the differences were not statistically significant. After sugar-beet harvesting, density of the loess soil under investigation ranged within 1.25-1.30 g/cm³. This value, when considered against the density – physical properties complex,

Fig. 1. Relation between density and water – air properties of soil
indicates good air conditions, particularly for corn. In such cases deep cultivation may be reduced to the minimum, and mere surfacé levelling of the field is sufficient.

In very damp years density of the soil under investigation was considerably high and, after sugar-beet harvesting, it ranged within 1.35-1.45 g/cm³. The air conditions of soil at this level of density are no longer favourable and deep cultivation is needed. Similar analyses may be accomplished in order to estimate the water-air properties after any other crop, from the point of view of the needs of the plant following in crop rotation.

The analyses carried out on other soils prove the practicability and adequacy of the method described above. For lack of space, we were not able to discuss other examples.

The investigation discussed on the preceding pages may be blamed for its schematic approach, which, however, could hardly be avoided here. Irrespective of the ways in which it is presented, the problem itself seems interesting and worth further discussion.

Literature cited
The changes of the soil physical characteristics and yield caused by different systems of cultivation introduced once in rotation.

Henryk Domżał, Mieczysław Palikot
Academy of Agriculture Lublin Poland

Abstract

The study presents preliminary results of investigations concerning physical properties of soils and yields in a field experiment. A variety of simplified methods of cultivation for winter wheat have been used. Preliminary results indicate that, for the loam and loess soils under investigation, there exists a positive correlation between the advantageous physical properties due to traditional plough cultivation and higher yields. Shallow cultivations made the soil denser in the deeper layers and were characterized by slightly lower yields.

Introduction

For several years there have been attempts to work out such methods of basic soil cultivation which would be less energy-consuming. Successful experiments on simplified cultivation or even zero tillage have encouraged some authors to undertake investigations pertaining to this problem [1, 2, 3, 4].

In our soil and climatic conditions, the use of considerably simplified methods and zero tillage in particular, throughout complete crop rotation, has not, so far, given any positive results [5]. As a rule, this caused rapid deterioration of the physical properties of soil. However, the prospect of using more economical methods of cultivation is significant from a practical point of view. Therefore, we have attempted to estimate to what extent simplified cultivation introduced once in crop rotation may influence the physical characteristics of soil and
its yields, in comparison to the traditional method of cultivation.

Methods

The field experiments were carried out on two soils:
- brown soil formed from medium heavy loam, geologically nonuniform, on marl,
- brown soil formed from loess.

The properties of both soils have been described in a study entitled "The influence of soil moisture ...", contained in the present volume.

The experiment was carried out in four repetitions. The following rotation of crops was adopted: sugar-beet, spring barley, pea, winter wheat. After pulse crops, which are a good forecrop, the following methods of cultivation were used:
1. Zero tillage with surfacy loosening of soil to the depth of 3-5 cm, in order to facilitate sowing (control).
2. Plough cultivation to the depth of 25 cm, plus harrow.
3. Plough-miller cultivation to the depth of 20 cm.
4. Shallow rotary-tiller cultivation to the depth of 10 cm.
5. Active harrow cultivation to the depth of 10 cm.

The norms for sowing, fertilization and the use of herbicides were identical on each experimental field.

In order to define the physical properties of soils, probes of 100 cm$^3$ were taken during the whole vegetation period, from the following layers: 0-10 cm, 10-20 cm, 20-30 cm. Soil density, pore space, water and air capacity were estimated, as well as other properties which are not discussed in the present study.

The analysis of the physical properties of soil after cultivation is based on data gathered in the first year of the experiment (1980). The results from the next year (1981) are still not complete, and hence they were not accounted for in the present study. However, yields of winter wheat are given for both years.

Results

Physical properties of soil

The results of the experiment in the first year clearly
point to the fact that the methods of cultivation which were used diversified to a large extent the principal physical properties of the soils under investigation. Three effects present themselves fairly distinctly:
- changes in soil characteristics immediately after cultivation and in autumn,
- changes in the distribution of the physical properties under investigation from spring till harvesting-time,
- changes in soil reaction to the cultivation procedures used.
Immediately after cultivation as well as in autumn, density of both soils in the arable layer was greatest on fields with zero tillage and active harrow plus rotary tiller cultivation. This may be attributed to differences in the depth of initial loosening.

Rapid condensation could be observed in loam soil, immediately after cultivation. The distribution of the results which were then recorded remained unchanged in spring as well as during the whole period of vegetation. At harvesting-time higher values of density and lower pore space values were observed in soil with shallow cultivation, i.e. cultivated chemically, with the use of active harrow and rotary tiller. The arable layer of soil subjected to plough and plough-miller cultivation exhibited markedly lower density and a higher value of pore space. That is to say, the loosening effect of employing these implements was maintained until harvesting. This distribution of results is connected with the stable structure of the loam soil under investigation (fig.1).

As far as the loess soil is concerned, loosening effect at the time of cultivation is maintained throughout all the autumn terms.
In winter, the density of soil rapidly increases, which is evidenced by the results of density and pore space tests. Beginning with the spring terms, the above mentioned properties stabilize at a similar level for each experimental field, until harvesting-time (fig.1).
Water capacity did not depend much on the method of cultivation. However, in the case of deep cultivation one may observe slightly greater capacity in the arable layer. This effect is more pronounced in loam than in loess soil (fig.2).

Air capacity was marked by a change analogical to that characteristic of porosity, which is fairly obvious, considering the fact that cultivation increases loosening due to the increase of big pore volume (fig.2).
Yields

In 1980, at a very unfavourable complex of climatic conditions - excessive rain-falls, low temperatures - the highest yields, for both types of soils, were obtained in consequence of traditional plough cultivation. Similar results were also recorded in the case of loess soil after plough-miller cultivation. The yields were markedly lower on other fields, although
no statistically significant differences were observed (tab.1).

Tab.1. The influence of different systems of cultivation on winter wheat yields

<table>
<thead>
<tr>
<th>Implement</th>
<th>Year</th>
<th>Systems of cultivation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Soil</td>
<td></td>
<td>q/ha</td>
</tr>
<tr>
<td>Loamy soil</td>
<td>1980</td>
<td>24.0</td>
</tr>
<tr>
<td></td>
<td>1981</td>
<td>42.0</td>
</tr>
<tr>
<td>Loess soil</td>
<td>1980</td>
<td>30.4</td>
</tr>
<tr>
<td></td>
<td>1981</td>
<td>43.3</td>
</tr>
</tbody>
</table>

Literature cited
EFFECT OF TILLAGE SYSTEMS ON THE STRUCTURE OF THREE EUROPEAN SOILS AND THE INTERACTION WITH CROPPING SEQUENCE AND CLIMATE

MICHAEL J. GOSS\textsuperscript{a}, FRANS R. BOONE\textsuperscript{b}, WILFRIED EHLERS\textsuperscript{c}, JOS KROESBERGEN\textsuperscript{b}, and JAMES T. DOUGLAS\textsuperscript{a}

Abstract

A joint project has been established between members of ISTRO to study the effect of direct drilling and ploughing on soil structure at locations in Germany, Netherlands and United Kingdom. Sites differ in soil type, cropping history and climate. The type of soil properties of interest and methods chosen to investigate them are presented.

Introduction

Reflecting on the contributions at the 8th Conference of the ISTRO and in the literature, Professor Kuipers has pointed out that crop responses to zero tillage systems so far reported are far from simple\textsuperscript{(10)}.

A good example can be seen in the crop yields reported from several experiments in 1976 where a comparison of ploughing with direct drilling was included. The grain yield at Boigneville, France, for maize in monoculture was 10\% less on direct-drilled land\textsuperscript{(2)}; at Gottingen, West Germany, for winter oats there was no difference due to cultivation treatment\textsuperscript{(8)}, and at Compton Beauchamp, England for winter wheat in a rotation, direct-drilled crops yielded 7\% more than after ploughing\textsuperscript{(4)}.

\textsuperscript{a}Agricultural Research Laboratory, Letcombe Regis, Wantage, Oxon OX12 9JT, United Kingdom.
\textsuperscript{b}Tillage Laboratory, Department of Agricultural Engineering, Agricultural University, Wageningen, Netherlands.
\textsuperscript{c}Institute for Plant Breeding and Agronomy, University of Gottingen, Gottingen, West Germany.
Such variation in crop response can sometimes be attributed to differences in climatic or agronomic practices. However, the effects on soil physical conditions also appear to vary considerably. Thus on a verti-eutric gleysol, a clay soil, the stability of surface soil aggregates was greater after direct drilling than after ploughing but on a rendzina, a silt loam soil, the reverse was true(5). These results show the need to identify the major changes in soil structure which result from different methods of cultivation, how these occur, and to identify whether differences in soil type, climate and crop rotation affect the changes. It should then be possible to predict the effects of a range of climates on the soil physical conditions which may be experienced by subsequent crops and identify critical factors.

In 1981 we started a joint project to study the effects of direct drilling and ploughing on soil structure on three soils with different crop rotations and where different weather patterns could be expected. The purpose of this report is to describe the background of the experimental sites and give details of the measurements made.

Site locations

Details of the three sites chosen for the work are given in Table 1. The advantages from choosing these sites were three-fold. Firstly, the cultivation treatment had already been applied for several years and so further changes due to treatment would be expected to be small. Secondly, work on each site was well documented(3,4,5,6,7,8,9) and some soil measurements had already been carried out. Finally, the sponsors of these sites were enthusiastic about the project and made them available for sampling. Climatic variation between sites is not large but cropping patterns have differed considerably so that some separation of these effects could be expected.
TABLE 1

Characteristics of the three experimental sites

<table>
<thead>
<tr>
<th>Location</th>
<th>Compton Beauchamp Wantage, England</th>
<th>De Bouwing Wageningen, Netherlands</th>
<th>Rosdorff Gottingen, West Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall (mm)</td>
<td>699</td>
<td>750</td>
<td>613</td>
</tr>
<tr>
<td>Soil type</td>
<td>Verti-eutric gleysol</td>
<td>Fine textured river levee</td>
<td>Eutroboralfs</td>
</tr>
<tr>
<td>Clay content (%)</td>
<td>49</td>
<td>36</td>
<td>13</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>6.9</td>
<td>2.1</td>
<td>1.9</td>
</tr>
<tr>
<td>Cultivation treatments</td>
<td>Ploughing and Direct drilling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth of ploughing (cm)</td>
<td>20</td>
<td>27</td>
<td>18</td>
</tr>
<tr>
<td>Date first applied</td>
<td>1974</td>
<td>1964</td>
<td>1970</td>
</tr>
<tr>
<td>Previous cropping</td>
<td>Grass</td>
<td>Arable</td>
<td>Arable</td>
</tr>
<tr>
<td>Fixed:</td>
<td>Winter oats</td>
<td>Opportunist including</td>
<td>Opportunist including</td>
</tr>
<tr>
<td></td>
<td>Winter wheat</td>
<td>sugar-beet, maize, winter wheat</td>
<td>maize, oats, winter</td>
</tr>
<tr>
<td></td>
<td>Winter oats</td>
<td>Field beans</td>
<td>winter barley</td>
</tr>
<tr>
<td></td>
<td>Winter wheat</td>
<td>Oats</td>
<td>winter rye</td>
</tr>
<tr>
<td></td>
<td>Winter oilseed rape</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Winter wheat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimental Crop rotation</td>
<td>Many earthworms</td>
<td>Few earthworms</td>
<td>Many lumbricoid</td>
</tr>
<tr>
<td></td>
<td>Water-table in top</td>
<td>Well drained</td>
<td>earthworm channels</td>
</tr>
<tr>
<td></td>
<td>50 cm throughout winter</td>
<td></td>
<td>in subsoil</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Well drained</td>
</tr>
<tr>
<td>Characteristic feature of soil</td>
<td>Many earthworms</td>
<td>Few earthworms</td>
<td>Many lumbricoid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Well drained</td>
<td>earthworm channels</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>in subsoil</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Well drained</td>
</tr>
</tbody>
</table>
Sampling Programme

One objective of the joint programme was to widen the range of measurements made on the soil at each location. Furthermore it provided each collaborator with an opportunity to see and discuss the methods used for sampling and analysis special to the other laboratories.

A number of principles became clearer as the final plans were agreed and the following list accepted (Table 2). The key feature was that sampling in each plot was based on pedological features rather than simply according to depth. This was especially critical as a number of samples were taken to characterize the transition zone between topsoil (Ap horizon) and subsoil (B horizons). In the event samples were collected in the depth zone 0-50 cm with the exact depths varying from site to site according to normal depth of ploughing (Table 1).

| TABLE 2 |
| List of soil properties and methods chosen for investigation |

| Soil constituents (basic description of the properties of each soil) | particle size distribution |
| mean particle density |
| clay mineralogy |
| organic matter content |
| free calcium carbonate content |
| pH |

| Pore space (Indicative of steady state conditions and as a medium for water and nutrient uptake) | total porosity |
| pore size distribution (pF curve) |

| Soil structure/pore continuity (Indicative of soil behaviour under transient conditions and as a medium for root extension) | hydraulic conductivity |
| gas diffusion |
| air permeability |
| chloride breakthrough curves/dye infiltration |
| micromorphology |
| earthworm channel counts |

- 455 -
Appropriate samples would be collected from each site and then taken to the Institute undertaking the particular method of analysis. As two of the sites were on clay soils which showed considerable shrinkage, early spring (April 1981) was chosen for samples to be collected. At this time soils could be expected to have reached their fully swollen state, the best condition for measurement, but their strength would be least so presenting problems for sample collection and transportation. Considerable care was taken in handling and packing samples so that there was no damage evident despite the distances travelled.

The value of making some preliminary tests was also demonstrated. Even after sampling depths had been chosen some modifications became necessary. For example in the clay soils the density changes from the Ap to B horizon were sufficiently large to prevent measurement of hydraulic conductivity using the method of Arya et al\(^1\). Thus only saturated hydraulic conductivity measurements were made on samples which included this interface.

Early results show that on average over the three sites the saturated hydraulic conductivity of the interface layer was 1.45 times greater in direct-drilled than in ploughed soil. From measurements of gas diffusion and air permeability it is pores $>300$ $\mu$m which appear to have greater continuity in direct-drilled soil.

Full details of the experimental results will be presented as they become available.

Acknowledgements

We wish to thank our colleagues who have encouraged this work and gratefully acknowledge the support from NATO Research Grant No. 156.80.

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Penetrometer soil strength (PSS) and root growth were studied intensively on a grey brown podzolic loess soil. PSS was dependent on soil bulk density and water content. Although PSS was higher within the Ap-horizon (0-20 cm) of untilled soil, root growth was not substantially retarded. On the other hand root growth into the subsoil was limited in tilled soil by the presence of a tillage pan in 25-30 cm depth. Root growth ended at a PSS of 36 bar in tilled soil, but in untilled soil root growth stopped at 46 to 51 bar. One explanation for root growth at higher PSS in untilled soil is that roots of a following crop can reenter biopores created by earthworms and by roots of preceding crops. These passes for roots are left preserved in a non-swelling loess soil under zero-tillage cultivation.

Introduction

When regular cultivation operations are abandoned from arable land and zero-tillage is introduced, bulk density within the Ap-horizon increases and by the same time also soil strength increases. There has been concern about this increase in soil strength on untilled soil (Bauder et al. 1981) as soil strength is known to be one of the limiting factors of root growth. This paper will report on soil strength on tilled and untilled loess soil as measured with a penetrometer and will discuss its relevance for root growth of oats.

Materials and Methods

The soil is a grey brown podzolic soil derived from loess with a high silt content. The experiment with zero-tillage versus conventional tillage (mouldboard plow) started in
1970. Root growth of oats was studied on tilled and untilled soil in 1976 (Köpke, 1979) by determination of rooting density (cm root per cm\(^3\) of soil) with the profile wall method (Böhm, 1979) once a week. Bulk density was determined in 1976 within several layers and in 1980 within two layers of tilled and untilled soil. In both years oats were grown. Soil water content was measured in 1976 two or three times a week and in 1980 once a week. Penetrometer soil strength was evaluated in 1980 weekly using a hand held penetrograph (van Soesbergen and Vos, 1971). Bio pores were counted in 1981 (under winter wheat). They were distinguished according to diameter.

Results

Within the top 20-cm layer of the Ap-horizon bulk density is higher on untilled soil (1.4-1.5 g/cm\(^3\)) as compared to tilled soil (1.3-1.4 g/cm\(^3\)). On tilled soil, however, bulk density increases in about 25 cm depth up to 1.55 g/cm\(^3\), indicating the presence of a traffic pan.

Penetrometer soil strength (PSS) as measured in 1980 was plotted as a function of water content for the soil layers of tilled and untilled soil with different bulk densities (Fig. 1). Changes in PSS were related to changes in bulk density and water content by an equation given in Fig. 1.

\[
PSS = 4.72H_2O + 162.6BD - 4.61BD\cdot H_2 O - 173.4
\]

\[R^2 = 0.81\]

Fig. 1: Penetrometer soil strength (PSS) as a function of moisture content and bulk density (BD). The equation refers to all soil layers of tilled and untilled soil. Measured and calculated PSS are presented for three layers of tilled soil only.
In order to calculate not measured PSS in 1976, when root growth had been studied, the relation in Fig. 1 was linearly extrapolated to lower water contents. Calculated PSS values (Fig. 2) for the 1976 season are higher in the top layers of untilded soil as compared to tilled soil. On the other hand in the 25-30 cm layer of tilled soil the presence of a traffic pan with high PSS is evident.

![Fig. 2: Calculated penetrometer soil strength (PSS) of tilled and untilled soil in 1976 as a function of soil depth and time. Numbers indicate PSS in bar.](image)

Apparently differences in soil strength modified root growth of oats in 1976 (Fig. 3). Rooting density was higher in tilled soil within the 5-25 cm layer, but was less below 25 cm depth as compared to untilled soil (Köpke, 1979).

In order to relate root growth data to PSS the "relative growth rate of root length" (RGR) was calculated. The relation between RGR and PSS is presented for the Ap-horizon (0-25 cm) and the subsoil (25-60 cm) of tilled and untilled soil (Fig. 4). In the Ap-horizons the coefficients of correlation are low but still the relations are highly significant ($\alpha = 0.001$). Root growth stopped (RGR = 0) at a PSS of 36 bar in the tilled Ap-horizon, but in the untilled Ap-horizon and in both (untilled) subsoils root growth stopped at 46 to 51 bar (Fig. 4).
Discussion

In laboratory investigations with remolded soils and young seedling plants a relation between soil strength and root growth was found by several authors. Taylor et al. (1966) and Cockroft et al. (1969) showed that root growth ended at a PSS of 20 to 25 bar, a strength value higher than the pressure actually exerted by growing roots (Russell and Goss, 1974; Whiteley et al., 1981). According to our investigation roots
grew at higher PSS and the limiting PSS, when root growth ceased, was higher in untilled soil as compared to tilled soil (Fig. 4). The question is left for discussion what caused the difference in the RGR-PSS relation between a loess soil that is regularly tilled and that is left untilled.

One explanation is that root growth of oats in our field experiment was mainly dependent on the soil water content influencing PSS (Fig. 1). This explanation, however, would contradict results of other root growth studies (Merrill and Rawlins, 1979). Another explanation, which is more plausible is that PSS is not an adequate indicator of soil strength, which roots encounter in untilled soil layers. In non-swelling loess soils biopores created by earthworms (Ehlers, 1975) and by roots are left preserved when tillage is abandoned. These pores are privileged passes of growing roots as may be seen from Fig. 5, where in untilled soil rooting density within earthworm channels makes up a higher proportion of total rooting density as compared to tilled soil. A close up view on small biopores created by roots of preceding crops (< 1 mm) showed that also these pores were partially reentered by roots of the following crop winter wheat in 1981.

Fig. 5: Rooting density as a function of soil depth in tilled and untilled soil. Total rooting density and the portion of roots growing through earthworm channels (black area) are demonstrated (after Köpke, 1979).
We conclude that continuous biopores in a non-swelling loess soil left untilled may enhance root growth although the bulk soil strength as measured with a penetrometer increases with zero-tillage.

References


Measurement of differences in soil colour resulting from tillage and their relationship to calcium carbonate, organic matter and the length of time under tillage

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Abstract

A method for quantifying soil colour is described and applied to a range of soils in particular on the Upper Chalk. Measurement of calcium carbonate and organic matter contents shows that lightening of colour is closely related to calcium carbonate content. Using field management history a relationship is found between lightening of colour and the number of years under tillage for the Chalk soils. This is expressed in terms of rate of increase in calcium carbonate.

Introduction

Soil colour is a very striking parameter and has been used to differentiate soils similar to those investigated here (Hodgson, 1967). Colour has become increasingly important in soil classification (Soil Survey Staff, 1975). While colour may affect soil temperature (Stanhill, 1965) it may reflect chemical composition (Ramamurthy and Viswanath, 1944) and this can have an important influence on crop performance. Therefore changes in colour and composition arising from tillage could influence soil capability.

The sites studied and sampling

The main site is at Aldworth in Berkshire on the Downs (G.R. SU554803). An additional site at Marcham in Oxfordshire (G.R. SU454960) provides contrasting soils.

The Aldworth site comprises silty clay loam Rendzina soils on the Upper Chalk (white limestone) dominantly Icknield series and clay loam soils on overlying Reading Beds dominantly Yattendon series (Jarvis, 1968). The soils are mainly Typic Rendolls (with Entic and Eutrochreptic Rendolls) on the Chalk and Typic Hapludalfs on Reading Beds (Soil Survey Staff, 1975).

The soils at Marcham are sandy soils, loamy terrace soils and clay alluvium of Fyfield, Kelmscot and Thames series respectively (Jarvis, 1973). These correspond to Psammentic Hapludalfs, Vertic Haplaquepts and Mollic Haplaquepts.

The sites have well known management histories salient to this study as summarised in Table 1. Land at Aldworth is either permanent pasture or cereals
with both grass and a root crop one year in eight. At Marcham continuous cereals are dominant.

Table 1 A summary of land unit management histories

(a) The Aldworth site

<table>
<thead>
<tr>
<th>Permanent pasture: 2A, 2B, 2C, 2D, 7A, 7B. Pasture since 1910: 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>First tilled 1970-71: 8A, 8D</td>
</tr>
<tr>
<td>First tilled 1954-57: 6A, 6B</td>
</tr>
<tr>
<td>First tilled pre 1910: 3B, 3C, (6C,6D,6E)*, (4A, 4B, 4C, 4D)**, 5</td>
</tr>
<tr>
<td>(* but derelict in 1910, ** but pasture ca. 1920 to 1940-41)</td>
</tr>
</tbody>
</table>

(b) The Marcham site

Tilled for at least 50 years - 6 land units. Permanent pasture - 3 units.
Short duration (less than 10 years) pasture - 2 units.

Field enlargement necessitated sampling subdivisions of fields termed land units which have like soils or management or both. Ten samples (0-15 cm) were collected from each of 36 units on traverses.

Quantification of soil colour

While colour can be quantified using colour charts, laboratory measurement using instrumentation gives a more controlled result as carried out by Schields et al (1968). Chromoscan 200, a light beam scanner, is used here.

A dry sample is sieved with the aid of a brush and a less than 0.1 mm fraction photographed in standardised conditions using Kodak 25 colour positive film. This is then scanned. The instrument provides a measure of optical density on a chart and a digital integral output. A measure of colour is obtained by recording density with colour filters sequentially. Photographs of the Revised Standard Soil Colour of Japan allow the arbitrary values to be interpreted. The per cent contribution for each colour is determined as the ratio of the integral for that colour to the sum of all three colours as a percentage.

Colour standards are included in each photograph to monitor variations in exposure. Results show that the values are reproducible. The mean values using all filters and four standards range by ± 2.6 integral units. Per cent red results range by ± 1.4%.

Results of soil colour analysis

Most of the variation in the per cent colour is expressed in % red. Image density (neutral density filters only) and % red are used for sample
interpretation.

All the results were plotted on a graph of image density (I.D.) against % red. By delineating the scatter of points for each land unit it is possible to compare each unit in turn with all the others (630 comparisons). 76% of the comparisons indicate that distributions do not overlap and a further 14% slightly overlap. This shows that the colour of land units is distinct in spite of only 5 major soil series. Land management is the other major factor.

The relationship between image density and chemical determinations

Median samples in colour analysis received thermogravimetric analysis to determine calcium carbonate and organic matter contents. Figure 1 shows there is a good relationship between carbonate and I.D. with a correlation coefficient of -0.94. Soil colour chart values for 7.5 YR Chroma 2.5 are included. By contrast a poor relationship is found for organic matter (Figure 2). Ramanurphy and Viswanath (1944) also found colour to be associated with inorganic rather than organic components.

The relationship between image density and length of time soils have been tilled

The management histories of land units on the Chalk are used to relate lightness of colour to the number of years under tillage as shown in Figure 3. Permanent pasture is included although not directly comparable. The light colour of some pasture probably reflects localised animal activity possibly ants.

Figure 3 shows that there is not a precise relationship. However some land units are particularly comparable being adjacent and of similar slope. These are units 8A and 8B as highlighted in Figure 3. A broad trend is indicated on the graph together with ranges. The results reiterate the need to consider the individuality of units.

Figure 4 shows that results for the other units at Aldworth where Reading Beds and associated materials occur. In contrast, no definite lightening with time is apparent.

The trend line for Chalk soils can be equated with increasing calcium carbonate contents and corresponds to a rate of increase in carbonate in the tilled layer of 2 to 3% per decade and the ranges 2 and 7% decade. Changes in this order could have important practical consequences on soil behaviour.

Investigation of these consequences in terms of soil structure and erosion relationships will be published later.
Figure 1. The relationship between image density and calcium carbonate content.

\[ Y = -0.96X + 129.7 \]

Value

-2 
-3 
-4 
-5 
-6 
-7

Aldworth
Chalk
Other
Marcham
Sand
Loam
Clay

Figure 2. The relationship between image density and organic matter content.

\[ Y = 1.83X + 84.9 \]

Organic Matter Content (T.G.)

Value

-2 
-3 
-4 
-5 
-6 
-7

Aldworth
Chalk
Other
Marcham
Sand
Loam
Clay

Organic Matter Content (T.G.)
Figure 3 Changes in image density in relation to the year first tilled for Chalk soils at Aldworth.

Figure 4 Changes in image density in relation to the year first tilled for other soils at Aldworth.
Conclusions

A method for quantifying colour is applied to a range of soils and a wide range in colour is demonstrated. This is related to calcium carbonate contents and a broad trend of soil lightening associated with length of time tilled and calcium carbonate is observed for the Chalk soils.

Details of Chromoscan 200. Operating conditions and photography

Manufacturer; Joyce-Loebl Ltd., Gateshead. Optical mode; transmission. Wedge; 3.0. Cam; A. Sensitivity; 3. Aperture 0.45 x 1.52 mm (equivalent to 3.7 x 12.5 mm sample scale). Lamp; quartz-halogen. Filters; blue-435-480 nm, green - 500-560 nm, red - 610-750 nm. Photography; Ikon F2 + micronikor lens. Lighting 2 Unipack flash producing 6500° K at 45° and 1.6M from sample.

Acknowledgements

I am indebted to Dr. J.B. Dalrymple of Reading University for supervising the work and to the Ministry of Agriculture, Fisheries and Food for financing the research.

References


INFLUENCE OF SPEED AND PHYSICAL PROPERTIES OF SOIL IN RELATION TO THE SPECIFIC RESISTANCE AND QUALITY OF WORK OF MOLD BOARD AND DISK PLOWS.

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Departamento de Mecanización Agraria, Universidad Politécnica, Madrid (Spain)

ABSTRACT

Several relations within certain soil variables and the forward speed of work have been established in order to be related to the specific draught force with a range of validity under certain work conditions. These expressions are more general than others usually used in field trials.

At the same time, certain variables related to the "quality of work" were measured in order to achieved a more objective knowledge of the work done.

1. INTRODUCTION.

Among main tillage practices in Spain, soil tillage has been, and still is, one of the most important, by its influence in the final crop yields and by its energy requirements.

Nowadays the new techniques of "minimum tillage" and "direct drilling" are becoming important in our farmers' minds with some delay; 95% of farmers are still employing the traditional methods of tillage. The arable land in Spain is about 20 millions of ha, 10 of which are occupied by "annual crops", 5 millions are in fallow and the other 5 millions are occupied by forest; so the annual tillage practices reach to 15 millions of ha.

The aim of this paper is to find some empirical relations between the specific resistance of the soil, the forward speed of work and the variables that characterize the soil.

Previous works related to tillage practices may be classified into two basic groups:

1) Those works done in laboratory, where the trials take place in soils with known characteristics and with experimental tools. The main objective is to establish and prove predicting models related to Soil Implement mechanics, being this the first step in implement design.

2) Field trials, give more reliable data although they are restricted to very specific conditions.
There is a third kind of research about implements behaviour that is dealt in this paper, which can be considered as the intermediate type between the other two. Some characteristics of the soil are defined here and some restrictive conditions of the application of implements are established in this kind of research, studying the relations among the more significative variables.

2. OBJECTIVES.

The main objectives of this research are:

a) To establish several empiric equations in which the specific resistance of soil is related to the forward speed and the parameters which characterize the soil in moldboard and disk ploughs.

b) To establish a method to define and analyze a set of variables related to the "quality of work".

3. PREVIOUS WORKS

Several works on soil tillage have been done according to different parts of view as far as specific resistance under different implements is concerned. We have tried to arrange by simple mathematical relations the well-known equation of Gorjatschkin (1909) with the passive soil resistance stated by Sokolowski (1960) and adapted later by Hettiaratchi et al (1966).

The Department of Agricultural Mechanization of the Polytechnic University of Madrid has been working in this problem during the last six years (HERNANZ et al, 1979), (ORTIZ-CANAVATE et al, 1979).

4. MATERIALS AND METHODS

There were chosen for this trial: a moldboard plough and a disk plough.

The moldboard ploughs chosen were a cylindrical type and a warped type, as it was stated by the classification of HERNANZ, 1979.

To establish differences in behaviour between both types, the same share, coulter and landside were kept. Both moldboards had the same whirling area and the share was of 14" cut width, being the cutting and setting angles of 31° and 45° respectively.

The disk used was one of 66 cm diameter and was mounted on a frame where the tilt and disk angles were \( \gamma = 25° \) and \( \alpha = 37° \) respectively.

Physical and mechanical properties of soil are the following ones:

<table>
<thead>
<tr>
<th>Plot</th>
<th>Coarse sand (%)</th>
<th>Fine sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>Atteberg limits</th>
<th>Group index</th>
<th>Proctor moisture density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>L. L., P. I.</td>
<td>G. I.</td>
<td>H, B. D.</td>
</tr>
<tr>
<td>1</td>
<td>10,12</td>
<td>39,72</td>
<td>17,70</td>
<td>32,46</td>
<td>30,00</td>
<td>13,60</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>18,69</td>
<td>44,69</td>
<td>11,64</td>
<td>25,04</td>
<td>26,00</td>
<td>11,40</td>
<td>8</td>
</tr>
</tbody>
</table>


4.1. Variables measured.

a) Soil:
   - Bulk density before and after ploughing (BD), with "my" equipment.
   - Soil strength and cone index (CI), with cone penetrometer before and after ploughing.
   - Soil moisture content (H).

b) Tillage:
   - Width (a) and depth (p) in four locations within the furrow.
   - Roughness (R) before and after ploughing.
   - Swelling (e).

c) Implements:
   - Forward speed (v). Each trial was done under three following speeds: 5; 6.5, 5 and 7.5 km/h.
   - Draught force (F), established by means of a frame specially designed for mounted implements and a registering dynamometer.

4.2. Analytic method.

a) Specific resistance (\( \sigma \))

It is well-known that the specific resistance is the ratio between draught force and cross section of the soil prism.

For the moldboard plough: \( \sigma = \frac{F}{a \cdot p} \)

For the disk plough: \( \sigma = \frac{F}{S} \) is the real cross section of work, as it can be seen in fig. 1.

Fig. 1. - Work cross section of the disk: (a: maximum, b: projections over a perpendicular plane to the forward speed).

\[
S = \frac{D^2}{8} \left( \varphi - \sin \varphi \right) \cos \alpha \cos \psi - \left[ \sqrt{\left( D - \frac{P}{\cos \varphi} \right) \cdot \frac{P}{\cos \varphi} \cdot \cos \alpha - \frac{a}{2}} \right]
\]
for our disk: \[ \phi = 2 \cdot \text{arc} \cos \left(1 - \frac{p}{29,91}\right); \quad c = 29,91 - \sqrt{384,5 - 0,322a} \]
c = height of ridges

b) **Swelling index (e)**:

It can be modelled by an equation of the form: \[ e = \frac{h_m - h'_m}{p_m} \]

- \( h_m \) = average of the reference points of the land after ploughing (referred to a determined level)
- \( h'_m \) = average of the reference points of the land before ploughing (referred to a determined level)
- \( p_m \) = average depth of the furrows.

c) **Roughness (R)**

It is defined by the equation \[ R = 100 \cdot \log \frac{S}{S^*} \]

- \( S \) = standard deviation of the depth point references of the land after ploughing.

4.3 Derived Analytic Expressions.

The most significant variables are:

a) **For specific resistance**

- Forward speed (v); bulk density (BD); soil moisture content (H); cone index (CI).

The regression equations stated with those variables are:

\[ f = A + Bv^2 \]
\[ \sigma = A + CI(B + Cv^2) \]
\[ \sigma = BD(A + Bv^2) \]

b) **For swelling index**

- Dry bulk density (BDD) and depth of work (p). The analytic expression obtained by regression analysis is:

\[ e = A + Bp + C \cdot \text{BDD} \]

c) **For roughness**

Only the forward speed (v) was significant, and the regression stated was:

\[ R = A + Bv \]

d) **For cone index**

The most important variable was the soil moisture content (H), and the regression stated was:

\[ CI = A + BH \]
In all the cases A, B and C are the regression coefficients of each equation.

5. RESULTS AND DISCUSSION

The results obtained for each regression are the following:

a) Specific resistance ($\sigma$)

- Equation $\sigma = A + Bv^2$ (kPa)

<table>
<thead>
<tr>
<th>Plot</th>
<th>Implement</th>
<th>Equation $\sigma$</th>
<th>Correlation coefficient ($r$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cylindrical M.</td>
<td>$30.70 + 3.93v^2$</td>
<td>0.952</td>
</tr>
<tr>
<td></td>
<td>Warped M.</td>
<td>$19.56 + 9.90v^2$</td>
<td>0.938</td>
</tr>
<tr>
<td></td>
<td>Disk</td>
<td>$28.70 + 7.26v^2$</td>
<td>0.946</td>
</tr>
<tr>
<td>2</td>
<td>Cylindrical M.</td>
<td>$27.44 + 4.86v^2$</td>
<td>0.934</td>
</tr>
<tr>
<td></td>
<td>Warped M.</td>
<td>$39.13 + 1.99v^2$</td>
<td>0.827</td>
</tr>
<tr>
<td></td>
<td>Disk</td>
<td>$28.37 + 3.25v^2$</td>
<td>0.956</td>
</tr>
</tbody>
</table>

- Equation $\sigma = A + C(B+Cv^2)$

<table>
<thead>
<tr>
<th>Plot</th>
<th>Implement</th>
<th>Equation $\sigma$</th>
<th>Correlation coefficient ($r$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cylindrical M.</td>
<td>$69.54 + C(-7.27 + 0.049v^2)$</td>
<td>0.840</td>
</tr>
<tr>
<td></td>
<td>Warped M.</td>
<td>$77.06 + C(-11.06 + 0.0674v^2)$</td>
<td>0.853</td>
</tr>
<tr>
<td></td>
<td>Disk</td>
<td>$70.68 + C(-10.18 + 0.080v^2)$</td>
<td>0.739</td>
</tr>
<tr>
<td>2</td>
<td>Cylindrical M.</td>
<td>$82.85 + C(-21.30 + 0.070v^2)$</td>
<td>0.715</td>
</tr>
<tr>
<td></td>
<td>Warped M.</td>
<td>$41.55 + C(-1.78 + 0.0384v^2)$</td>
<td>0.778</td>
</tr>
<tr>
<td></td>
<td>Disk</td>
<td>$39.63 + C(-1.87 + 0.072v^2)$</td>
<td>0.602</td>
</tr>
</tbody>
</table>

- Equation $\sigma = BD(A + Bv^2)$

<table>
<thead>
<tr>
<th>Plot</th>
<th>Implement</th>
<th>Equation $\sigma$</th>
<th>Correlation coefficient ($r$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cylindrical M.</td>
<td>$BD(26.483 + 0.102v^2)$</td>
<td>0.997</td>
</tr>
<tr>
<td></td>
<td>Warped M.</td>
<td>$BD(25.155 + 0.148v^2)$</td>
<td>0.996</td>
</tr>
<tr>
<td></td>
<td>Disk</td>
<td>$BD(20.630 + 0.200v^2)$</td>
<td>0.997</td>
</tr>
<tr>
<td>2</td>
<td>Cylindrical M.</td>
<td>$BD(20.950 + 0.123v^2)$</td>
<td>0.988</td>
</tr>
<tr>
<td></td>
<td>Warped M.</td>
<td>$BD(24.371 + 0.066v^2)$</td>
<td>0.994</td>
</tr>
<tr>
<td></td>
<td>Disk</td>
<td>$BD(21.110 + 0.138v^2)$</td>
<td>0.998</td>
</tr>
</tbody>
</table>

For all implements and soils tested only this last equation each variable had a level of significance superior to 99,9%. The ranges of validity that can be stated for the bulk density, soil moisture content and forward speed in this equation are as followed:

$1,20 \leq BDD \leq 1,48$; $8 \leq H \leq 20\%$; $4,5 \leq v \leq 9 \text{ km/h}$
Fig. 2. - Specific draft force for different implements and soils given by the equation: \[ \sigma = \text{BD}_0(A + B\nu^2) \]

Soil cohesion restricts the validity of this equation whenever the soil is packed and dry, meanwhile the range of validity is restricted to those moisture contents where cohesion variations are too small in comparison to those obtained at lower moisture contents than 8\%. 

---

475
b) Swelling index \((e)\)

<table>
<thead>
<tr>
<th>Plot</th>
<th>Implement</th>
<th>Equation (e=)</th>
<th>Correlation coefficient ((r))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cylindrical M.</td>
<td>(20.64 - 2.06p + 43.17) BDD</td>
<td>0.537</td>
</tr>
<tr>
<td></td>
<td>Warped M.</td>
<td>(0.33 - 2.96p + 75.64) BDD</td>
<td>0.652</td>
</tr>
<tr>
<td></td>
<td>Disk</td>
<td>(18.83 - 0.57p + 15.32) BDD</td>
<td>0.592</td>
</tr>
<tr>
<td>2</td>
<td>Cylindrical M.</td>
<td>(-44.61 - 0.68p + 60.37) BDD</td>
<td>0.765</td>
</tr>
<tr>
<td></td>
<td>Warped M.</td>
<td>(5.015 - 0.459p + 82.96) BDD</td>
<td>0.522</td>
</tr>
<tr>
<td></td>
<td>Disk</td>
<td>(-69.26 - 0.756p + 82.96) BDD</td>
<td>0.522</td>
</tr>
</tbody>
</table>

In all the cases \(p\) and BDD had levels of significance over 90%.

c) Roughness \((R)\)

<table>
<thead>
<tr>
<th>Plot</th>
<th>Implement</th>
<th>Equation (R=)</th>
<th>Correlation coefficient ((r))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cylindrical M.</td>
<td>(74.51 - 2.05v)</td>
<td>0.360</td>
</tr>
<tr>
<td></td>
<td>Warped M.</td>
<td>(78.43 - 2.25v)</td>
<td>0.326</td>
</tr>
<tr>
<td></td>
<td>Disk</td>
<td>(85.93 - 3.17v)</td>
<td>0.435</td>
</tr>
<tr>
<td>2</td>
<td>Cylindrical M.</td>
<td>(63.05 - 3.05v)</td>
<td>0.512</td>
</tr>
<tr>
<td></td>
<td>Warped M.</td>
<td>(66.39 - 2.74v)</td>
<td>0.534</td>
</tr>
<tr>
<td></td>
<td>Disk</td>
<td>(83.75 - 4.56v)</td>
<td>0.668</td>
</tr>
</tbody>
</table>

Although the level of significance for the forward speed was over 90% the regression coefficients are very low because other variables, not measured in the trial, have to be taken in account.

d) Cone index \((CI)\)

<table>
<thead>
<tr>
<th>Plot</th>
<th>Equation (CI=)</th>
<th>Correlation coefficient ((r))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(5.75 - 0.168H)</td>
<td>0.884</td>
</tr>
<tr>
<td>2</td>
<td>(3.95 - 0.111H)</td>
<td>0.736</td>
</tr>
</tbody>
</table>

Soil moisture content significance level is 99.9%. From these two equations it is deduced that the cone index increases, for the same moisture content, with the content in clay and is also related to the draught specific resistance.

6. CONCLUSIONS

Certain equations may be stated to predict the specific resistance of the soil related to the forward speed of work and bulk density for each implement and type of soil. These equations have a certain range of validity. Their mathematic expression is similar to that of Gorjatschkin, although its range of validity is wider.
Several parameters have also been studied in order to achieve a correlation between them and the quality of work. This correlation between these variables has prove to be of a hight significative level.

7. BIBLIOGRAFIA


EFFECT OF TILLAGE AND STOVER MANAGEMENT ON SOIL TEMPERATURE

J.W. Ketcheson, P.H. Groenevelt, B.D. Kay, C.D. Grant

Department of Land Resource Science
University of Guelph
Guelph, Canada

Abstract

Soil temperature is critical for corn growth in temperate climates such as southern Ontario, Canada. Tillage and stover management influence temperatures throughout the year. Field plot studies indicate that zero tillage without surface stover gives higher soil temperatures in spring at seed depth (5 cm) than conventional ploughing. Stover on the surface gives a lower temperature. During winter, fall ploughing results in a greater accumulation of frost than from zero tillage. Zero tillage affects neither germination nor first month's growth of corn, final yield of grain is reduced. The role of temperature in grain yield requires further study.

Introduction

Increasing costs for energy and machinery requires maximum efficiency in tillage operations for crop production. Zero tillage for corn (*Zea mays* L.) is effective in reducing erosion on Ontario soils by leaving more residues on the soil surface, but yields are normally reduced with this practice (Table 1). This occurs on all soil textures except some coarse sands and gravelly loams. The reasons currently given for yield reductions with zero tillage are lack of pulverization or reduction of aggregate sizes and greater soil strength as reflected by higher penetrometer measurements (Ketcheson, et al., 1979).

Although soil temperature can be affected by tillage and can in turn affect crop growth (Ketcheson, 1970), temperature is not believed the reason for our observed yield depressions with zero tillage in Ontario (Vyn, et al., 1979). Our reason for believing this is the lack of any growth retardation on zero tillage during emergence and early growth stages when soil temperatures are most affected by tillage differentials.
Table 1: Effect of zero tillage on grain corn yields in Ontario, Canada.

<table>
<thead>
<tr>
<th>Texture</th>
<th>Sandy Loam</th>
<th>Loam</th>
<th>Silt Loam</th>
<th>Clay Loam</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976-1980</td>
<td>t/ha</td>
<td></td>
<td>t/ha</td>
<td>t/ha</td>
</tr>
<tr>
<td>Fall moldboard ploughed</td>
<td>6.2</td>
<td>5.6</td>
<td>5.4</td>
<td>4.8</td>
</tr>
<tr>
<td>Spring disc or cultipack</td>
<td>5.4</td>
<td>5.0</td>
<td>4.5</td>
<td>4.5</td>
</tr>
</tbody>
</table>


The purposes of this paper are to review tillage-related soil temperature regimes, to present recently-collected freeze-thaw data for ploughed and zero-tilled soils, and to discuss possible implications of tillage-induced soil temperature effects on crop yield.

Table 2: Effect of stover and tillage on soil temperature at seed-level (5 cm depth) and early corn growth. Well-drained loam, Vyn, T.J., et al., 1966.

<table>
<thead>
<tr>
<th>Soil Temperature</th>
<th>Plant Height (cm)</th>
<th>Max Plant Height (cm)</th>
<th>Mean Plant Height (cm)</th>
<th>Min Plant Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 24 to June 13</td>
<td>24</td>
<td>35</td>
<td>37</td>
<td>14</td>
</tr>
<tr>
<td>June 13 to 23</td>
<td>16</td>
<td>35</td>
<td>37</td>
<td>14</td>
</tr>
<tr>
<td>June 23 to 8</td>
<td>14</td>
<td>34</td>
<td>34</td>
<td>14</td>
</tr>
<tr>
<td>June 8 to 22</td>
<td>12</td>
<td>34</td>
<td>34</td>
<td>14</td>
</tr>
</tbody>
</table>

The stover was incorporated below the soil for zero tillage (Fig. 1). The cover was incorporated below the soil for zero tillage (Fig. 1).
surface in the ploughed soil but remained on the soil surface with zero tillage. Night (minimum) temperatures tended to be the reverse with equal or higher temperatures in zero-tilled soil.

1970 - On a moderately well-drained silt loam, day-time soil temperatures measured on zero-tilled field plots were approximately one degree C below ploughed soil (Table 3). Emergence and early plant heights did not reflect the May 8 and 15 temperature advantages of ploughed soil. July 23 heights and final yield were significantly higher on the ploughed soil.

Table 3: Effect of tillage on day time soil temperature, emergence and height of corn seedlings and corn yield. University of Guelph Research Station, Elora, 1970.

<table>
<thead>
<tr>
<th>Tillage</th>
<th>Day time temperature °C</th>
<th>Plant height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 cm depth</td>
<td>Emergence</td>
</tr>
<tr>
<td></td>
<td>May 8 May 15</td>
<td>June 2 June 13 July 23 Yield† t/ha</td>
</tr>
<tr>
<td>Moldboard ploughed in fall</td>
<td>9.0 13.6</td>
<td>66 8.3 122 176</td>
</tr>
<tr>
<td>disc, harrow in spring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zero tillage with corn stover remaining</td>
<td>7.9 12.8</td>
<td>66 9.6 119 167</td>
</tr>
</tbody>
</table>

†U 108 hybrid planted May 7.

Winter 1971-72 - studies on the effects of tillage on winter soil temperatures and freeze-thaw phenomena showed that zero tillage with corn stover on the soil surface collected a greater depth of snow than moldboard ploughing (Table 4). Frost penetration was corresponding less where snow cover was greater. The extra snow did not appear to persist longer in spring to prevent soil warm-up, never-the-less the ploughed surface allowed the enhanced frost accumulation below it to be dissipated and surface temperatures to equal or exceed those of the zero tillage by planting time.
Table 4: Effect of tillage on snow cover and accumulation of frost in loam soil, Hydrology Station, Guelph, February, 1972.

<table>
<thead>
<tr>
<th>Tillage</th>
<th>Snow depth</th>
<th>Frost accumulation†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm</td>
<td>C degree days</td>
</tr>
<tr>
<td>Moldboard ploughed</td>
<td>10</td>
<td>82</td>
</tr>
<tr>
<td>Zero tillage</td>
<td>30</td>
<td>15</td>
</tr>
</tbody>
</table>

† Degrees C below freezing point of soil multiplied by number of days prevailing.

Winter 1979–80 – Frost penetration, measured throughout the winter on a silt loam soil at Elora and on a silty clay loam soil at Milton, was greater with fall moldboard ploughing than with zero tillage. Water tables were high initially, but dropped rapidly in February, then rose again in March. The effect of frost on relative volumes of solids, air, and water (ice) before and after frost disappeared was more pronounced with ploughed than with zero-tilled soil. During melt, water apparently finds its way through melt channels in these frost layers before the frost disappears completely. Zero-tilled soil often loses its last traces of frost a few days prior to a corresponding occurrence in a ploughed soil.

Winter 1980–81 – A continuation of the frost-depth work of 1979–80 on the same soils confirmed that frost penetration was greater on ploughed than on zero-tilled soil, as illustrated by the data for the Elora soil (Fig. 2).

Fig. 2: Frost depths (solid lines) and frost depth ratio for Elora during the Winter 1980/81.
The highest ratio of ploughed/zero tillage frost depths occurred in late January at each site. Snow depth averaged 8 cm more on zero tillage than on ploughed soil. Snow reached a maximum depth of 36 cm by mid-February at Elora, and 28 cm by mid-January at Milton.

The amount of heave or increase in surface elevation from freezing corresponded with the depth of frost penetration. The Elora soil, in particular, developed a greater heave on the ploughed soil earlier than it did on the zero-tilled soil. If total frost was calculated (degrees < 0°C integrated over soil depth), ploughed soil contained ten times as much frost as zero-tilled soil at the time of greatest frost penetration (end of January).

Discussion and Conclusion

Superior tilth, which is often evident in fall ploughed soil compared with unplowed soil, has been attributed to various phenomena, including greater freeze-thaw action in the rough surface of the fall ploughed soil. Allmaras (1972) attributed the effect in Minnesota soils to greater heat storage through the winter and a warmer spring soil. In Ontario it appears that any warmth advantage for ploughed soil develops in the spring following a greater frost penetration during the winter. The more intense frost action in ploughed than in zero-tilled soil may help explain any tilth advantage in spring. More detailed studies of reconsolidation following ice lens formation and disintegration, together with the behaviour of plant roots is needed to fully evaluate frost action under different tillage-residue management regimes.

Zero-tilled soil can exhibit a desirable structure with good aggregation of the soil particles. However, these aggregates fit closely together unless disturbed by tillage. Without disturbance, bulk density and resistance to root penetration appear too high for maximum yield. Early growth with zero-tille is not different from ploughed soil. This may be due to the localized disturbance by the planter in the vicinity of the seedling. Later growth exhibits retardation, possibly due to the root system encountering undisturbed soil, or sub-optimal soil temperatures in the stover covered interrow space. The role of soil temperature in plant growth under different tillage regimes is not clear. From temperature measurements taken in the planting row (and in the absence of surface stover), it appears that soil temperature may not be responsible for corn...
yield reductions on Ontario soils. However, coupled with higher mechanical resistance, there may be a less favourable temperature regime (due in part to residue cover) in the interrow space. Furthermore, while mean temperatures may be similar for ploughed and zero-tilled soil, the range between minima and maxima may differ (ploughed soil may reach higher temperatures in day and lower temperatures at night than stover-covered zero-tilled soil).

We conclude, for our soil and climate conditions in Ontario, greater attention must be given to different tillage regimes and the management of residues resulting from each. Effects on soil temperature and soil structure as they affect plant growth should be of particular concern in such studies. Plant genotypes selected for one particularly tillage regime may not be best suited to some of our current regimes.

References


INFLUENCE OF DIFFERENT SOIL TILLAGE IMPLEMENTS ON YIELDS AND ON SOME CHEMICAL AND PHYSICAL SOIL PROPERTIES IN A LONG TERM EXPERIMENT

A. Maillard and A. Vez,
Federal Agricultural Research Station Changins, CH-1260 Nyon (Switzerland)

Abstract

The effects of ploughing, chisel-ploughing, reduced tillage and direct drilling are compared in a clay humic soil and in a loamy soil since 1970. The total pore space and the air capacity at pH 2 (0.1 bar) are higher in the tilled plots than in those of direct drilling. This latter tillage implement caused a marked increase of the organic matter, P2O5 and K2O contents in the top layer of the soil, as well as a better soil aggregate stability. After a start period of adaptation, the wheat grain yields have been always higher in the direct drilled plots in comparison with the three other tillage implements since 1977.

Introduction and experimental design

This present experiment was carried out to investigate the possibilities and the long term effects of four different soil tillage implements. This trial was started in 1970 on two different soil types in Changins and includes the following treatments in a split plot design:

- **Main treatment:**
  1. Ploughing (20-25 cm)
  2. Chisel-ploughing (25-30 cm)
  3. Reduced tillage (5-10 cm)
  4. Direct drilling (0-5 cm)

- **Sub-unit treatment:**
  1. Normal N fertilization N
  2. Fertilization N + 30

- **Soil type:**
  A = clay humic soil (51% clay, 22% silt, 5% org. matter)
  B = loamy soil (26% clay, 22% silt, 2% org. matter)

- **Crop rotation:**
  wheat - maize - wheat - rape

- **Size of the plots:** 160 m²
Number of replicates: 3 in the (A) soil and 4 in the (B) soil

Results and discussion

1. Effects on some chemical and physical soil properties

When we consider the two extreme soil tillage implements only (treatments 1 and 4), the porosity of the top soil layer indicates about the same evolution in both soil types (Fig. 1). Over the 12 experimental years, the tilled plots, which were checked each year in April, have a higher total pore space and a higher air capacity (0.1 bar) than those of the direct drilling. Similar results were found in another trial in Changins (VEZ, 1979a) and abroad (HANSEN and RASMUSEN, 1979).

Concerning the soil aggregate stability (method of HENIN, 1969), the results indicate a better soil structure in the clay humic soil (A) than in the loamy soil (B). The higher clay and organic matter contents in the former soil are mainly responsible for those differences (HARTGE, 1978). In both trials, we observed a decrease of the soil aggregate stability in the tilled plots in comparison with the three other tillage implements (Table 1). This is due mainly to a higher content of organic matter that was found in the plots of reduced tillage and direct drilling particularly (VEZ, 1979b).

Finally, the results of the P₂O₅ and K₂O contents in the soil indicate in both soil types a significant accumulation of these fertilizing nutrients in the top layer (0-10 cm) of both reduced tillage and direct drilling practices (Table 1). These observations have been found already in many fields experiments (VEZ, 1972; KAHNT, 1976).

2. Effects on yields

When we consider the wheat grain yields over the 6 years of trial (B), the analysis of variance indicates that the differences between the four tillage implements are not significant in both soil types (Table 2). However, we can notice that the yields have been lower in the tilled plots since 1977 in comparison with the three other tillage implements. This evolution is more representative in the clay humic soil (A) than in the loamy soil (B). Many factors have contributed to this situation. In the first experimental years, we did not get quite under control all the technical restraints of these new tillage implements (2, 3, 4) and had some problems with the grass weeds (Agropyron repens). Last but not least, the improvement of the chemical and physical soil properties took some years
Table 2 - Effect of different soil tillage implements on the wheat grain yields (%)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A = CLAY HUMIC SOIL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Ploughing</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>(100)</td>
</tr>
<tr>
<td>2. Chisel</td>
<td>101.3</td>
<td>104.1</td>
<td>91.5</td>
<td>112.9</td>
<td>108.6</td>
<td>117.0</td>
<td>(105.9)</td>
</tr>
<tr>
<td>3. Red. tillage</td>
<td>100.4</td>
<td>106.8</td>
<td>87.1</td>
<td>110.2</td>
<td>112.0</td>
<td>123.5</td>
<td>(106.6)</td>
</tr>
<tr>
<td>4. Direct drilling</td>
<td>95.6</td>
<td>97.0</td>
<td>86.8</td>
<td>114.7</td>
<td>118.3</td>
<td>127.2</td>
<td>(106.6)</td>
</tr>
<tr>
<td><strong>LSD 5%</strong></td>
<td>n.s.</td>
<td>n.s.</td>
<td>8.0</td>
<td>5.8</td>
<td>9.0</td>
<td>14.1</td>
<td>(n.s.)</td>
</tr>
<tr>
<td><strong>B = LOAM SOIL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Ploughing</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>(100)</td>
</tr>
<tr>
<td>2. Chisel</td>
<td>95.4</td>
<td>100.9</td>
<td>84.0</td>
<td>102.0</td>
<td>115.1</td>
<td>113.7</td>
<td>(101.8)</td>
</tr>
<tr>
<td>3. Red. tillage</td>
<td>96.1</td>
<td>100.7</td>
<td>87.7</td>
<td>100.2</td>
<td>108.6</td>
<td>111.9</td>
<td>(100.8)</td>
</tr>
<tr>
<td>4. Direct drilling</td>
<td>89.1</td>
<td>94.1</td>
<td>90.2</td>
<td>107.8</td>
<td>117.8</td>
<td>118.8</td>
<td>(102.9)</td>
</tr>
<tr>
<td><strong>LSD 5%</strong></td>
<td>4.3</td>
<td>n.s.</td>
<td>4.5</td>
<td>6.9</td>
<td>5.9</td>
<td>6.6</td>
<td>(n.s.)</td>
</tr>
</tbody>
</table>

n.s. = not significant

until they could affect the yields positively.

Conclusion

The large range of available herbicides and tillage implements allows nowadays an appreciable reduction of the seed bed preparation for cereals without any decrease of the grain yields.

In Switzerland, chisel-ploughing and reduced tillage are both soil cultivation techniques that many farmers are already practising. Yet, they are still reserved regarding the direct drilling.

Literature


Table 1 - Effect of different soil tillage implements on the organic matter, P$_{205}$, K$_{20}$ contents in the soil and on the aggregate soil stability (0-10; 10-20 cm).

A = CLAY HUMIC SOIL

<table>
<thead>
<tr>
<th></th>
<th>1975</th>
<th>1981</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORGANIC MATTER %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Ploughing</td>
<td>4,80</td>
<td>4,90</td>
</tr>
<tr>
<td>2. Chisel</td>
<td>4,90</td>
<td>4,80</td>
</tr>
<tr>
<td>3. Red. tillage</td>
<td>5,37</td>
<td>5,03</td>
</tr>
<tr>
<td>4. Direct drilling</td>
<td>5,46</td>
<td>4,87</td>
</tr>
</tbody>
</table>

LSD 5% n.s. n.s. n.s. n.s. 0,21  n.s. 0,62 n.s.

P$_{205}$ - INDEX (0,0356 mg/100 g soil)

<table>
<thead>
<tr>
<th></th>
<th>1975</th>
<th>1981</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ploughing</td>
<td>6,8</td>
<td>9,8</td>
</tr>
<tr>
<td>2. Chisel</td>
<td>7,8</td>
<td>5,2</td>
</tr>
<tr>
<td>3. Red. tillage</td>
<td>14,6</td>
<td>5,2</td>
</tr>
<tr>
<td>4. Direct drilling</td>
<td>22,3</td>
<td>6,5</td>
</tr>
</tbody>
</table>

LSD 5% 7,3  n.s. 3,1  n.s. 5,6  n.s. 5,4  n.s.

K$_{20}$ - INDEX (mg K$_{20}$/100 g soil)

<table>
<thead>
<tr>
<th></th>
<th>1975</th>
<th>1981</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ploughing</td>
<td>0,87</td>
<td>0,83</td>
</tr>
<tr>
<td>2. Chisel</td>
<td>0,93</td>
<td>0,66</td>
</tr>
<tr>
<td>3. Red. tillage</td>
<td>1,26</td>
<td>0,60</td>
</tr>
<tr>
<td>4. Direct drilling</td>
<td>1,60</td>
<td>0,66</td>
</tr>
</tbody>
</table>

LSD 5% 0,39  n.s. 0,20  n.s. 1,13  n.s.  n.s.  n.s.

AGGREGATE STABILITY S

<table>
<thead>
<tr>
<th></th>
<th>1979</th>
<th>1981</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ploughing</td>
<td>1,06</td>
<td>1,56</td>
</tr>
<tr>
<td>2. Chisel</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3. Red. tillage</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4. Direct drilling</td>
<td>0,66</td>
<td>0,63</td>
</tr>
</tbody>
</table>

LSD 5% n.s. n.s. n.s. 0,18  n.s. n.s. 1,05  n.s.

1) The aggregates are all the more stable as the index S is low. n.s. = not significant
Fig. 1 - Evolution of the total pore space in % and the air capacity at pH 2 (0.1 bar) in tilled and untilded plots (top layer of the soil, 0-20 cm)

A CLAY HUMIC SOIL

B LOAMY SOIL

(1) Tilled plots
(4) Untilled plots
ABSTRACT

The results of a series of seven tillage trials conducted on soils of varying clay content in South Africa are discussed. Soils with a high fine sand content compacted easily and required special rip under row and controlled traffic techniques if maize yields were to be maintained in seasons of unfavourable moisture supply.

The heavier soils displayed few problems due to compaction. Where no-till maize was planted on a heavy soil fairly high bulk densities developed near the surface but this phenomenon did not restrict either root or moisture penetration and grain yields were excellent.

An automatic recording penetrometer was used to obtain computer print-out soil strength profile plots. These print-outs proved extremely valuable. They also demonstrated how easily secondary cultural practices recompact even deeply loosened profiles in a single season.

INTRODUCTION

In 1966 a comprehensive tillage research programme was launched in Rhodesia (Grant, 1968) and fully reported on by Rankin (1975) who concluded that the presence and relative depth of hard layers created by ploughing had an important influence on maize yield, this being especially so when plant available water was limiting. Koch (1974) in South Africa showed that soils with a high percentage of fine wind blown sand and a low clay content were very susceptible to compaction requiring special ripping and controlled traffic management techniques. Mallett (1972) initiated a maize direct drilling research programme but because of weed problems (Cyperus esculentus) has as yet not been able to recommend the system to commercial growers, although recent herbicide developments look promising.
The fossil fuel crisis generated serious interest in tillage investigations and the Summer Grain Centre, a South African commodity oriented research organisation instituted a 'tillage team' in 1976 to investigate tillage problems on the most important maize producing soils. Other research organisations engaged in the production of sugarcane, grapevines and winter cereals also launched tillage research programmes albeit on a smaller scale.

Although the consequences of compaction upon root growth and yield have been well documented (Trouse, 1971), little positive local evidence existed for specific soil types, conditions or situations. The initial objective of the Summer Grain Centre's tillage team was therefore to develop a relationship between the minimum amount of primary tillage necessary and soil type in the most important producing maize areas. As it was anticipated that the various soils would react differently, a series of trials was planned on a representative range of soil types.

MATERIALS AND METHODS

Seven tillage trial sites representing 80\% of the soils under maize in South Africa were selected. These varied from a deep well drained clay loam in the humid east to a fine wind blown sand overlaying clay at 900 mm in the drier west. A list of the sites selected appears in Table 1. The precipitation, although given as annual rainfall occurs mainly during October through March with the winters being virtually dry.

Table 1. Siting, soil type and annual rainfall of tillage trials.

<table>
<thead>
<tr>
<th>Site</th>
<th>Soil Type</th>
<th>Clay content of B21 horizon (o/o)</th>
<th>Annual Rainfall (mm)</th>
</tr>
</thead>
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<tr>
<td>Cedarab</td>
<td>Hutton</td>
<td>45</td>
<td>890</td>
</tr>
<tr>
<td>Winterton</td>
<td>Avalon</td>
<td>38</td>
<td>710</td>
</tr>
<tr>
<td>Winterton</td>
<td>Hutton</td>
<td>34</td>
<td>710</td>
</tr>
<tr>
<td>Dundee</td>
<td>Avalon</td>
<td>18</td>
<td>790</td>
</tr>
<tr>
<td>Schweizer Reneke</td>
<td>Bainsvlei</td>
<td>16</td>
<td>430</td>
</tr>
<tr>
<td>Viljoenskroon</td>
<td>Avalon</td>
<td>8</td>
<td>590</td>
</tr>
<tr>
<td>Viljoenskroon</td>
<td>Avalon</td>
<td>3</td>
<td>590</td>
</tr>
</tbody>
</table>

The tillage treatments imposed were limited to varying degrees of primary tillage and comprised direct drilling, offset disc to 100 mm, rip to 250 mm and 450 mm and moulboard plough to 250 and 450 mm. The direct drill treatment was only carried out at Cedara, a sophisticated research station where weed control which has proved a serious problem in no-till situations, could be carefully exercised. All other trials were conducted off-station. On the three sites with clay contents below 18°/o, rip below the row and traffic control treatments were included.

The field programme was commenced in season 1977/78 and maize was planted annually at each site. Besides measuring grain yield, profile pits were dug in each plot of one replication at each site every season. Rooting pattern descriptions were made and soil cores taken for bulk density and particle size analysis. Soil strength determinations were made by means of a hand held penetrometer.

It soon became obvious that penetrometry would provide the best picture of the effect traffic and implements were having upon the soil. However, using a hand held penetrometer proved too slow and labour intensive. It was therefore decided to design and build an automatic recording instrument.

In 1979 the construction of a traversing automatic recording constant speed penetrometer was completed (Mallett, Erasmus & Whittal, 1981). This instrument made a recording on magnetic tape, of force values at 1 mm depth increments as a cone was forced into the soil to a maximum depth of 1 m. Sixty-five probings were made in a single 3.2 m traverse. A computer soil strength contour plot of the 3.2 x 1 m profile was then produced. Before using the penetrometer the site was wet to field capacity to eliminate differences in soil strength due to moisture content.

RESULTS

ROOT STUDIES revealed vast differences in proliferation between soil series regardless of tillage treatment. The higher the clay content the more profuse the root system. Root growth was severely restricted and frequently inhibited below wheel tracks in the sands and although some restriction was noted in the heavier soils the problem was not nearly as serious. Rip under the row and controlled traffic techniques definitely enhanced root growth on the sands. If some roots from each plant penetrated to deep moisture reserves, yields were maintained but where dense layers restricted all deep root growth, yields declined drastically in dry seasons.

GRAIN YIELDS. Over the five year report period there were no differences in grain yield between tillage treatments on the four sites with clay contents of 18°/o and above. Root studies revealed that although compaction in the shallow disc and moulboard plough treatments excluded roots from large volumes of soil in the Avalon series (clay content 18°/o), a small proportion of roots penetrated deeper layers, enabling the crop to obtain sufficient moisture supplies to produce normal yields.
On the sandy sites (Bainsvlei, Bleaksand and Viljoenskroon series), yields were adversely affected during seasons of poor rainfall supply or distribution on all plots with shallow tillage or moulboard plough treatments. During these seasons the rip over row treatments always proved superior.

**BULK DENSITY** determinations were made below the row and between rows at regular depth intervals. Tractor and implement wheel compaction could be easily identified having values of 1.5 g/cc in the clays and over 1.7 in the sandiest soil. Values of 1.5 in soils with clay percentages up to 18% inhibited root growth while bulk densities of 1.5 in the heavier soils allowed some root penetration.

Although these findings were informative the limited intensity of sampling and the lack of replication made cause and effect interpretations difficult.

The adoption of controlled traffic techniques proved most effective in reducing the proportion of compacted soil in the potential root zone.

**SOIL STRENGTH.** The hand held penetrometer used initially to obtain an indication of changes in soil strength brought about by the different tillage treatments proved informative but clear and consistent patterns were difficult to identify. The handling and processing of the mass of data obtained from even a single day in the field was a mammoth task so that a tractor transported constant speed automatic recording penetrometer mounted on rails that allowed a 3.2 m traverse was built and first used in season 1979/80 (Mallett et al., 1981). The computer print-outs obtained from the processed field data gave a very clear indication of the changes brought about by the various tillage treatments. These print-outs were in the form of soil strength contour plots and a number of them are reproduced in Figs. 1 to 6. The examples selected clearly illustrate the degree of detail obtainable.

Possibly one of the most striking features of the print-outs is the absence of the beautifully uniform layers so often seen in the literature. This would explain why the results obtained from limited probings with hand held penetrometers were so confusing.

Fig. 4 showing the results obtained from a profile that had not been wet, clearly illustrates the problems that arise if the penetrometer was used when differential soil moisture patterns existed in the profile. In this case it was not possible to distinguish between high soil strength values resulting from compaction and zones dried out by the roots of the crop.

**DISCUSSION AND CONCLUSIONS**

Before the soil strength contour print-outs became available with the introduction of the automatic recording penetrometer there appeared to be no consistent or predictable treatment response pattern. The print-outs soon demonstrated that even big initial differences in loosened soil volumes between treatments were largely eliminated once secondary operations such as seedbed preparation, planting, side-dressing and pest control had been carried out.
FIG. 1. Despite deep ripping (500mm), subsequent passes with tractors and machinery in the same season effectively re-consolidated the loosened profile.

FIG. 2. Note dense layer just below surface in no-till plot. Despite this, root and moisture penetration was excellent.

FIG. 3. This plot was deep ripped in 1979. No further ripping took place before penetration readings were made in March 1981. Strict controlled traffic practices since then have accounted for the preservation of the ripped zones.

FIG. 4. This print-out illustrates the misleading nature of data obtained from a profile that had not been pre-wet to field capacity. Note the high soil strength values recorded directly under the crop row due to moisture removed by the crop.

FIG. 5. Here wheel tracks were ripped at time of last field operations resulting in increased volume of loosened soil and higher yields on sandy soils in dry seasons.

FIG. 6. Note extremely dense zone below plough depth and current season wheel track compaction effect.
This together with the fact that root growth was generally more profuse on the heavier soils explained why no differences in grain yield were recorded on these soils. On the sands where root growth was more sparse, yield advantages were recorded in dry seasons on plots where treatments such as rip-under-row allowed deeper root penetration.

The direct drilling treatment was only conducted at Cedara on a Doveton soil with a 45\% clay content. Penetrometer print-outs showed that a fairly dense layer had developed in the top 250 mm but because this was undisturbed it was easily penetrated by new roots and precipitation via channels created by insects, worms and past roots. Similarly high bulk densities (1.6 g/cc) in disturbed surface soil layers in conventionally tilled profiles would in all probability have been disastrous.

This programme has demonstrated the folly of conducting tillage trials without comprehensive back-up programmes involving detailed soil physics studies. It was only after a clear picture of the physical changes brought about by different tillage operations became available that logical explanations for yield responses could be made.

BIBLIOGRAPHY

GRANT, P.M. 1968. The effect of depth of ploughing on maize yields and soil properties. (Rhodesian experiments). In 'Soil Tillage in the Tropics'. Supplement to Modern Farming, June, 1888.


EFFECTS OF MECHANICAL AND PNEUMATIC SUBSOIL LOOSENING ON THE PHYSICAL PROPERTIES AND CROP YIELDS OF 3 DIFFERENT TYPES OF SOILS

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*This paper has been prepared at the Institute for Soil Science of the University of Bonn, Federal Republic of Germany.
INTRODUCTION


The latest developments in the field of loosening devices are the stroke-tilting loosener ("Stechhubblockerer") and a pneumatic loosener. The stroke-tilting loosener is expected to produce a very intensive loosening of the subsoil, while the pneumatic loosener is suited above all for special crops, steep slopes and park areas. The effect of these two looseners on the physical soil properties, root growth and crop yields was to be ascertained by field tests with three different types of soils.

TEST SITES

To investigate the effect of the looseners, an evaluation was made of loosening experiments carried out by Dr. Schulte-Karring on a pseudogley soil near Ahrweiler consisting of solifluxion debris of loess and grauwacke weathering material with small portions of grey loam, a deposal near Ahrweiler consisting of deposited weathering material of grauwacke and argillaceous schist and a vertisol-pelosol (Smonica) in the area of Bad Kreuznach consisting of tertiary clay marl. In the Ahrweiler region mean annual precipitation amounts to 600 mm; average temperature is 8.5 °C. In Bad Kreuznach mean annual precipitation is 525 mm, mean annual temperature 9.5 °C. For further details regarding the test sites see MARTINOVIC (1982).

METHODS USED

Testing started in autumn 1979 under favourable conditions. The first soil-physics tests were carried out in autumn 1980, the subsequent tests in spring 1981. In each case, samples were taken
at 4 different depths with eightfold replication. The statistical evaluation was based on a multi-factorial analysis of variance.

The data were obtained using the following test methods:

1. Air volume by pycnometer according to LANGEN, water volume by drying of samples, the temperature being 105 °C (vol.%).
2. Total pore volume (vol.%): the sum of air and water volumes constitutes the total pore volume.
3. Distribution of pore sizes (vol.%): according to RICHARDS and FIREMAN (1943), partly with "undisturbed" soil samples according to RICHARDS (1949), partly with "disturbed" samples.
4. Density of compaction (g/cm³): from net weight of cylinder samples.
5. Water permeability (k_f): as prescribed by HANUS (1964) calculating the coefficient of permeability according to HANUS and FRANKEN (1967).
6. Infiltration (mm/s): with double-ring infiltrometer in the field according to DIN 19682 (1972).
7. Resistance to shearing (cm/kp): according to SCHAFFER (1960).

RESULTS AND DISCUSSION

1. Soil-physics properties

In the first year following subsoil loosening, the pore volume had been increased very substantially on the mechanically loosened plots at all 3 sites as compared with the plots not loosened. Pneumatic loosening produced a marked rise in pore volume on the pseudogley whereas the rise was minor on the deposol and vertisol soils. In the second year after subsoil loosening, the pore volume showed a slight decrease as against the first year.

At all three sites the volume of coarse pores was increased very
considerably by mechanical loosening, but only slightly by pneumatic loosening. At the end of the second test year the volumes of coarse pores fell insignificantly but remained high enough to ensure sufficient percolation and aeration of the soil.

Both loosening procedures caused negligible changes in the effective field capacity on the sites being investigated. Nevertheless, as a result of subsoil loosening, the plants are altogether supplied with more water than before because they can extract it from a wider soil space. This is attributable to the fact that the density of compaction has been reduced considerably as was proved by measurements using the neutron probe. At the same time, the mechanical compactness has become less as well. The values ascertained for the resistance to shearing show a decline especially on mechanically loosened soils allowing an intensive root growth.

Owing to the rise in pore volume, particularly in the coarse pore volume, the water permeability was increased substantially (Table 1).

It may be seen that maximum water permeability occurs at depths between 0 and 30 cm and that there are no major differences among the alternatives. In these cases, soil tilling activities have overlapped the differences caused by subsoil loosening. At all 3 sites water permeability at depths between 30 and 50 cm has been improved slightly by pneumatic subsoil loosening, but very remarkably by mechanical loosening. At depths between 50 and 70 cm conditions are very similar. As mechanical subsoil loosening extends to a maximum depth of 80 cm, water permeability reaches a minimum at depths between 70 and 100 cm. It is conspicuous, however, that in pneumatically loosened subsoils water permeability at these depths is altogether higher than in mechanically loosened or unloosened subsoils. The reason for this is that pneumatic subsoil loosening reaches down to a depth of up to 1 m. Proof of a substantial improvement of the water permeability was also furnished by determining the rate of infiltration in double-ring infiltrometers. Furthermore, increased water conductivity of the soils was reflected in a conspicuous change in water dynamics. Whereas
Table 1: Water permeability (kf cm/s $ \cdot 10^{-4}$)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Year</th>
<th>Depth cm</th>
<th>Soil type</th>
<th>Soil type</th>
<th>Soil type</th>
<th>Soil type</th>
<th>x-Treatment</th>
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<td>No loosening</td>
<td>1980</td>
<td>0-30</td>
<td>36.5</td>
<td>9.1</td>
<td>121.5</td>
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<tr>
<td></td>
<td>1981</td>
<td>0-30</td>
<td>155.0</td>
<td>205.0</td>
<td>19.5</td>
<td>126.5</td>
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<tr>
<td></td>
<td>1981</td>
<td>0-30</td>
<td>200.0</td>
<td>63.5</td>
<td>55.0</td>
<td>106.1</td>
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<td>91.7</td>
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<tr>
<td></td>
<td>1981</td>
<td>0-30</td>
<td>175.0</td>
<td>225.0</td>
<td>14.4</td>
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<td>3.8</td>
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<td>70-100</td>
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<td>0.4</td>
<td>4.9</td>
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<td>0.59</td>
<td>LSD5%</td>
<td>8.93</td>
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</table>
on untreated plots rainwater penetrates the soil only approximately 40 cm deep, which means that deeper soil layers remain dry even during the winter season, it percolates into the ground of treated plots right down to the loosened subsoil. Unconfined water may run off freely. Thanks to the improved water dynamics plants are supplied with more water than before.

2. Root growth and crop yields

The reduction of the density of compaction and mechanical compactness of the soils, the improvement of the water conductivity and aeration as well as the rise in the water-holding capacity of the subsoil have favoured an intensive growth of roots. Mechanical loosening in particular and, to a small extent, pneumatic loosening have brought about an intensified root inhabitation in the subsoil. As a result, water and nutrients in the deeper soil layers can be exploited as well. Besides, the roots in the subsoil help to convert the mechanically formed and consequently relatively weak primary structure into a stable secondary structure.

Intensification of root inhabitation accompanied by an improvement of the nutrient and water transport has resulted in increased crop yields on loosened soils (Table 2). At all 3 sites the size of the increases in crop yields attributable to mechanical subsoil loosening was most impressive; pneumatic loosening, too, produced moderate increases in crop yields. The additional yields by far exceed the costs incurred. As crop yields were equally high in the second year, it is to be expected that the loosening effect will last for many years.

As regards pneumatic loosening, the breaking-up effect has to be intensified by applying higher air pressure. The loosening gear has already been appropriately adapted. In addition, this gear permits loosening to a greater depth as well as the application of fertilizers and the insertion of synthetic soil improvement material (Styroperl) for stabilizing the crevices formed by loosening. In spring-time, tillage of loosened soils can be started earlier as the loosened soil dries up more rapidly. Another advantage is that the towing force requirement is less on these
### Table 2: Crop yields (dt/ha)

#### Pseudogley

<table>
<thead>
<tr>
<th>Year and Crops</th>
<th>1980</th>
<th>1981</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No loosening</td>
<td>38.42</td>
<td>50.72</td>
<td>44.57</td>
</tr>
<tr>
<td>Pneum. loosening</td>
<td>40.20</td>
<td>52.23</td>
<td>46.22</td>
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<tr>
<td>Mech. loosening</td>
<td>46.34</td>
<td>58.07</td>
<td>52.20</td>
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<tr>
<td>X Crop/Year</td>
<td>41.65</td>
<td>53.67</td>
<td>47.66</td>
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LSD 5% Treatment = 6.78

#### Deaposol

<table>
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<th>X</th>
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</thead>
<tbody>
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<tr>
<td>Pneum. loosening</td>
<td>26.46</td>
<td>27.51</td>
<td>26.98</td>
</tr>
<tr>
<td>Mech. loosening</td>
<td>28.96</td>
<td>40.41</td>
<td>34.68</td>
</tr>
<tr>
<td>X Year</td>
<td>26.92</td>
<td>31.65</td>
<td>29.28</td>
</tr>
</tbody>
</table>

LSD 5% Treatment = 5.43

#### Smonica

<table>
<thead>
<tr>
<th>Year and Crops</th>
<th>1980</th>
<th>1981</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No loosening</td>
<td>59.33</td>
<td>36.60</td>
<td>47.96</td>
</tr>
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<td>66.89</td>
<td>38.35</td>
<td>52.62</td>
</tr>
<tr>
<td>Mech. loosening</td>
<td>73.02</td>
<td>50.62</td>
<td>61.82</td>
</tr>
<tr>
<td>X Crop/Year</td>
<td>66.41</td>
<td>41.85</td>
<td>54.13</td>
</tr>
</tbody>
</table>

LSD 5% Treatment = 3.81
soils. The areas loosened mechanically and pneumatically should preferably not be submitted to deep and intensive but, instead, rather careful tillage in order to avoid a recompaction of the soils.

SUMMARY

In 1979, subsoil loosening tests were started on a pseudogley and a deposal soil in the Ahrweiler region and on a vertisol-pelosol (Smonica) in the Bad Kreuznach region to investigate the efficiency of a new mechanical loosening device ("Stechhublocker-l-stroke-tilting looser") and a pneumatic loosening gear ("Terralift"). In 1980 and 1981 soil-physics tests were carried out and the numbers of roots and crop yields were ascertained. The main results of these tests may be summarized as follows:

1. The soil-physics properties and the water dynamics were improved substantially by mechanical loosening and slightly by pneumatic loosening.

2. Root numbers and crop yields rose markedly as a result of mechanical loosening but only moderately by pneumatic loosening.

3. In the meantime, the efficiency of the pneumatic loosening gear has been improved by applying a higher air volume and air pressure.

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THE EFFECT ON SOME FIELD-MEASURED SOIL PHYSICAL PROPERTIES OF RESTRUCTURING A SOIL MECHANICALLY

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ABSTRACT

Results of careful field measurements of hydraulic conductivity, thermal conductivity and soil temperature are presented which show that the restructuring effects of tillage can be quantitatively assessed despite the associated problem of soil spatial variability.

INTRODUCTION

There are still gross deficiencies in our understanding of the relationship between tillage and plant development (Hadas et al., 1978). This is due in large measure to a lack of precise quantitative data with which to describe both soil structure per se (Greenland, 1977) and, moreover, how this structure is changed by tillage, particularly through changes in physical properties that are most important in influencing plant development and yield (Hadas et al., ibid.). With this priority in mind, our research programme has included, over a number of years, attempts to make field measurements of soil physical properties relevant to plant performance and also to evaluate changes in these properties brought about by various controlled tillage operations.

At the last ISTRO conference in 1979 we displayed some field data on hydraulic and thermal properties of a soil subjected to various idealised tillage treatments. An implicit shortcoming of these results was a large experimental uncertainty which made it difficult to define causal relationships between the behaviour of these properties and the interactive effect of tillage. This is a common problem in determining soil properties on a field scale, since they are complicated by variations in soil structure both with depth and areally (Greenland, 1977; Keising et al., 1977). Also many of the properties are time dependent, either because the soil structure changes and/or soil water content or temperature alters. In determining the precise effects of tillage on soil physical properties, therefore, it is important
that uncertainties due to these effects within one treatment are both known and minimised so that the significance of differences between treatments can be assessed. Such a requirement can only be met by considerable replication of physical measurements both spatially and temporally. For this to be practicable, a greater control of instrument operation and of data collection and analysis is demanded than is possible manually. In the period since 1979, therefore, we have automated in situ physical measurements wherever possible and applied computer control to data collection and analysis (North, 1980). We present here some findings on the effect of a simple, though carefully controlled, tillage treatment on the hydraulic conductivity, water storage, thermal conductivity and temperature of a silty clay loam soil.

METHODS

Site
The experiment was carried out in 1980 at a specially developed field site (Legg et al., 1978). A series of concrete tractor-ways are provided so that experimental plots can be tilled at virtually any water content whilst maintaining traction and avoiding wheel compaction; they also permit access to instrumentation without trampling of plots. The whole experimental area (420 m²) is covered automatically by two mobile shelters at the onset of rain, thereby allowing tillage to be performed at a desired soil water content by suitable irrigation of the plots. Remote scanning units are housed on-site to multiplex the analogue signals from the numerous sensors located in the experimental plots and to convert these signals to digital form for transmission on a single data line to an HP1000 computer located at the edge of the site: this minimises both cable cost and undesirable signal noise.

Treatments and measurements
Our experimental design was simple in order to limit the number of variables and minimise instrument replication. Comparison was made between a soil uniformly tilled to 30 cm at a pre-adjusted water content (mean profile water content of 0.22 v/v) and the same soil left undisturbed and fallow for two years. Each treatment was triplicated in plots 9.2 m x 2.3 m: all plots remained fallow throughout the experiment. The tillage operation, although recognised as unconventional, was devised to restructure the soil in such a way as to restrict soil spatial variability over the plot area, particularly in the direction perpendicular to implement travel. It consisted of initial deep tine cultivation to 30 cm followed by deep reciprocal power-harrowing to
the same depth.

Soil measurements capable of automation were profiles of temperature (using thermocouple probes), thermal conductivity, $\lambda$, (by a line heat-source method) and water potential (using soil tensiometers linked to a pressure transducer). Details of these measurement techniques are to appear in the literature shortly. In addition, manual measurements of soil water content, $\theta_v$, (by neutron probe) were made and soil cores extracted to determine total porosity and a measure of pore size distribution. All these measurements were made on all plots and replicated within each plot.

Hydraulic conductivity, $K$, was determined at several depths between 0 and 30 cm using the instantaneous profile method (Rose et al., 1965), it being derived from the ratio of instantaneous values of soil water flux and hydraulic head gradient at a given depth. The one dimensional drainage of a profile therefore provides, through the elimination of the time variable, a relationship between $K$ and $\theta_v$ which is characteristic of the pore size distribution of the soil. In a similar way, the time course of water loss from the soil profile was utilised to give the $\lambda-\theta_v$ relationship at various depths. In both relationships we were mainly concerned with the wet range since this represents changes in physical properties due to the movement of water in the coarse and transmission pores, that is, pores greater than approximately 50 $\mu$m equivalent cylindrical diameter (ecd), which are those most affected by tillage.

RESULTS AND DISCUSSION

Hydraulic conductivity

Drainage was found to be less rapid on the restructured treatment in the 24 hour period following saturation. For example, at 25 cm depth one hour after drainage had commenced, drainage fluxes on the restructured and undisturbed treatments were 35 and 130 mm d$^{-1}$, respectively. Fluxes became similar (~7 mm d$^{-1}$) on both treatments after a day and declined to an approximately constant value of about 1 mm d$^{-1}$ after seven days. Associated with these flux changes was a decrease in soil-water pressure, the minimum measured for both treatment profiles after seven days being -40 mbar at 5 cm depth.

Hydraulic head gradients were nearly constant with depth for both treatments, although less in magnitude on the restructured treatment, and did not show as marked a variation with time as did flux over this drainage period.

Derived $K-\theta_v$ relationships showed for both treatments the important effect water content has on $K$, the latter decreasing by at least two orders of
magnitude at all depths for a 50% fall in \( \theta_w \). Restructuring the soil had, except near the surface (5 cm depth), decreased its conductivity markedly, and at some water contents the difference was as much as one order of magnitude. This implies a loss of larger pores due to restructuring, a result that is qualitatively consistent with a simple interpretation of the moisture characteristics derived from our in situ measurements of soil-water pressure and water content. The first derivative of such characteristics gives a measure of pore size distribution (albeit for an idealised porous medium) and, compared to the distribution for the undisturbed soil, the maximum of the distribution for the restructured soil at most depths was shifted towards smaller pore diameters and was accompanied by a decrease in the total volume of transmission pores (50 to 500 \( \mu \text{m} \)). The exception was again at 5 cm depth for which the two distributions were very similar, but this is in accord with the similar conductivities found at this depth.

It was anticipated that tillage would affect pores in the above size range, but in the opposite sense to that observed, i.e., to increase their volume. We explain this effect, at depths greater than 5 cm, in terms of the particulate tillage sequence adopted in the experiment: the deep reciprocating power harrowing, considered physically expedient to improve soil uniformity, produced a size gradation of soil aggregates that enabled the soil to pack to a higher bulk density than in the undisturbed soil, particularly in the presence of the water added latterly to furnish the conductivity measurements. There is evidence that this tillage sequence also affected the number of storage pores (0.5 to 50 \( \mu \text{m} \)), since at the stage when drainage became negligible, that is, all transmission pores had emptied, about 18% more water was stored in the 0-25 cm layer on the restructured treatment: tillage had thus increased the volume of storage pores. This inverse relationship between the changes in volume of storage pores and transmission pores has also been found by De Leenheer (1977) for a silty loam soil, although in the different context of the relationship of soil physical properties, climatic factors, plant nutrition and crop yield.

**Thermal Conductivity**

During a twenty-day measurement period following thorough wetting of both treatments (but not profile saturation), average daily-mean thermal conductivities, \( \lambda \), at a given depth in the range 10 to 25 cm were always smaller on the restructured treatment by at least 20%. At 5 cm, differences were of the same sign but barely significant. Inter-plot variations in \( \lambda \) were
also smaller on the restructured treatment particularly at shallow depths. Within each treatment, depth changes in general followed the expected pattern of increasing with depth due to commensurate increases in bulk density and water content, the value of \( \lambda \) at 25 cm being approximately twice that at 5 cm at the end of the 20 day period; 1.34 and 0.62, W m\(^{-1}\)K\(^{-1}\), respectively, for the undisturbed treatment and 1.02 and 0.48 W m\(^{-1}\)K\(^{-1}\), respectively, for the restructured treatment.

Water content is a soil factor strongly influencing the value of \( \lambda \) in wet soils. In view of the differences in \( K \) between the two treatments referred to earlier, it might be expected that the above differences in \( \lambda \) could be due totally or in part to differences in water content on the two treatments. Derived \( \lambda - \theta \) relationships indicate that values at 5 cm depth for both treatments share a common curve, but at other depths distinct curves exist for each treatment. Thus at 5 cm depth, water content differences alone adequately explain the observed effect on \( \lambda \) of restructuring the soil. At other depths, differences in soil structure between the two treatments must be an additional contributory factor in causing the observed changes in \( \lambda \) on tilling the soil.

**Temperature**

The following observations relate to temperature profiles to 95 cm depth measured every 10 minutes during the two month period July and August 1980.

Maximum daily temperatures were always greater on the restructured treatment at all depths, but this difference was only statistically significant (i.e. >0.5 °C) to a depth of 20 cm; at 5 cm depth a difference of as much as 2 °C was observed on clear days. Minimum daily temperatures, however, were not significantly different on the two treatments at any depth. Diurnal wave amplitudes were significantly greater on the restructured treatment to 20 cm depth, by as much as 20%. Daily mean temperatures were greater on the restructured treatment at all depths but only significantly so to 15 cm depth. It was not possible to detect a tillage-induced phase shift in the yearly temperature wave with only a limited period of measurement and marked variability in climatic conditions.

Temperature gradients within the soil profile were greater at all depths in the tilled layer. Assuming for simplicity that heat fluxes at a particular depth were the same for both treatments, such a difference in gradient would imply a decrease in thermal conductivity at that depth on the restructured treatment as is indeed found by measurement (see above). The estimated
magnitude of this decrease is of the same order as is found experimentally.

CONCLUSION

The results given in this paper show that with the aid of controlled tillage procedures and careful and well replicated field measurements, changes that occur in important soil physical properties can be directly attributed to the mechanical restructuring effects of tillage and, moreover, that these changes can be assessed quantitatively, despite complications of soil spatial variability. These results also demonstrate sensible and important interactions between soil properties, and in particular the decisive role played by water content. Such careful experimentation we hope will form a sound basis for our future physical studies of the interaction of tillage with plant growth.

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WORKABILITY TEST PROCEDURE FOR ARABLE LAND

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Abstract

Soil workability has a large influence on cost and profit levels in agriculture. An objective workability test, if available, would enable us, to transform the practical experience into knowledge. Therefore it is suggested to replace the qualitative Atterberg consistency limits by quantitative information according to the proposed pressure-permeability test.

It is shown, that the test results help us to understand the potential soil workability. Next field observations (m.c. of top layers) were conducted on approx. 60 sugar-beet fields in springtime and autumn. Connected test and field data show that predicted and measured values rather well agree, introducing the relevant workability limits. Relevant pF values (2.7 and 2.2 resp.) predicted less accurate. Continued research is needed to evaluate the actual workability in the field.
Introduction

Agricultural fieldwork is strongly weather dependent. Weather has a direct as well as an indirect effect (through soil and crop) on the course, time and quality of the work. The workability of the soil is so important for the agricultural users, that they have named the various soil types by this phenomenon. Talking about light and heavy soils, required energy input and available days for tillage are involved. Soil related activities may be attended with processes like:

- loosening and cutting moist cohesive soil during primary tillage, sugar-beet harvest etc. performed with shares
- crumbling dry weathered soil during secondary tillage performed by tines
- compacting soft soil during traction and transport performed by tyres.

The pursued effects of tillage are always attended with the involved effects of traction. The optimum soil conditions for tillage and traction are found at different and characteristic soil consistencies, governed by soil type, moisture content (m.c.) and density.

Soil related activities have a large influence on cost and income levels; moreover tillage and transport are an important part of the overall work on the farm. ZACHARIASSE (1974) concluded that approx. 33% of the yield differences of sugar-beets were directly related to seeding depth. It is also known that differences in farm results are for 33% correlated with physical yield differences, which illustrates the importance of tillage in springtime.

Harvest and transport of crops in autumn are dependent on the stability of the soil. With intensive farming approx. 60% of the labour in agriculture is spent on transport. All this justifies further study of the field workability. In practice soil workability is tested in a subjective way; the soil is judged by the user for characteristics as friability and compressibility, which by practical experience will give him an idea of the effect of the machines. An objective workability test, if available, would offer the opportunity to transfer this knowledge. The well-known Atterberg consistency limits clearly describe the transition from one situation to another, distinguishing solid, plastic and liquid consistency. The lower plastic limit is most relevant as far as tillage is concerned; below this limit the soil mass can be broken down into smaller pieces.

However, detailed information is missing in relation to the different intensity of various tillage tools, the more so as the results of the Atterberg method are man-dependent i.e. subjective. Therefore the Ag.Engineering Institute has developed a workability test procedure, based on the determination of air...
permeability, after the sample has been subjected to pressure, gathering strength step by step.

Workability test procedure

Laboratory test

Soils in general consist of solids and voids, air- and/or water filled. During tillage, attended with compression, the air filled voids will be closed and the decrease in pore volume can be attributed to the lowering in air volume. The largest pores will disappear first, resulting in a drastic drop in air permeability of the soil sample. The test procedure starts with soil particles, sieved and graded in the fraction 2.8-4.0 mm. Next this granular soil is put into a 100 cc cylinder (Ø 50 mm). The structural arrangement of this equal spheres corresponds to "simple cubic", causing the high initial pore volume: circa 66-70 %. In the beginning the cylinder (height 50 mm) was filled completely and subjected to the uni-axial force, applied top-down and bottom-up. Later on, VULLINGS (1980) proved unaffected results, using lower samples (height 30 mm), compressed top-down only. This procedure really saves labour and is therefore continued. Step by step the pressure is increased from 1, 2, 4 to 6 bar with help of a hand operated compression apparatus (Soil-test U-160). In the meantime the loading is interrupted for measuring the air permeability by means of an air permeameter according to Kmoch (1961).

In principle a well-known volume of air within the gasholder (float) will pass under well defined air pressure through the sample prepared, see Fig. 1. After the time has been clocked in, the intrinsic permeability can be calculated according to Kmoch:

\[
K = \frac{V \eta}{1/P \times A \times t},
\]

wherein:

- \( K \) = intrinsic permeability, \( \mu m^2 \);
- \( V \) = air volume, \( cm^3 \);
- \( \eta \) = viscosity of the air, \( dyne \ sec/cm^2 \);
- \( l \) = length of the sample, \( cm \);
- \( P \) = air pressure, \( dyne/cm^2 \);
- \( A \) = sample cross section, \( (20) \ cm^2 \);
- \( t \) = time to pass measuring section, s.

Technical data:

\[
\frac{V}{P \times \eta} \times 10^{-2} (1.7 \times \text{section length}); \eta \times 10^{-6} (177.26 + 0.49 \times \text{centigrade})
\]

The results are presented on semi-logarithmic paper, Fig. 2, for plot nr. 10. The intrinsic permeability decreases with increased pressure; the slope and position of the lines are highly dependent on the soil m.c. (dry weight). The various m.c. are prepared after grading (2.8 - 4.0 mm) by wetting or drying small portions of the soil granules. Each plot will display a characteristic set of lines. In order to compare the various plots with each other, data is
A. Outer cylinder with water
B. Soil sample
C. Conducting bar with marks
D. Gas-holder (float)
E. Float inner tube
F. Air inlet pipe, hose
G. Air tap

Fig. 1 - Scheme of air permeameter after Knöch, model IMAG.

Reduced by setting the variable $K$ at $1 \text{ cm}^2$; an arbitrary value by the way.

Fig. 3 shows the sloping m.c. pressure lines per plot. It should be noted that different groups of plots may display different slopes!

The laboratory investigations have been completed by determining the pF curves of all plots, encountered in the field observations. For this purpose the graded soils involved have been precompacted to circa 55 - 60% pore volume.

Field observations

A few years ago PERDOK et al. (1974) have paid attention to workability problems in practice during seedbed preparation for potatoes. They reported, that potato ridge formation is normally carried out after the stability of the top soil (0-8 cm) has passed the limit of 4.0 bar pressure, see Fig. 3. In addition it has been shown that the above limit more or less corresponds to pF 2.7, however lighter soils settle for lower and heavier soils for higher pF values, according to PERDOK and TANIS (1975).

The above approach seemed promising; therefore recently attention has been paid to seedbed preparation and harvest activities related to sugar-beets, conducted by HENDRIKSE (1982). This study was carried out within the context of a multi-factor analysis (of circa 60 sugar-beet plots) by the Research Institute.
Station for Arable Farming and Field Production of Vegetables.

Fig. 2 - Relation between pressure (state of compaction) and permeability for graded samples at various moisture contents (%o dry weight), plot nr 10.

Fig. 3 - Relation between pressure and moisture content for $K = 1 \mu m^2$, various plots.

During springtime 1980, 43 plots have been followed by which the changes in moisture content of the top layers 0-4 cm and 4-8 cm have been determined; characteristic data of plot nr 10 are shown in Fig. 4.

Fig. 4 - Moisture content-time diagram of top layers 0-4 cm and 4-8 cm in springtime, plot nr 10.
The workable moments and the time of tillage have been noted. All this information together offered the base for a correct estimation of the workability limit; for plot nr 10 being 17.0 % for the layer 0-8 cm. Although the data of the sub-layers were available, the calculated 0-8 cm data is used because workability and trafficability are involved, see introduction. The same approach was followed during harvest activities in autumn; 36 plots, forming part of the same group, were involved. It should be noted that the soil composition of the whole group ranges from 10-34 % lutum.

Results
The m.c. per individual plot is converted into a pressure value, using Fig. 3 (representing the m.c.- pressure lines). In Table I, some relevant data is given for three plots, as example. The mean pressure for the whole group of 43 plots in springtime amounts to 4.2 bar. It should be noted that this value fairly well agrees with the level, found before i.e. 4.0 bar for potato fields. The calculated mean moisture suction amounts to pF 2.7 which exactly agrees with the potato fields examined before. In autumn, 36 plots and data are available. The mean stability is calculated at 1.3 bar and the mean moisture suction amounts to pF 2.2. This mean values 4.2 bar in springtime (a) and 1.3 bar in autumn (b) have been marked in Fig. 3.

The predicted m.c. per individual plot will differ from the actual m.c. in practice, see Table I. Therefore, correlations (1) and (2) have been presented in Table II. These equations are also shown in Fig. 5. Furthermore workability limits have been related to the soil composition of the individual plots. Parameters like lutum and organic matter seem relevant with respect to workability. The best fit was found, using the combined parameter %lutum + 10 x org.matter), see equation (3), Table II.

Discussion
In the above section an attempt was undertaken to relate laboratory test data to observed field data. The test data are fairly consistent and reproducible because the test procedure has been standardized to a large measure. The field data on the contrary are marked by wide variations due to non-uniform field conditions, irregularities in sampling (depth mistakes), subjective evaluation of the workability situation etc. It can be seen, that autumn data (eqn 1b) are characterized by a better goodness of fit ($R^2 = 0.61$) compared to springtime data (eqn 1a) $R^2 = 0.42$. This is caused by the facts that less people were involved (2 in stead of 3 researchers) and that the plots have
Fig. 5 - Correlations between field and test limits for springtime (1a) and autumn (1b). Idem pF and test limits, (2a) and (2b).

Table I - Example of data with respect to soil composition and to field and test results.

<table>
<thead>
<tr>
<th>Plot</th>
<th>Lutum</th>
<th>Lutum</th>
<th>Seedbed preparation, springtime</th>
<th>Harvest activities, autumn</th>
</tr>
</thead>
<tbody>
<tr>
<td>nr.</td>
<td>% + 10% org. matter,</td>
<td>%</td>
<td>m.c. practice</td>
<td>pF</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>42</td>
<td>17.0</td>
<td>19.4</td>
</tr>
<tr>
<td>21</td>
<td>31</td>
<td>56</td>
<td>19.2</td>
<td>20.7</td>
</tr>
<tr>
<td>26</td>
<td>14</td>
<td>37</td>
<td>16.8</td>
<td>16.3</td>
</tr>
</tbody>
</table>

Table II - Workability limits and correlations of field and laboratory data, incl. soil composition.
been sampled with higher intensity; twice instead of once a week (except plot nr 10!). Test data and pF data fit rather well, $R^2 = 0.61$ in equations 2a and 2b, because laboratory data are involved. For prediction purposes, the test is preferred to the pF limit as may be derived from Fig. 5; the slopes of the lines, based on the test, are closest to the ideal value of 1. Soil composition has an obvious effect on the m.c. at the workability limits, equations 3a and 3b. $R^2$ values (0.43) however are too low to utilize this correlations for prediction purposes.

Conclusions, suggestions
- The proposed workability test procedure may be very helpful in order to judge the potential workability of soils.
- Especially in cases were tillage research is involved and when little is known about the soils encountered. In developing countries e.g., the test data may help to fill the gap of lacking knowledge. As a matter of fact, in rain fed and irrigated areas it is of vital importance to utilize every available hour.
- For prediction purposes the test limits are preferred to pF limits; it should be noted that pF limits have to be related to soil composition to some extent.
- The test procedure is restricted in principle to silt and clay soils, because sandy soils will not produce the required granules. Sandy soils however will always display relatively high permeability values i.e. $K > 1 \mu m^2$.
- Determinations of actual "in situ" workability limits are not quite possible so far, owing to the need for grading. Soils in the field are mostly too wet to endure this action.
- For the time being, there is a need for a quick and easy determination of the actual m.c. of the top layer in the field.
- More soil related field activities have to be studied in order to be informed about relevant workability limits.
- Controlled traffic experiments show, that tillage and traction limits not always coincide.
References


Abstract

Soil water content and matric potential were measured in field experiments where winter or spring barley was grown after conventional mouldboard ploughing and direct drilling. Soil-water diffusivity was also measured in one experiment. All of the ploughed soils dried faster in spring, probably because of their higher diffusivity. During autumn and winter in a winter barley experiment, the direct drilled soil at 0.1 m depth wetted to higher potentials and dried to lower potentials than the ploughed soil. These differences were associated with differences in measured water release characteristics and restricted drainage at the bottom of the plough layer. The depth of unsaturated soil was generally greater after ploughing than after direct drilling.

Introduction

There are only a few weeks between harvest and the optimum sowing date for winter barley in most of the cereal-growing areas of Scotland. The area of winter barley is increasing and, thus, there is increasing interest in direct drilling, because of the associated time savings. There is also some interest in direct drilling for spring barley on some soils because it can be a cheaper method of crop establishment than mouldboard ploughing. When direct drilling is substituted for ploughing, there may be changes in soil water regimes (Ehlers et al., 1980) which influence crop growth. Therefore, we are investigating the effects of these cultivations on the content,
potential and conductivity of water in field experiments on some typical Scottish cereal-growing soils and here we present some of the preliminary results.

Methods and Sites

Soil water content was measured gravimetrically and matric potential with tensiometers in field experiments in south-east Scotland. The texture and drainage of the sites is in Table 1.

At South Road, soil water diffusivity was measured in 50 mm high, 73 mm diameter core samples using the method of Arya et al. (1975). Water was evaporated from the samples in a stream of hot air and diffusivity was calculated from the resulting water content distributions.

Table 1. Soil water content (% w/w) at 0 to 60 mm depth in spring.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Site (texture)</th>
<th>Drainage</th>
<th>Date</th>
<th>Plough</th>
<th>Direct</th>
<th>s.e.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter barley</td>
<td>Rosewell (sandy loam)</td>
<td>Free</td>
<td>8 April</td>
<td>13.2</td>
<td>15.1</td>
<td>0.97</td>
</tr>
<tr>
<td>(1981)</td>
<td></td>
<td></td>
<td>30 April</td>
<td>9.4</td>
<td>12.4</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>Glencorse (sandy clay loam)</td>
<td>Imperfect</td>
<td>6 April</td>
<td>23.8</td>
<td>29.5</td>
<td>1.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>29 April</td>
<td>22.7</td>
<td>25.7</td>
<td>1.10</td>
</tr>
<tr>
<td>Spring barley</td>
<td>Carberry (sandy loam)</td>
<td>Imperfect</td>
<td>18 April</td>
<td>14.2</td>
<td>18.2</td>
<td>0.90</td>
</tr>
<tr>
<td>(1979)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>South Road (sandy loam to sandy clay loam)</td>
<td>Imperfect to poor</td>
<td>20 April</td>
<td>20.8</td>
<td>31.0</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Results

Soil water content was higher near the surface in direct drilled than in ploughed soil in spring (Table 1). This was observed for both winter and spring sown crops, both where stubble was burnt (Carberry, Glencorse and Rosewell) and was still present (South Road). Matric potential decreased faster in spring in ploughed than in direct drilled soil under both winter and spring sown crops, as shown for two sites in Fig. 1a,b. These differences were associated with differences
in soil water diffusivity, at the site where this was measured (Fig. 1c).

![Fig. 1](image-url)  
**Fig. 1.** Matric potentials and soil water diffusivity in spring. P and D refer to ploughing and direct drilling respectively in this and subsequent figures.

Matric potential in the autumn and early winter for one of the winter barley sites is in Fig. 2. At 0.1 m depth between October and December the direct drilled soil wetted to higher potentials and drained to lower potentials than the ploughed soil. Hydraulic potentials, that is the sum of the matric and gravitational potentials, on selected occasions in the same time period and at the same site are in Fig. 3.

**Discussion**

The rate of evaporation from the soil in spring may be increased by increased surface roughness and reduced by crop residues where present. The soil surface tended to be rougher after ploughing than after direct drilling, particularly for the spring-sown crops (Soane et al., 1970) but at Rosewell, surface
Fig. 2. Matric potential at 0.1 m depth and rainfall after sowing winter barley at Glencorse, 1981.

Fig. 3. Hydraulic potentials on five occasions after sowing winter barley at Glencorse, 1981. The diagonal lines are the gravitational potentials. Points below these lines represent saturated soil.
roughness differences were negligible because the site was rolled after sowing. The soils were drier than field capacity, which is about 5 kPa in these soils, so that drying was probably by evaporation, rather than drainage. Therefore, the main reason for the differences in surface soil water contents between cultivations is probably the greater diffusivity in the ploughed soil than in the direct drilled soil (Fig. 1c). Both the winter and spring direct drilled soils were at lower matric potentials than the corresponding ploughed soils in mid-April. By mid-May the potentials were lower in the ploughed soils because they dried more quickly.

Close to saturation, more water is released per unit decrease in matric potential from these soils after ploughing than after direct drilling (Ball and O'Sullivan, 1982). Thus, if the soils of both treatments are at the same high matric potential and the same volume of water is added to each, the resulting increase in potential is greater in the direct drilled than in the ploughed soil. This may explain why the direct drilled soil wetted to higher potentials than the ploughed soil (Fig. 2).

When the ploughed soil was drying, on October 26th and November 9th (b and d in Fig. 2 and 3), hydraulic potential tended to a maximum (least negative) at 0.2 m depth, probably because drainage was restricted at the bottom of the plough layer. The rain which fell between the 26th and 30th of October caused a larger increase in hydraulic potential at 0.8 m depth in the direct drilled soil, which is further evidence of impeded drainage in the ploughed soil. These differences in drainage may explain why the direct drilled soil dried to lower potentials near the surface than the ploughed soil.

The depths at which the hydraulic and gravitational potentials intersected (Fig. 3) tended to be greater in ploughed than in direct drilled soil, particularly after rain (Fig. 3 a, c and e), indicating a greater depth of unsaturated soil in the ploughed than in the direct drilled treatment. This, together with the higher macroporosity of the ploughed soil, indicates that it may be generally better aerated, despite the impeded drainage.
References


Abstract
Long-term experiments with ploughing, harrowing and rotavating at 3 soil types have shown, that total porosity and the volume of coarse pores (>30 μm) decreases as a result of reduced tillage. The content of P and K in the topsoil (0-10 cm) increased and the aggregates were more stable after reduced tillage. The root development in the deeper soil layers was better on loamy than on sandy soil, but no differences were found between the treatments. The attack of take-all (Glabermannysces graminis) was equal after the different treatments. The yield was significant highest after plowing at all levels of nitrogen.

Soil types and methods
Long-term experiments with reduced tillage were carried out on a coarse sandy soil, a sandy loam and a silty loam sea marsh soil in the years 1973-81. The soil texture is shown in table 1 and the soil types are classified as recommended by Hansen (1976). Treatments were as follows: 1. Ploughing to about 20 cm depth, 2. Harrowing to about 10 cm, and 3. Rotavating to about 5 cm. Treatments 1 and 2 included stubble-cultivating to about 10 cm depth after harvest. In treatment 1 the soil was ploughed in November-December, traditional seed-bed preparation was carried out in treatment 1 and 2 in spring. If required, chemical control of couch grass (Agropyrum repens) in treatment 3 was carried out in autumn.

Table 1: Soil texture, per cent of dry weight

<table>
<thead>
<tr>
<th>Locality</th>
<th>Depth cm</th>
<th>Humus</th>
<th>Clay &lt; 2 μm</th>
<th>Silt 2-20 μm</th>
<th>Fine sand 20-200 μm</th>
<th>Coarse sand &gt;200 μm</th>
<th>Soil type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jyndevad</td>
<td>0-20</td>
<td>3.5</td>
<td>3.1</td>
<td>4.5</td>
<td>13.1</td>
<td>75.8</td>
<td>coarse</td>
</tr>
<tr>
<td></td>
<td>30-35</td>
<td>3.6</td>
<td>3.2</td>
<td>4.0</td>
<td>11.1</td>
<td>78.1</td>
<td>sand</td>
</tr>
<tr>
<td>Rønhave</td>
<td>0-20</td>
<td>2.6</td>
<td>15.4</td>
<td>16.6</td>
<td>45.6</td>
<td>18.9</td>
<td>sandy</td>
</tr>
<tr>
<td></td>
<td>30-35</td>
<td>1.9</td>
<td>16.9</td>
<td>15.5</td>
<td>44.4</td>
<td>21.3</td>
<td>loam</td>
</tr>
<tr>
<td>Højer</td>
<td>0-20</td>
<td>3.0</td>
<td>15.6</td>
<td>15.4</td>
<td>65.1</td>
<td>0.9</td>
<td>silty</td>
</tr>
<tr>
<td></td>
<td>30-35</td>
<td>1.7</td>
<td>19.6</td>
<td>14.4</td>
<td>63.1</td>
<td>1.2</td>
<td>loam</td>
</tr>
</tbody>
</table>
Sowing was performed with a traditional sowing machine in all of the treatments. The crop was barley every year. On the sandy and the sandy loam soil, P and K were supplied as required, whereas the nutritive rich silty loam marsh soil received no P or K. Chemical control of weeds and preventive pest- and disease control were carried out.

Porosity and volume of coarse pores
Since 1975 soil samples were taken for determination of the total porosity. 9 replicates were taken with 100 ccm cores in 4 depths in each treatment as described by Rasmussen (1973). Table 2 shows that the porosity in 10-20 cm depth has decreased up to 4 p.c. after harrowing and rotavating.

Table 2: The total porosity of the soils, volume p.c. 1975-81

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Depth cm</th>
<th>Ploughing</th>
<th>Harrowing</th>
<th>Rotavating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse sand</td>
<td>0-5</td>
<td>53.2</td>
<td>52.5</td>
<td>52.9</td>
</tr>
<tr>
<td></td>
<td>5-10</td>
<td>47.9</td>
<td>45.5</td>
<td>46.7</td>
</tr>
<tr>
<td></td>
<td>10-15</td>
<td>46.1</td>
<td>42.2</td>
<td>42.1</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>44.2</td>
<td>42.7</td>
<td>42.5</td>
</tr>
<tr>
<td>Sandy loam (1975-79)</td>
<td>0-5</td>
<td>49.2</td>
<td>48.5</td>
<td>51.2</td>
</tr>
<tr>
<td></td>
<td>5-10</td>
<td>42.0</td>
<td>41.3</td>
<td>45.1</td>
</tr>
<tr>
<td></td>
<td>10-15</td>
<td>41.0</td>
<td>39.0</td>
<td>39.1</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>42.0</td>
<td>39.7</td>
<td>40.2</td>
</tr>
<tr>
<td>Silty loam</td>
<td>0-5</td>
<td>53.9</td>
<td>56.0</td>
<td>55.1</td>
</tr>
<tr>
<td></td>
<td>5-10</td>
<td>46.5</td>
<td>47.8</td>
<td>45.9</td>
</tr>
<tr>
<td></td>
<td>10-15</td>
<td>47.2</td>
<td>45.0</td>
<td>45.8</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>46.1</td>
<td>44.9</td>
<td>46.0</td>
</tr>
</tbody>
</table>

In 1979 nine replicates of 100 ccm cores were taken in 4 depths in each treatment for estimating the pore size distribution as described by Rasmussen (1976). The volume of coarse pores (>30 μm) is calculated (table 3).

Table 3: Volume p.c. of coarse pores (>30 μm), 1979

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Depth cm</th>
<th>Ploughing</th>
<th>Harrowing</th>
<th>Rotavating</th>
<th>LSD95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse sand</td>
<td>0-5</td>
<td>40.7</td>
<td>42.2</td>
<td>42.9</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>5-10</td>
<td>28.9</td>
<td>26.2</td>
<td>38.6</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>27.6</td>
<td>23.2</td>
<td>23.3</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>30-35</td>
<td>25.5</td>
<td>20.4</td>
<td>19.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>0-5</td>
<td>15.4</td>
<td>10.0</td>
<td>12.7</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>5-10</td>
<td>11.4</td>
<td>8.0</td>
<td>9.2</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>12.9</td>
<td>9.5</td>
<td>9.1</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>30-35</td>
<td>8.8</td>
<td>11.6</td>
<td>11.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Silty loam</td>
<td>0-5</td>
<td>15.1</td>
<td>24.1</td>
<td>22.3</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>5-10</td>
<td>6.3</td>
<td>17.8</td>
<td>4.1</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>15-20</td>
<td>7.7</td>
<td>9.2</td>
<td>8.4</td>
<td>n.a.</td>
</tr>
<tr>
<td></td>
<td>30-35</td>
<td>4.9</td>
<td>10.9</td>
<td>9.0</td>
<td>2.5</td>
</tr>
</tbody>
</table>
At each soil type and at each treatment, the volume of the coarse pores declines with depth. At the coarse sandy soil, the volume of coarse pores is significant higher in o-10 cm depth after rotavating than after ploughing, whereas the opposite is true for the 15-25 cm depth. At the sandy loam soils, the volume of coarse pores is significant highest in o-20 cm depth after ploughing, but lowest in 30-35 cm depth. At the silty loam soil, the volume of coarse pores is significant highest after harrowing in the depths 5-10 and 30-35 cm, whereas no significant differences are found in 15-20 cm depth.

Soil chemical analysis

Soil samples were taken in the depths o-10 and 10-20 cm every second year to be analysed for the pH-value, the content of humus and the index of P and K. Only small and insignificant differences were found as regards the pH-value and the content of humus. However there was a tendency for a little higher content of humus in the upper layer after reduced cultivation. The P- and K-index in table 4 indicates no differences between the two depths after ploughing, whereas both the P- and the K-index were highest in o-10 cm depth after reduced cultivation.

Table 4: Topsoil P- and K-index 1980

<table>
<thead>
<tr>
<th>Soil types</th>
<th>Depth cm</th>
<th>Ploughing</th>
<th>Harrowing</th>
<th>Rotavating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>o-10</td>
<td>6.0</td>
<td>7.9</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>5.6</td>
<td>6.2</td>
<td>5.2</td>
</tr>
<tr>
<td>Sandy</td>
<td>o-10</td>
<td>8.1</td>
<td>10.4</td>
<td>10.4</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>8.4</td>
<td>6.4</td>
<td>7.4</td>
</tr>
<tr>
<td>Loam</td>
<td>o-10</td>
<td>10.7</td>
<td>9.1</td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>10.7</td>
<td>8.0</td>
<td>8.5</td>
</tr>
<tr>
<td>Silty</td>
<td>o-10</td>
<td>10.7</td>
<td>9.1</td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td>10-20</td>
<td>10.7</td>
<td>8.0</td>
<td>8.5</td>
</tr>
</tbody>
</table>
| Aggregate stability

Soil samples for determination of the aggregate stability by the wet-sieving procedure of Hartge (1971) were taken in o-5 cm depth after harvest. The results are shown in figure 1. The stability of the aggregates is expressed as Δ VGD, which is the change in the average diameter of the aggregates, i.e. small changes are an expression of a good stability. In spite of the variation from year to year, a significant poorer stability is found after ploughing.
Take-all (Gáumannomyces graminis)

Investigations of the attack of take-all have shown the lowest attack at the silty loam soil, but no significant effect of the tillage at any of the soils, as shown in table 5.

Table 5: Per cent of the roots attacked by take-all (Gáumannomyces graminis), average 1973-81

<table>
<thead>
<tr>
<th>Soil types</th>
<th>Ploughing</th>
<th>Harrowing</th>
<th>Rotavating</th>
<th>LSD95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse sand</td>
<td>16</td>
<td>17</td>
<td>20</td>
<td>n.s.</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>13</td>
<td>18</td>
<td>17</td>
<td>n.s.</td>
</tr>
<tr>
<td>Silty loam</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

Root growth

About the earing-stage, soil samples were taken in 0.5 m long tubes with a diameter on 7 cm. 6 replicates per treatment were taken each year. The soil columns were sectioned into subsamples of 10 cm length and root length was measured as described by Hignett (1976). The results of 3 years investigations are shown in table 6. There was a very large variation between the replicates, and statistical analysis have shown, that the number of samples must be at least 12-15. Because of the variations, no significant differences were found between the treat-
ments. At every soil type the largest root quantity was found in the upper 25 cm soil layer. Root development in the deeper soil layers is better in the loamy soil than in the sandy soil.

Table 6: The root intensity, cm · cm⁻³, average 1978-81

<table>
<thead>
<tr>
<th>Soil types</th>
<th>Depth cm</th>
<th>Ploughing</th>
<th>Harrowing</th>
<th>Rotavating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse sand</td>
<td>0-25</td>
<td>9.99</td>
<td>10.60</td>
<td>10.76</td>
</tr>
<tr>
<td></td>
<td>25-95</td>
<td>0.54</td>
<td>0.59</td>
<td>0.58</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>0-25</td>
<td>5.43</td>
<td>5.98</td>
<td>6.82</td>
</tr>
<tr>
<td></td>
<td>2 years</td>
<td>1.29</td>
<td>1.35</td>
<td>1.21</td>
</tr>
<tr>
<td>Silty loam</td>
<td>0-25</td>
<td>7.29</td>
<td>6.94</td>
<td>7.94</td>
</tr>
<tr>
<td></td>
<td>3 years</td>
<td>1.76</td>
<td>1.55</td>
<td>1.76</td>
</tr>
</tbody>
</table>

Weeds
Immediately before chemical weed-control in the early summer and again before harvest, weed investigations were carried out (Pinnerup 1981). As shown in Table 7, there was a large increase in the total number of weed-plants after reduced cultivation, especially after rotavating. Different species-compositions were found after different treatments. The investigations have shown that the number of weed-plants are decreasing with increasing level of nitrogen.

Table 7: The number of the 8 most common weed-species. Average of 4 countings 1979 and 1980 on coarse sand soil

<table>
<thead>
<tr>
<th>Species</th>
<th>Ploughing</th>
<th>Harrowing</th>
<th>Rotavating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stellaria media</td>
<td>39</td>
<td>78</td>
<td>225</td>
</tr>
<tr>
<td>Myosotis arvensis</td>
<td>31</td>
<td>50</td>
<td>223</td>
</tr>
<tr>
<td>Poa annua</td>
<td>1</td>
<td>49</td>
<td>255</td>
</tr>
<tr>
<td>Spergula arvensis</td>
<td>16</td>
<td>52</td>
<td>70</td>
</tr>
<tr>
<td>Viola arvensis</td>
<td>4</td>
<td>1</td>
<td>82</td>
</tr>
<tr>
<td>Polygonum convolvulus</td>
<td>6</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Chenopodium album</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Matricaria matricarioides</td>
<td>0</td>
<td>21</td>
<td>1</td>
</tr>
<tr>
<td>Total of 8 species:</td>
<td>101</td>
<td>262</td>
<td>859</td>
</tr>
</tbody>
</table>

Yield
The grain-yields are shown in Table 8. At all 3 soil-types and at all 3 nitrogen-levels, rotavating resulted in the lowest yields. The differences between rotavating and harrowing were significant only at the highest nitrogen-level at coarse sand and silty loam soil, and the differences between ploughing and rotavating were - apart from 30 N at silty loam - significant at all of the soil-types. The variation in yield from year to year was very large, especially at the loamy soils. The highest yields after reduced cultivation were obtained in
years with good germination and a mild growing season with precipitation less than "normal", whereas the lowest yields after reduced cultivation were obtained in years with cold and moisty climate.

Table 8: Yields and excess-yields. kg grain per hectare 1973-81

<table>
<thead>
<tr>
<th>Soil types</th>
<th>kg N per hectare</th>
<th>Ploughing</th>
<th>Harrowing</th>
<th>Rotavating</th>
<th>LSD95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse sand</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>36.8</td>
<td>-3.9</td>
<td>-5.0</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>43.7</td>
<td>-1.4</td>
<td>-2.2</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>46.5</td>
<td>-1.5</td>
<td>-4.8</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>Sandy loam</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>38.9</td>
<td>-5.0</td>
<td>-6.9</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>1973-79</td>
<td>44.3</td>
<td>-1.4</td>
<td>-6.3</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>46.0</td>
<td>-1.5</td>
<td>-6.6</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>Silty loam</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>41.4</td>
<td>-1.8</td>
<td>-2.8</td>
<td>n.s.</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>45.1</td>
<td>-2.2</td>
<td>-3.7</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>48.6</td>
<td>-3.5</td>
<td>-5.6</td>
<td>1.5</td>
<td></td>
</tr>
</tbody>
</table>

Literatur


Abstract

The failure of soil by an implement can be classified into two types: brittle failure and flow failure. In cultivation practice, brittle failure is desirable, flow failure is undesirable. The paper considers these two types of failure in terms of soil workability and goes on to describe some of the soil and implement factors that determine failure mode. It is possible to devise an index, based on such factors, that will indicate in which mode soil will fail. The index would, therefore, give limits for soil workability.

Cultivation efficiency, timeliness and soil workability

In recent years, there has been increasing interest in the factors influencing the number of work days available for equipment that interacts with the soil, the work rate of that equipment and the 'efficiency' of cultivation operations. Attempts have been made to quantify and predict the efficiency of cultivation techniques (Stroppel, 1977) and to use operational research techniques to optimise procedures and equipment for arable farms in order to minimise returns (Audsley, 1970). Thomasson (1982) has developed a method of assessing soil workability and trafficability based on soil classification, meteorological and agronomic factors. He emphasised the vital role played by soil water in determining whether a soil is workable by soil-engaging equipment and/or trafficable to field vehicles. Such approaches are very useful for providing general guidelines to when soil may or may not be worked.

The parameter most commonly used in determining whether a soil is workable or not is the plastic limit, the moisture content at which the mechanical behaviour of soil changes from friable (or brittle) to plastic. Although the plastic limit may be of value in indicating a range of moisture contents over which soil becomes workable, recent work (Spoor and Godwin, 1979, Stafford, 1981) has shown that other soil and implement parameters affect the soil's workability. The aim of this paper is to investigate the possibility of formulating a 'workability' index or number that incorporates both soil and implement parameters.

What is 'workability'?

The essential requirement of a cultivation operation is usually that the larger structural units are broken down into smaller units, i.e. soil bulk density is reduced. Soil that is in the required state after cultivation is often referred to by terms such as friable, crushed, shattered or crumbled. If cultivation is carried out when the soil is, to any extent, unworkable then the result is summed up in words such as smear, compact or plastic flow. In such cases, soil density is increased and smaller structural units may coalesce into larger units. A third regime may be identified, that in which too much work is done
to the soil and the structural units are reduced to fine aggregates or even to soil particles. The net effect, after initial loosening, is for the soil density to increase because of the loss of porosity. Such effects can occur in high speed soil cutting operations using, for instance, rotary cultivators.

Soil, therefore, can be said to fail in one of two ways when deformed by a cultivation implement. It may fail in a brittle fashion such that distinct shear planes run through the soil mass, reducing it to an assemblage of smaller structural units. Or the soil mass as a whole may fail and bulk material flow of some kind occurs. This type of failure will be called flow failure and includes plastic flow and granular flow. Flow failure is undesirable in cultivation operations and the soil may then be considered to be 'unworkable'. Thus the term workability is being used in a wider sense than is usual. Although the two failure modes appear to be very different phenomena, critical state soil mechanics provides a unifying concept to explain them within one model.

The relevance of the critical state concept of workability

'Workability' is to do with the deformation characteristics of a soil as it is subjected to a system of stresses. Similarly, the critical state model describes the effect of an external or internal stress field on the deformation of an element of soil. The main tenet of the model is that an element of soil at any initial condition, when subjected to a stress field, will deform continuously with change of density until it reaches a critical state. Further deformation is accommodated by distortion only with no change of density. The model can be illustrated graphically by a three dimensional plot of soil specific volume and the stress field (defined by spherical pressure, p, and deviatoric stress, q) that determines specific volume, v. The graphical representation is shown in fig. 1.

![Graphical representation of critical state concept](image-url)
The initial state of an element of soil, free of shear stress, will be represented by some point on the p-v plane. With stress application, the element deforms, first elastically and then plastically, when it reaches a yield surface such as H or R. It will in fact follow some stress path until its condition is represented by a point on the critical state line and no further change occurs in p, q or v. The soil has failed and the critical state line is the locus of all such failure points.

Now, the nature of such failure will depend on whether the stress path approaches the critical state line from the origin side or from the side remote from the origin. If yield occurs on the R surface then soil density has increased and plastic flow (compaction) has occurred. If yield occurs on the H surface then the soil dilates and shear cracks run through the element. The element has failed in a brittle manner. The stress conditions may be such that the path, though starting on the origin side, runs 'under' the critical state line and yield occurs on the R surface.

The critical state concept was developed to describe the behaviour of the near-saturated and uniform sub-soils that are of interest to civil engineers. Recent work (Hettiaratchi and O'Callaghan, 1980; Stafford, 1981), however, has indicated the application of critical state concepts to explain stress phenomena observed in agricultural top soils. A soil, then, that is in such an initial condition and is stressed such that yield and failure occur on the side of the critical state line remote from the origin, may be considered 'unworkable' from a cultivation standpoint.

Factors that determine the failure mode

Soil moisture content clearly plays a major role; when it is too high then soil compacts by flowing plastically i.e. yield and failure occur from the R surface on to the critical state line. In general, failure by compressible flow will occur when the spherical pressure (or 'confining stress') acting on the soil element is sufficiently high or is increasing sufficiently rapidly in relation to deviatoric (or shear) stress.

Such conditions can be brought about by working an implement too deeply, for then the soil over-burden creates conditions of high confining stress. This has been very clearly illustrated by Spoor and Godwin (1977) in their critical depth concept. Where an implement is working below the critical depth, flow failure occurs below the critical depth whilst brittle failure occurs above. The shape of the implement may also affect the failure mode by increasing confining stresses in the soil around the implement sufficiently. This effect has clearly been shown by Stafford (1981) for a simple implement, a chisel tine. As the rake angle was increased, failure mode changed from brittle to flow. For implements of more complex shape, brittle failure may be caused over parts of the implement and flow failure over others. Soil wedges or smeared clods may often be found after the passage of an implement that, otherwise, performs a quite acceptable cultivation of the soil.

As the shear strength of soil increases with strain rate, implement speed may affect the failure mode. At high speed, spherical pressure may increase very rapidly relative to deviatoric stress such that the stress path passes 'under' the critical state line and yield occurs on the R surface. Stafford (1981) has shown that the failure mode may change from brittle to flow by increasing
the speed of a simple chisel tine. Under some initial soil conditions, the change over occurred between 2 and 3 m/s, i.e. within the range of normal cultivation speeds. The effect occurred even with dry compacted soils where granular flow of the material occurred at high speed. The change in failure mode was accompanied by an increase in draught force. The same speed effect may be occurring with rotary cultivators which sometimes do too much work to the soil, breaking it down to too fine a tilth. An analysis, however, is complicated by other factors such as soil throw against the implement shield. Evidence that implement speed affects the form of soil failure has also been gathered by Hendrick and Gill (1973). From Russian literature, they found reference to a critical soil deformation velocity, the value of which varied from 14-360 km/h.

Another factor that affects failure mode is the initial density of the soil. Generally, in cultivation practice, the initial soil density is relatively high and the point in p-q-v space representing that initial condition will lie on the origin side of the critical state line. When the soil is in a loose condition then applied stress will cause compaction; this is clearly so when a wheel moves over, say, a loose seed bed structure.

A soil failure index for tillage operations

There is no disputing that a 'go - no-go' test of soil workability would be universally welcomed by farmers! However, there is no one spot measurement that could provide the necessary criterion. Thomasson (1982) has sought to include soil classification, meteorological and agronomic factors in his workability assessment. Another approach is to consider the specific soil reaction to a particular implement (or ground drive) in terms of soil and machine variables. The concepts and phenomena described in previous sections provide a basis for such a soil workability, or failure, index.

The mode of failure depends on a number of factors; soil moisture content and density, implement speed, depth and geometry have been identified in the previous section. The common mechanism though, is the amplitude and rate of change of confining stresses around the implement or wheel. There is, therefore, an interdependency between soil and implement factors. For instance, the critical depth for change of failure mode will increase if speed is reduced; the critical moisture content will be increased if implement rake angle is reduced. The above five parameters may, therefore, be constituted into an index which has a critical value indicating the boundary between brittle and flow failure - between workable and unworkable soil.

From the author's previous observations (Stafford, 1981), the failure index would be proportional to functions of speed, moisture content, rake angle and depth and inversely proportional to density. High values of the index would then indicate flow failure and low values brittle failure. A possible course of action to determine the functional form of the index is to use dimensional analysis to form a dimensionless number. Such analysis would only be satisfactory if all relevant parameters were included. Whilst the five factors mentioned are the more important there are doubtless others, yet unidentified, that affect confining stress and thus failure mode. Although it is not possible to apply dimensional analysis at this stage, further comment can be made on the range and form of the five factors.
In order to determine the failure index, normalisation and modification of the five factors are necessary. For a composite implement, rake angle would be replaced by a 'geometrical function' or 'characteristic length' which would be determined for each specific implement. Moisture content would be normalised with respect to the plastic limit moisture content, in order to relate it to different soil types. Depth would be replaced by the depth/implement width ratio (Godwin and Spoor, 1977). Density would be indicated by specific volume. The change in failure mode cannot be brought about over the entire possible range of each parameter; at very high moisture contents, plastic flow will occur whatever the values of the other parameters, for instance. An indication of the critical ranges for each parameter can be deduced from work reported by Stafford (1981), Campbell, Stafford and Blackwell (1980) and Spoor and Godwin (1979). It is quite feasible to measure or determine each parameter in the field and so a good basis has been provided for the implementation of a practical failure index for soil workability.

Conclusions

The possibility of determining a compound index for indicating the change in soil failure from brittle to flow - i.e. from 'workable' to 'unworkable' - has been explored. By compounding five parameters that may be measured or determined in the field, an index may be derived, the value of which indicates whether the soil will be workable or unworkable.

References


COMPARISON OF THREE DIFFERENT TILLAGE SYSTEMS WITH RESPECT TO AGGREGATE STABILITY; THE SOIL AND WATER CONSERVATION AND THE YIELDS OF SOYBEAN AND WHEAT ON AN OXISOL.

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Soil Management and Conservation Program, Agricultural Research Institute of Paraná/Brazil (IAPAR)

ABSTRACT

This paper deals with the impact of four years of different soil tillage systems on aggregate stability, the water holding capacity, the surface runoff and soil loss, as well as soybean and wheat yields on an oxisol.

It has been determined that the conventional tillage technique (disc ploughs) in comparison to the direct drill technique increases erosion on one hand, and decreases the aggregate stability, the water holding capacity and also the soybean and wheat yields on the other hand.

INTRODUCTION

Farmers in the state of Paraná, Brazil who do not recognize the effects of tillage and crop rotation on water erosion have to face, within ten years, a considerable loss of profits and in some places even a change of location or suspension of agriculture.

According to Jafert (quoted by Maak) the soil loss created by water erosion in Brazil amounts to 312–701 m³/ha/year.

Findings of the agricultural research institute in Londrina (IAPAR) show clearly, that a tillage operation preserving soil structure or a sowing of small grains (e.g. by direct drill) can reduce soil erosion to a minimum, without having to fear reduction of yields in comparison to conventional tillage (IAPAR 1981, Kemper et al. 1981 and Sidiras et al. 1981).
Soil tillage or sowing operations preserving or improving soil structure on one hand strongly reduce the risk of erosion of the soil during a period without vegetation cover, and on the other hand enable a more timely and economical sowing of summer and winter crops.

MATERIALS AND METHODS

The soil of this location can be characterized as an oxisol. Details of the properties, climate, experimental set up, crops grown, as well as research methods for the determination of the physical and chemical properties of the soil are given in earlier publications (Kemper et al. 1981 and Sidiras et al. 1981).

For the determination of the aggregate stability, soil samples (72) were collected on four locations per plot (three plots for each soil tillage treatment) at depths of 0-10 cm and 11-20 cm. From the field samples (water content 18-22%) the aggregate size fraction of 9.52-5.66 mm was separated by means of sieving. One hundred (100) grams of this fraction were placed on the upper sieve of the Yoder (1936) apparatus. After the dipping process the amount of water stable aggregates was determined.

Run off and soil loss were measured on 3.5 x 11 m plots by means of commonly used steel strips and collecting barrels.

RESULTS AND DISCUSSION

1. Aggregate size distribution and aggregate stability


Figure 1 shows that in the upper 10 cm layer, the aggregate size class of 9.52-5.66 mm dominates with DD whereas with the CP and CT the classes of 4.0-2.0 mm, 2.0-1.0 mm and 1.0-0.5 mm dominate.

At cultivating depths between 11-20 cm, the aggregate class of 4.0-2.0 mm had the highest percentage with DD followed by the aggregate class of 9.52-5.66 mm. With the other tillage systems the situation was similar to that in the upper layer.

For the upper 10 cm with the DD, 67% of the aggregates 9.52-5.66 mm were water stable, for the CP this was 23% and for the CT this was only 3%.
Fig. I - Distribution of the water stable aggregates (100 g aggregates the class 9.52-5.66 mm) at the soil depths 0-10 cm and 11-20 cm after 4 years of conventional tillage, chisel plough and direct drill (Londrina, Oxisol).

At a depth of 11-20 cm, DI showed an increase of 2.5 times the water stable aggregates of 9.52-5.66 mm (20% vs. 8.2%) in comparison to the CT.

In the aggregate fractions smaller than 0.5 mm there were only negligible differences between the tillage treatments as well as between the soil depths.

In table 1 it can be seen, that in soil depths of 0-10 cm and 11-20 cm the negative correlations between aggregate stability in water and coarse pore volume (CPV) were the lowest. The bigger the CPV gets, or the more intensive the soil tillage (e.g. with disc plough) the more the water stability of the macro aggregates will be affected, so the greater will be the degree of erodibility of this soil.

Also between water stable aggregates and Ca$^{2+}$ + Mg$^{2+}$, a very high correlation was calculated ($r = 0.87^{**}$).

From the high correlations $r = 0.84^{**}$ and $r = 0.80^{**}$ it is shown that the organic matter and the bulk density had an important impact on the water
Table 1 - Regressions and correlation coefficients between the water stable aggregate 9.52-5.66 mm and some important soil properties, Londrina, Oxisol.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Regressions</th>
<th>Correlation coefficients</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td>0 - 10 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggregate 9.52-5.66 mm-coarse pore: ( y = 118,4-3,36 \times x ), ( r = -0,88 )**</td>
<td>( y = -75,9+14,8 \times x ), ( r = 0,87 )**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-Ca(^{2+})+Mg(^{2+}): ( y = 118,4-3,36 \times x ), ( r = -0,88 )**</td>
<td>( y = -75,9+14,8 \times x ), ( r = 0,87 )**</td>
</tr>
<tr>
<td></td>
<td>-C-Content: ( y = -82,8+62,0 \times x ), ( r = -0,84 )**</td>
<td>( y = -82,8+62,0 \times x ), ( r = -0,84 )**</td>
</tr>
<tr>
<td></td>
<td>-bulk density: ( y = -209,6+237,9 \times x ), ( r = 0,80 )**</td>
<td>( y = -209,6+237,9 \times x ), ( r = 0,80 )**</td>
</tr>
<tr>
<td>11 - 20 cm</td>
<td>-Ca(^{2+})+Mg(^{2+}): ( y = 41,2 - 1,32 \times x ), ( r = -0,67 )*</td>
<td>( y = 41,2 - 1,32 \times x ), ( r = -0,67 )*</td>
</tr>
<tr>
<td></td>
<td>-C-Content: ( y = -82,8+62,0 \times x ), ( r = -0,84 )**</td>
<td>( y = -82,8+62,0 \times x ), ( r = -0,84 )**</td>
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<tr>
<td></td>
<td>-bulk density: ( y = -209,6+237,9 \times x ), ( r = 0,80 )**</td>
<td>( y = -209,6+237,9 \times x ), ( r = 0,80 )**</td>
</tr>
</tbody>
</table>

stability of the macro aggregates of size 9.52-5.66 mm.

2. Water holding capacity at 0.06, 0.33 and 1 bar

Table 2 shows, that the water content with the DD is considerably

Table 2 - Soil water at different suctions after 4 years of conventional tillage (CT), chisel plough (CP) and direct drill (DD). Londrina, Oxisol.

<table>
<thead>
<tr>
<th>Tillage treatment</th>
<th>Suction in bar</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>0.06</td>
<td>0.33</td>
<td>1</td>
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<tr>
<td></td>
<td>3 - 10 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>36,4 (100)</td>
<td>30,8 (100)</td>
<td>29,0 (100)</td>
<td></td>
</tr>
<tr>
<td>Chisel plough</td>
<td>39,2 ** (108)</td>
<td>34,6 ** (112)</td>
<td>32,6 ** (112)</td>
<td></td>
</tr>
<tr>
<td>Direct drill</td>
<td>44,7 ** (123)</td>
<td>40,3 ** (131)</td>
<td>38,2 ** (131)</td>
<td></td>
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<tr>
<td></td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>11 - 20 cm</td>
<td></td>
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</tr>
<tr>
<td>Conventional</td>
<td>38,9 (100)</td>
<td>33,2 (100)</td>
<td>31,4 (100)</td>
<td></td>
</tr>
<tr>
<td>Chisel plough</td>
<td>42,6 ** (109)</td>
<td>38,0 ** (114)</td>
<td>35,9 ** (114)</td>
<td></td>
</tr>
<tr>
<td>Direct drill</td>
<td>43,3 ** (111)</td>
<td>39,9 ** (120)</td>
<td>38,1 ** (121)</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>21 - 30 cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>43,3 (100)</td>
<td>39,1 (100)</td>
<td>37,4 (100)</td>
<td></td>
</tr>
<tr>
<td>Chisel plough</td>
<td>42,8 (99)</td>
<td>39,1 (100)</td>
<td>37,9 (101)</td>
<td></td>
</tr>
<tr>
<td>Direct drill</td>
<td>45,5 ** (105)</td>
<td>41,0 (105)</td>
<td>39,5 * (106)</td>
<td></td>
</tr>
</tbody>
</table>

* Significant at \( p = 0.05 \)
** * ** * Significant at \( p = 0.01 \)
higher at the suction levels of 0.06, 0.33 and 1 bar in comparison with CT. Under DD the water contents at the Field Capacity (F.C.) level of 0.33 bar (Reichardt 1978) in the soil layers 3-10 cm, 11-20 cm and 21-30 cm rose to 31%, 20% and 5%. This could be explained by the improvement of the soil structure; this process was interrupted by the CT which led to a fine granular powder structure without aggregates.

3. Surface runoff and soil loss

Soil tillage with the disc plough has led during the four years of experimentation to higher soil losses and, with exception of the summer of 1981, to higher surface runoff.

The surface runoff was higher under CT, although in the tilled layer both the coarse pore volume and the infiltration rates (data not published) were higher (tab. 3). This can be explained by the following facts:

a. Under DD there is more organic plant residue on the surface, so the downhill movement of the excess rainwater at the surface is reduced and the infiltration time is extended (increase of surface storage capacity).

b. Under DD, more water can be retained in the soil because of the higher F.C. and because of the increase in organic matter in the soil (Sidiras et al. 1981).

Table 3 - Runoff and soil losses 1978/79 and 1979/80 under conventional tillage (CT), chisel plough (CP) and direct drill (DD). Oxisol, plot size: 3.5 by 11 m., crop rotation: soybean/wheat, slope: 4%.

<table>
<thead>
<tr>
<th>Month</th>
<th>Conventional tillage</th>
<th>Direct drill</th>
<th>Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>surface runoff %</td>
<td>soil loss kg/ha</td>
<td>surface runoff %</td>
</tr>
<tr>
<td>1978/79</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Nov.</td>
<td>0,9</td>
<td>88,0</td>
<td>0,1</td>
</tr>
<tr>
<td>Dec.</td>
<td>0,2</td>
<td>46,4</td>
<td>0,1</td>
</tr>
<tr>
<td>Jan.</td>
<td>0,9</td>
<td>176,4</td>
<td>0,6</td>
</tr>
<tr>
<td>Febr.</td>
<td>0,9</td>
<td>241,8</td>
<td>0,2</td>
</tr>
<tr>
<td></td>
<td>2,9</td>
<td>552,6</td>
<td>1,0</td>
</tr>
<tr>
<td>1979/80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nov.</td>
<td>4,5</td>
<td>884,3</td>
<td>0</td>
</tr>
<tr>
<td>Dec.</td>
<td>4,2</td>
<td>1415,2</td>
<td>1,9</td>
</tr>
<tr>
<td>Jan.</td>
<td>7,8</td>
<td>1188,9</td>
<td>8,9</td>
</tr>
<tr>
<td>Febr.</td>
<td>1,6</td>
<td>578,6</td>
<td>1,3</td>
</tr>
<tr>
<td></td>
<td>18,1</td>
<td>4067,0</td>
<td>12,1</td>
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<td></td>
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<tr>
<td></td>
<td>541</td>
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</tbody>
</table>
C. Under CT, the soil surface material will be easily dispersed and transported downhill by rainwater as a result of the unstable, fine granular-powdery structure.

D. Under CT and under a high rain intensity at the start of the rainy period, part of the macropores in the subsoil may become filled by the washing in of soil particles from the top layer. Also the well known surface (rain) crust may be formed here.

As table 3 shows, the soil loss in the dry 1978/79, soybean growing season under CT compared with DD, was 3 times as high and in the wet 1979/80 growing season it was approx. 8.6 times higher (553 vs. 183 resp. 4067 vs. 475 kg/ha). Erosion was most severe in February of the 1978/79 season and in the December 1979/80 season.

Based on the values in Table 3, there is no close correlation between rainfall and soil loss or runoff when considered per month. The condition of the soil structure as well as the soil cover by crop, do have in this respect an effect during the rainy period. In a later stage a detailed account of the erosivity of the precipitation will be published.

4. Yields and yield components of soybeans and wheat

The soybean and wheat yields (tab. 4) were for DD in comparison with CT higher (statistically reliable): 33.9% and 52.1% respectively.

On the DD treatment both with soybeans and wheat the germination (seeds per m²) was 25.3% and 19.2% higher. These advantages are mainly explained by the more favourable soil moisture conditions of the seed environment. On this point it should be remarked that with increasing dryness the differences in the moisture became noticeable for the DD (differences were and continue to be between 2 and 10%).

Soil temperature, particularly with soybeans had a big influence on the germination of the seed. The temperatures in the afternoon (11-17 hrs) during the part of the germination period were, in the 2.5-3.5 cm soil
<table>
<thead>
<tr>
<th>Tillage system</th>
<th>Soybean, 1980/81</th>
<th>Winter Wheat, 1981</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>emergence</td>
<td>harvested</td>
</tr>
<tr>
<td></td>
<td>pl./m²</td>
<td>pl./m²</td>
</tr>
<tr>
<td>Conventional</td>
<td>57.6</td>
<td>57.2</td>
</tr>
<tr>
<td>Chisel plough</td>
<td>58.6</td>
<td>57.0</td>
</tr>
<tr>
<td>Direct drill</td>
<td>72.2</td>
<td>72.6</td>
</tr>
<tr>
<td></td>
<td>p = 0.05</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>p = 0.01</td>
<td>5.2</td>
</tr>
<tr>
<td>Triticum aestivum</td>
<td></td>
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</tbody>
</table>

layer, between 30 and 50 °C for soybeans and between 25 and 35 °C for winter wheat (unpublished results).

The yield increase of soybeans and wheat, according to the calculated correlations, was credited primarily to the thousand grain weight (soybean: TGW = r = 0.84**, plants/m² = r = 0.74**; wheat: TGW = r = 0.86**, seeds/ear = 0.73** and plants/m² = r = 0.69*). The higher TGW values with soybeans and wheat could have been caused by the higher available water content under DD in the grain filling phase (Sidiras et al. 1981).

During the winter wheat crop 1981 there was only 152.2 mm of rain in the period May-September. The wheat survived the drought the best under the DD treatment when considering these yields (2500 kg/ha is a very good yield for this district).

LITERATURE

FUNDACAO INSTITUTO AGROVOLICO DO PARANÁ, 1981: Plantio Direto no Estado do Paraná, Londrina (IAPAR)


EFFECT OF TILLAGE DEPTH, INTENSITY OF FERTILIZATION, 
AND CROP ROTATION ON THE DYNAMICS OF MINERAL NITROGEN 
IN SLIGHTLY CALCAREOUS CHERNOZEM SOIL

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ABSTRACT

The deepening of tillage intensified nitrogen mineralization in soil preceding crop did not affect the contents of different forms of mineral nitrogen in the soil. The movement of mineral nitrogen was in correlation with the quantity of nitrogen fertilizer applied.

INTRODUCTION

Normal soils have the major portion of nitrogen incorporated in organic compounds and only a small part in inorganic form. The latter is directly available to plants, the former is a potential reserve for plant nutrition. However, specific conditions are required for the mineralization of organic nitrogen, i.e., mineral nutrients, aeration, temperature, moisture content, pH value. Numerous researchers have studied the effect of these factors on the processes of mineralization. Still, the effect of cultured plants on the processes of nitrogen mineralization has been studied insufficiently. Some theories explain the occurrence of a low nitrate accumulation under field crops by an intensified denitrification in the zone of roots. Other theories stated that the active root system affects depressively the process of nitrification (Iyon and Bizzell, 1918; Starkey, 1929; Iyon, 1930; Theron, 1951; Theron and Haylett, 1953; Rosselet, 1953). This depressive action is explained by the production of substances which intensify the processes of nitrification. When considering the effect of soil tillage on the amount of mineral
nitrogen, there is a general rule that soil tillage stimulates the decomposition of organic matter as the result of the mixing and stirring of the active soil layer. Frequently it takes a couple of years to reach the normal level of mineralization after tillage.

Numerous researchers reported the intensification of the processes of mineralization of stable humus in soil following the application of fresh organic matter (Löhnis, 1926; Norman and Werkman, 1943; Thorton, 1947; Broadbent and Norman, 1947; Walker et al., 1956).

METHOD

Experiments were conducted in a long-term trials established in 1946/47 and 1950/51 on slightly calcareous chernozem soil.

Soil samples were taken in the course of corn vegetation season of 1977 from the following variants: non-fertilized two-crop rotation corn-wheat (tilled at 20 and 35 cm), non-fertilized three-crop rotation corn-soybean-wheat (tilled at 20 and 35 cm), and 12-crop rotation which included the sequence—wheat-corn-soybean— (tilled at 20 and 35 cm).

The mineral fertilization in the last rotation is 60 N, 40 P₂O₅, 30 K₂O with the tillage at 20 cm and 120 N, 80 P₂O₅, 60 K₂O with the tillage at 35 cm. Corn was manured with 20 and 40 t/ha in the variants of tillage at 20 and 35 cm, respectively.

Soil samples were taken at 20-day intervals to follow the dynamics of mineral nitrogen. The first date of sampling was March 17, 1977. Samples were taken from the surface layer 0-20 cm and from all 15-cm layers to the depth of 200 cm. On the other dates, samples were taken from the layers 0-20 and 20-35 cm in four replications. Exchangeable ammonium and nitrate nitrogen were determined from soil extract obtained by 2 n KCl (Keeney and Bremner, 1965).

RESULTS

Dynamics of ammonium nitrogen

Table 1 shows the dynamics of ammonium nitrogen.
### Tab. 1 - Dynamics of $N\text{-NH}_4^+$ in the layer 0-200 cm, in ppt

<table>
<thead>
<tr>
<th>Depth in cm</th>
<th>Variant 1</th>
<th>Variant 2</th>
<th>Variant 3</th>
<th>Variant 4</th>
<th>Variant 5</th>
<th>Variant 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>13,92</td>
<td>12,18</td>
<td>12,18</td>
<td>13,92</td>
<td>12,18</td>
<td>13,92</td>
</tr>
<tr>
<td>20-35</td>
<td>13,92</td>
<td>13,92</td>
<td>13,92</td>
<td>12,18</td>
<td>13,92</td>
<td>13,92</td>
</tr>
<tr>
<td>35-50</td>
<td>8,70</td>
<td>13,92</td>
<td>8,70</td>
<td>12,18</td>
<td>6,96</td>
<td>10,44</td>
</tr>
<tr>
<td>50-65</td>
<td>3,48</td>
<td>13,92</td>
<td>8,70</td>
<td>10,44</td>
<td>6,96</td>
<td>8,70</td>
</tr>
<tr>
<td>65-80</td>
<td>3,48</td>
<td>12,18</td>
<td>8,70</td>
<td>8,70</td>
<td>4,22</td>
<td>6,96</td>
</tr>
<tr>
<td>80-95</td>
<td>3,48</td>
<td>8,70</td>
<td>6,96</td>
<td>6,96</td>
<td>3,48</td>
<td>6,96</td>
</tr>
<tr>
<td>95-110</td>
<td>3,48</td>
<td>8,70</td>
<td>5,22</td>
<td>5,22</td>
<td>3,48</td>
<td>5,22</td>
</tr>
<tr>
<td>110-125</td>
<td>3,48</td>
<td>6,96</td>
<td>5,22</td>
<td>5,22</td>
<td>3,48</td>
<td>5,22</td>
</tr>
<tr>
<td>125-140</td>
<td>3,48</td>
<td>5,22</td>
<td>5,22</td>
<td>5,22</td>
<td>3,48</td>
<td>5,22</td>
</tr>
<tr>
<td>140-155</td>
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<td>5,22</td>
<td>8,70</td>
<td>5,22</td>
<td>3,48</td>
<td>6,96</td>
</tr>
<tr>
<td>155-170</td>
<td>3,48</td>
<td>8,70</td>
<td>3,48</td>
<td>3,48</td>
<td>3,48</td>
<td>3,48</td>
</tr>
<tr>
<td>170-185</td>
<td>3,48</td>
<td>8,70</td>
<td>6,96</td>
<td>5,22</td>
<td>5,22</td>
<td>3,48</td>
</tr>
<tr>
<td>185-200</td>
<td>3,48</td>
<td>3,48</td>
<td>3,48</td>
<td>3,48</td>
<td>5,22</td>
<td>3,48</td>
</tr>
</tbody>
</table>

All variants had the largest amounts of ammonium nitrogen in the surface soil layer. Increased amounts of ammonium nitrogen went down to 35 cm with the shallower tillage but to 80 cm with the deeper tillage. Below these depths the amounts of ammonium nitrogen were equal. The above observation indicated that the mineralization of organic nitrogen reached further down with the deeper tillage, regardless of the fertilization practice.

### Tab. 2 - Dynamics of ammonium nitrogen in the layer 0-20 cm, in ppm

<table>
<thead>
<tr>
<th>Date of sampling in 1977</th>
<th>Variant 1</th>
<th>Variant 2</th>
<th>Variant 3</th>
<th>Variant 4</th>
<th>Variant 5</th>
<th>Variant 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr. 11</td>
<td>10,00</td>
<td>10,00</td>
<td>10,00</td>
<td>10,44</td>
<td>11,50</td>
<td>10,00</td>
</tr>
<tr>
<td>Apr. 29</td>
<td>10,84</td>
<td>11,31</td>
<td>10,88</td>
<td>9,57</td>
<td>9,57</td>
<td>10,88</td>
</tr>
<tr>
<td>May 20</td>
<td>6,97</td>
<td>7,83</td>
<td>8,70</td>
<td>8,40</td>
<td>8,70</td>
<td>8,27</td>
</tr>
<tr>
<td>June 10</td>
<td>6,97</td>
<td>4,79</td>
<td>6,96</td>
<td>7,40</td>
<td>10,88</td>
<td>12,40</td>
</tr>
<tr>
<td>July 4</td>
<td>6,97</td>
<td>6,96</td>
<td>6,52</td>
<td>5,22</td>
<td>10,88</td>
<td>12,18</td>
</tr>
<tr>
<td>July 25</td>
<td>8,70</td>
<td>7,83</td>
<td>6,96</td>
<td>6,96</td>
<td>7,83</td>
<td>7,83</td>
</tr>
<tr>
<td>Aug. 16</td>
<td>7,83</td>
<td>9,57</td>
<td>10,88</td>
<td>8,70</td>
<td>10,00</td>
<td>9,14</td>
</tr>
<tr>
<td>Sept. 2</td>
<td>6,97</td>
<td>5,66</td>
<td>7,40</td>
<td>5,22</td>
<td>7,40</td>
<td>9,57</td>
</tr>
<tr>
<td>Sept. 23</td>
<td>9,14</td>
<td>6,52</td>
<td>9,57</td>
<td>10,44</td>
<td>8,26</td>
<td>10,00</td>
</tr>
</tbody>
</table>

The dynamics of ammonium nitrogen was similar with all variants. Exceptions were the fertilized variants at the moment of fertilization when increased quantities of ammonium nitrogen were registered.

The dynamics of ammonium nitrogen was not prone to large variations. Generally, increases in ammonium nitrogen were observed in the course of April in all variants, to fall back in the second half of May. This pattern is explained by the
absence of plants and lower temperatures slowing down the processes of nitrification in April.

Tab. 3 - Dynamics of ammonium nitrogen in the layer 20-35 cm, in ppm

<table>
<thead>
<tr>
<th>Date of sampling in 1977</th>
<th>Variant 1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr. 11</td>
<td>11,31</td>
<td>10,44</td>
<td>11,31</td>
<td>11,31</td>
<td>11,74</td>
<td>11,31</td>
</tr>
<tr>
<td>Apr. 29</td>
<td>10,00</td>
<td>10,00</td>
<td>11,74</td>
<td>10,00</td>
<td>10,44</td>
<td>10,88</td>
</tr>
<tr>
<td>May 20</td>
<td>8,26</td>
<td>8,26</td>
<td>9,17</td>
<td>8,26</td>
<td>9,17</td>
<td>8,26</td>
</tr>
<tr>
<td>June 10</td>
<td>4,78</td>
<td>4,78</td>
<td>6,96</td>
<td>6,96</td>
<td>6,96</td>
<td>6,96</td>
</tr>
<tr>
<td>July 4</td>
<td>4,35</td>
<td>5,66</td>
<td>6,53</td>
<td>5,22</td>
<td>8,70</td>
<td>9,57</td>
</tr>
<tr>
<td>July 25</td>
<td>8,70</td>
<td>7,83</td>
<td>8,70</td>
<td>6,96</td>
<td>6,53</td>
<td>7,83</td>
</tr>
<tr>
<td>Aug. 16</td>
<td>7,83</td>
<td>7,83</td>
<td>10,00</td>
<td>8,26</td>
<td>7,40</td>
<td>9,57</td>
</tr>
<tr>
<td>Sept. 2</td>
<td>5,66</td>
<td>6,69</td>
<td>7,40</td>
<td>6,53</td>
<td>7,83</td>
<td>8,70</td>
</tr>
<tr>
<td>Sept. 23</td>
<td>8,26</td>
<td>7,83</td>
<td>7,83</td>
<td>10,00</td>
<td>8,70</td>
<td>8,70</td>
</tr>
</tbody>
</table>

The layers 0-20 and 20-35 cm did not differ in the dynamics of ammonium nitrogen, i.e., the layer 0-35 cm was rather uniform regarding the conditions for the processes of mineralization, ammonification, and nitrification.

Dynamics of nitrate nitrogen

Tab. 4 - Dynamics of nitrate nitrogen in the layer 0-200 cm, in ppm

<table>
<thead>
<tr>
<th>Depth in cm</th>
<th>Variant 1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>5,22</td>
<td>5,22</td>
<td>3,48</td>
<td>3,48</td>
<td>3,48</td>
<td>3,48</td>
</tr>
<tr>
<td>20-35</td>
<td>5,78</td>
<td>3,48</td>
<td>6,22</td>
<td>5,38</td>
<td>3,48</td>
<td>6,22</td>
</tr>
<tr>
<td>35-50</td>
<td>6,36</td>
<td>5,22</td>
<td>5,22</td>
<td>5,22</td>
<td>6,48</td>
<td>6,22</td>
</tr>
<tr>
<td>50-65</td>
<td>5,22</td>
<td>5,22</td>
<td>5,22</td>
<td>6,96</td>
<td>6,96</td>
<td>6,96</td>
</tr>
<tr>
<td>65-80</td>
<td>5,22</td>
<td>5,22</td>
<td>5,22</td>
<td>6,96</td>
<td>6,96</td>
<td>8,70</td>
</tr>
<tr>
<td>80-150</td>
<td>3,48</td>
<td>3,48</td>
<td>5,22</td>
<td>5,22</td>
<td>5,22</td>
<td>10,44</td>
</tr>
<tr>
<td>95-110</td>
<td>3,48</td>
<td>3,48</td>
<td>6,96</td>
<td>5,22</td>
<td>3,48</td>
<td>10,33</td>
</tr>
<tr>
<td>110-125</td>
<td>1,74</td>
<td>1,74</td>
<td>3,48</td>
<td>3,48</td>
<td>1,74</td>
<td>10,33</td>
</tr>
<tr>
<td>125-140</td>
<td>1,74</td>
<td>3,48</td>
<td>3,48</td>
<td>1,74</td>
<td>3,48</td>
<td>13,02</td>
</tr>
<tr>
<td>140-155</td>
<td>0,99</td>
<td>1,74</td>
<td>1,74</td>
<td>0,99</td>
<td>5,22</td>
<td>17,41</td>
</tr>
<tr>
<td>155-170</td>
<td>1,74</td>
<td>3,48</td>
<td>1,74</td>
<td>1,74</td>
<td>3,48</td>
<td>19,15</td>
</tr>
<tr>
<td>170-200</td>
<td>1,74</td>
<td>1,74</td>
<td>0,99</td>
<td>0,99</td>
<td>5,22</td>
<td>15,92</td>
</tr>
<tr>
<td>185-200</td>
<td>0,99</td>
<td>1,74</td>
<td>0,99</td>
<td>0,99</td>
<td>8,70</td>
<td>8,70</td>
</tr>
</tbody>
</table>

The fertilized variants experienced a significant movement of nitrate nitrogen, especially with the application of the larger dose of nitrogen. After the application of 120 N, nitrate nitrogen moved below 80 cm of the soil profile, accumulating to the highest concentration in the layer 155-170 cm but further increasing its concentration to the depth of 185 cm.
Tab. 5 - Dynamics of nitrate nitrogen in the layer 0-20 cm, in ppm

<table>
<thead>
<tr>
<th>Date of sampling in 1977</th>
<th>Variant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Apr. 11</td>
<td>3.92</td>
</tr>
<tr>
<td>Apr. 29</td>
<td>3.92</td>
</tr>
<tr>
<td>May 2o</td>
<td>4.35</td>
</tr>
<tr>
<td>June 1o</td>
<td>5.22</td>
</tr>
<tr>
<td>July 4</td>
<td>7.40</td>
</tr>
<tr>
<td>July 25</td>
<td>3.48</td>
</tr>
<tr>
<td>Aug. 16</td>
<td>3.92</td>
</tr>
<tr>
<td>Sept. 2</td>
<td>4.78</td>
</tr>
<tr>
<td>Sept. 23</td>
<td>3.48</td>
</tr>
</tbody>
</table>

The fertilized variants had a higher content of nitrate nitrogen on all dates of sampling. However, the amount of nitrogen used for top-dressing was in correlation with the content of nitrate nitrogen, the largest dose of nitrogen fertilizer bringing the highest content of nitrate nitrogen.

Tab. 6 - Dynamics of nitrate nitrogen in the layer 20-35 cm, in ppm

<table>
<thead>
<tr>
<th>Date of sampling in 1977</th>
<th>Variant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Apr. 11</td>
<td>4.53</td>
</tr>
<tr>
<td>Apr. 29</td>
<td>3.48</td>
</tr>
<tr>
<td>May 2o</td>
<td>5.22</td>
</tr>
<tr>
<td>June 1o</td>
<td>4.35</td>
</tr>
<tr>
<td>July 4</td>
<td>2.61</td>
</tr>
<tr>
<td>July 25</td>
<td>1.74</td>
</tr>
<tr>
<td>Aug. 16</td>
<td>3.48</td>
</tr>
<tr>
<td>Sept. 2</td>
<td>3.04</td>
</tr>
<tr>
<td>Sept. 23</td>
<td>2.18</td>
</tr>
</tbody>
</table>

The content of nitrate nitrogen was somewhat lower in the layer 20-35 cm than in the surface layer. This was probably the result of an intensive uptake of this nitrogen form by plants whose major portion of the root system was located in this layer. Still, the layer 20-35 cm reached its maximum content of nitrate nitrogen sooner than the surface layer, probably because of more favorable conditions for nitrification.

CONCLUSION

The deepening of tillage intensified nitrogen mineralization in soil. Preceding crop did not affect the contents of different forms of mineral nitrogen in the soil.
The movement of mineral nitrogen was in correlation with the quantity of nitrogen fertilizer applied.

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SOIL AND CLIMATIC ASPECTS OF WORKABILITY AND TRAFFICABILITY

Arthur J. Thomasson - Soil Survey of England and Wales
Rothamsted Experimental Station, Harpenden, U.K.

1. Introduction  Workability is defined as the ease with which operations to produce a satisfactory seed-bed or to harvest a root crop, can be undertaken. As these operations are influenced by transient moisture content as much as 'intrinsic' soil properties such as clay or organic matter content, an assessment of workability must include a time element involving the duration of good conditions for soil-engaging operations (Spoor 1979). Good soil workability implies an adequate period, in most years when cultivations can be undertaken, without damage to surface or subsoil horizons, to achieve a reasonable tilth, preferably without frost weathering. Poor workability implies only short periods of good conditions and that field operations are sometimes undertaken with damaging results. Good trafficability means that a power unit can move over the land easily to perform necessary work with negligible damage to the soil itself. Trafficability and workability are similar concepts; discrepancies are apparent for field operations which are not soil-engaging and also in very dry or highly organic soils.

2. Soil and Climatic Assessments  Under British conditions, excessive soil wetness is the main restriction for both workability and trafficability. Susceptibility of soils to damage by cultivations or traffic, with consequent penalties for sustained crop production, is governed by three main factors:-
   a) Soil wetness class (Hodgson 1976)
   b) water retention, plasticity and strength properties of the topsoil
   c) the climate, mainly the length of the field capacity period.

   For an experimental site it is possible to monitor all these factors and establish precisely the number of possible 'Machinery Work Days' (MWD's) for each farm operation. This paper offers a procedure to estimate the average length of the potential machinery work day period for the general run of agricultural land, from simple soil and climatic data.

2a. Water-tables and Permeability  Wind (1976) investigated spring workability using analog and numerical models and concluded that water-table depth had a critical effect on workability. He considered that in spring, good working conditions were achieved when soil moisture suction in the upper 5cm of soil
4. Conclusions The approach described can be applied to land classification and crop suitability studies, to assessments of need or benefits from drainage investment, and to studies of year-to-year farm crop performance (Rayner and Thomasson, in press). The system is capable of further development. It is clearly evident that tillage research and application at farm level need a system to assess and describe adequately the soil and climatic conditions which influence the efficiency and feasibility of new techniques and cropping systems.

References

Table 1 Soil Assessment
<table>
<thead>
<tr>
<th>Wetness Class</th>
<th>Depth to Impermeable Horizon (cm)</th>
<th>Retained Water Capacity; Mineral topsoils</th>
<th>Humose or Peaty topsoils</th>
</tr>
</thead>
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<td></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>&gt;80</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>&gt;80</td>
<td>a</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>40-80</td>
<td>b</td>
<td>b</td>
</tr>
<tr>
<td>III</td>
<td>&gt;80</td>
<td>b</td>
<td>c</td>
</tr>
<tr>
<td></td>
<td>40-80</td>
<td>c</td>
<td>c</td>
</tr>
<tr>
<td></td>
<td>&lt;40</td>
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<td></td>
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<td>d</td>
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</tr>
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<td>&gt;80</td>
<td>d</td>
<td>e</td>
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<td>e</td>
<td>f</td>
</tr>
<tr>
<td></td>
<td>&lt;40</td>
<td>e</td>
<td>f</td>
</tr>
<tr>
<td>VI</td>
<td>All Depths</td>
<td>f</td>
<td>f</td>
</tr>
</tbody>
</table>

a, easy -----> f, very difficult. Increasing restriction for workability and trafficability.
Table 2  
Soil Moisture Regime Classes—Wetness Class (Hodgson 1976)

Class I  
The soil profile is not wet within 70 cm depth for more than 30 days\(^1\) in most years\(^2\).

II  
The soil profile is wet within 70 cm depth for 30–90 days in most years.

III  
The soil profile is wet within 70 cm depth for 90–180 days in most years.

IV  
The soil profile is wet within 70 cm depth for more than 180 days, but not wet within 40 cm depth for more than 180 days in most years.

V  
The soil profile is wet within 40 cm depth for more than 180 days, and is usually wet within 70 cm for more than 335 days in most years.

VI  
The soil profile is wet within 40 cm depth for more than 335 days in most years.

\(^1\) The number of days specified is not necessarily a continuous period.  
\(^2\) 'In most years' is defined as more than 10 out of 20 years.

---

Table 3  
Mean Properties of Mineral Topsoils—not humose or peaty

<table>
<thead>
<tr>
<th>Particle Size Class</th>
<th>Retained water capacity (\theta_v(0.05)) % vol.</th>
<th>Water retained between 0.05 and 0.33 bar % vol.</th>
<th>Lower Plastic Retention Limit % mass Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>27, 48.0, 8</td>
<td>5.0</td>
<td>45, 13, &gt;45, High</td>
</tr>
<tr>
<td>Silty clay</td>
<td>18, 48.7, 6</td>
<td>5.9</td>
<td></td>
</tr>
<tr>
<td>Silty clay loam</td>
<td>31, 45.0, 6</td>
<td>5.7</td>
<td></td>
</tr>
<tr>
<td>Clay loam</td>
<td>47, 43.3, 7</td>
<td>6.0</td>
<td>32, 13, 35–45, Medium</td>
</tr>
<tr>
<td>Sandy clay loam</td>
<td>12, 38.9, 6</td>
<td>6.2</td>
<td></td>
</tr>
<tr>
<td>Sandy silt loam</td>
<td>16, 35.0, 4</td>
<td>6.3</td>
<td></td>
</tr>
<tr>
<td>Sandy loam</td>
<td>71, 31.0, 9</td>
<td>6.1</td>
<td>Non-cohesive &lt;35, Low</td>
</tr>
<tr>
<td>Loamy sand</td>
<td>13, 20.0, 4</td>
<td>5.7</td>
<td></td>
</tr>
</tbody>
</table>
### Table 4

Workability and Trafficability: Integration of soil and climatic components to estimate potential Machinery Work Days for the period 15th September to 30th April

<table>
<thead>
<tr>
<th>Climatic Assessment (Days)</th>
<th>Soil Assessment (Days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Field</td>
<td>Working Period</td>
</tr>
<tr>
<td>Period</td>
<td>-30th April</td>
</tr>
<tr>
<td>125</td>
<td>225</td>
</tr>
<tr>
<td>150</td>
<td>225</td>
</tr>
<tr>
<td>175</td>
<td>225</td>
</tr>
<tr>
<td>200</td>
<td>225</td>
</tr>
</tbody>
</table>

### Table 5

Autumn period 15th September onwards

<table>
<thead>
<tr>
<th>Field Capacity Zone</th>
<th>Date of return to field capacity</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>Machinery Work Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>125 Early Quartile</td>
<td>15 Nov</td>
<td>+20</td>
<td>80</td>
<td>60</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Late Quartile</td>
<td>25 Dec</td>
<td>-20</td>
<td>120</td>
<td>100</td>
<td>80</td>
<td>70</td>
</tr>
<tr>
<td>150 Early Quartile</td>
<td>20 Oct</td>
<td>55</td>
<td>35</td>
<td>15</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Late Quartile</td>
<td>10 Nov</td>
<td>-30</td>
<td>105</td>
<td>85</td>
<td>65</td>
<td>55</td>
</tr>
<tr>
<td>200 Early Quartile</td>
<td>25 Sept</td>
<td>-40</td>
<td>30</td>
<td>10</td>
<td>-10</td>
<td>-20</td>
</tr>
<tr>
<td>Late Quartile</td>
<td>15 Nov</td>
<td>-50</td>
<td>80</td>
<td>60</td>
<td>40</td>
<td>30</td>
</tr>
</tbody>
</table>

### Table 6

Spring period 1st March to 30th April

<table>
<thead>
<tr>
<th>Field Capacity Zone</th>
<th>Date of departure from field capacity</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>Machinery Work Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>125 Early Quartile</td>
<td>15 March</td>
<td>+10</td>
<td>55</td>
<td>45</td>
<td>40</td>
<td>35</td>
</tr>
<tr>
<td>Late Quartile</td>
<td>20 April</td>
<td>5</td>
<td>40</td>
<td>30</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>150 Early Quartile</td>
<td>20 March</td>
<td>20</td>
<td>50</td>
<td>40</td>
<td>35</td>
<td>30</td>
</tr>
<tr>
<td>Late Quartile</td>
<td>30 April</td>
<td>-10</td>
<td>30</td>
<td>20</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>200 Early Quartile</td>
<td>1 April</td>
<td>-5</td>
<td>40</td>
<td>30</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Late Quartile</td>
<td>15 May</td>
<td>-15</td>
<td>20</td>
<td>10</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>
ABSTRACT  Soil and Climatic Aspect of Workability and Trafficability
Arthur J. Thomasson.  UK.
Soil properties and average climatic data are integrated to allow long-term workability assessments for a range of soil types and climatic conditions. The procedures require only simple soil measurements or estimates to assess 'potential machinery work days' and can be used in studies of tillage, drainage, land classification and crop performance.
9. MODEL EXPERIMENTS IN TILLAGE
INFLUENCE OF CULTIVATION ON OXYGEN MOVEMENT TO A PLANT ROOT: AN ELECTRICAL MODEL STUDY

M.B. Kirkham

Evapotranspiration Laboratory, Kansas State University, Manhattan, Kansas 66506 USA

ABSTRACT

The objective of this work was to determine, by electrical analogue, how oxygen movement to a root is influenced by cultivation. Copper wire simulated a root. Copper electrodes of different widths simulated cultivated strips of different thicknesses. As width of cultivated strip increased, conductance of oxygen to the plant root increased exponentially. The analogue showed that young roots, with active zones of oxygen absorption 0.5 cm from the surface of the soil, absorbed four times more oxygen than did old roots, with active zones of oxygen uptake 12 cm below the surface of the soil.

INTRODUCTION

Roots of crops need at least 10% by volume air in the soil to survive (Wesseling and van Wijk, 1957, p. 472). Roots obtain oxygen from the air-filled pores in the soil. If the surface of the soil is crusted, oxygen cannot move to the roots and plants will die for lack of oxygen. Therefore, tillage of the soil is important because it permits oxygen to diffuse from the surface of the soil to the root, thus ensuring an oxygen supply for the root.

Electrical analogue (model) studies have long been used for water-movement studies and other linear-flow phenomena in soils and other media (Moon and Spencer, 1961; Luthin, 1974). Recently, Kirkham (1982) used the analogue technique for oxygen movement in soil as affected by earthworm channels. The objective of this work was to determine, by electrical analogue, how oxygen movement to a root was influenced by cultivation.

THEORY

The movement of gases in porous media, such as soil, occurs by two major transport mechanisms: mass flow and diffusion. In mass flow, the gas moves in response to a gradient in total pressure; in diffusion, the gas moves in response to a partial pressure or concentration gradient. Gaseous diffusion in soil occurs through the air-filled pore space between the solid particles and associated water films and is considered to be the most important process causing gaseous interchange between the soil and the atmosphere (Troeh, Jabro, and Kirkham, 1982).

The flow of gases in porous media, under low pressure gradients, is analogous to the flow of electricity in a conduc-
stores. Therefore, the theory of an electrical analogue applies to soil air. The movement of one gas into another, such as oxygen into air, is a linear-flow process. Fick discovered the linear-law of diffusion, which is called Fick's law, and it is as follows (Kirkham and Powers, 1972, p. 75):

\[ Q = DA(C_1 - C_2)/L \]  

(1)

where \( Q \) is the quantity of gas flowing through the soil per unit time, \( D \) is the diffusion coefficient, \( L \) is the length of the element through which the diffusion is occurring, \( A \) is the cross-sectional area of the element, and \((C_1 - C_2)/L\) is the concentration gradient. In differential form, Fick's law is as follows (Kirkham and Powers, 1972, p. 429):

\[ q_x = -D(dx)/(dx) \]  

(2)

where \( D \) is the diffusion coefficient (cm\(^2\)/sec), \( C \) is the concentration of diffusing substance (g/cm\(^3\)), \( q_x \) is the rate of transfer of mass per unit area [(g/cm\(^2\))/sec], and \( x \) (cm) is the distance of diffusion. When considering oxygen movement into air, \( D \) is 0.178 cm\(^2\)/sec at 0°C (Weast et al., 1964, p. F-24). Oxygen is only one of several gases in air. Therefore, for concentration in Eq. 2, we must replace \( C \) with partial pressure. Making use of Dalton's law of partial pressure and Boyle's ideal gas law, we find that the partial pressure \( P \) is related to concentration \( C \) as follows:

\[ C = P/\gamma \]  

(3)

where \( \gamma \) relates \( P \) and \( C \) (Kirkham and Powers, 1972, p. 433).

In this study, air was the diffusion medium for oxygen. The driving force was the difference in oxygen concentration (partial oxygen pressure) in air at the surface of the soil and oxygen concentration at the root surface.

METHODS

A plastic container, 5.1 cm wide (5.0 cm wall to wall), 24.0 cm long, and 2.5 cm tall, was used to hold the electrolyte, which was tap water (250 ppm salt). The 2.5-cm dimension does not enter into the model-flow analogy. Tap water was added to the plastic container until it stood 0.1 cm high. In the plastic container was placed one burnished piece of copper wire, 1 mm in diameter and 24 cm long, which simulated a root. The 1-mm depth of tap water just covered the 1-mm diameter root. In one test, the near-full length (23.5 cm) of the burnished wire was used to simulate a root active over its full length receiving oxygen. In another test, half the wire (12 cm) was insulated at the soil-surface end of the model. A series of such roots is similar to a root system from a row of plants in the field where the upper, older portions of the system become inactive and the lower, younger portions of the system are active metabolically and take up oxygen. Pairs of burnished copper electrodes, placed different distances apart, were inserted perpendicularly into the tap water. The electrodes simulated high-oxygen
concentration made by cultivator blades in breaking down crusted surface soil. The half (12 cm) of the copper wire (root) nearest the electrodes was insulated with masking tape. The bottom half (12 cm) of the copper wire was exposed to the tap water. The insulated root could not take up oxygen.

The model lay horizontally so that the tap water would not fall out of the plastic container. It is essentially a two-dimensional model, the unit cell being 5.0 cm wide and 24.0 cm deep and 1 mm thick. To visualize the model simulating field conditions, one must think of it in a vertical position, as seen in Fig. 1 and 2. Therefore, the root is vertical with the top 12 cm inert and the bottom 12 cm acting as an oxygen sink. No oxygen can move below the 24-cm depth, shown as a barrier in Fig. 1 and 2. Where the cultivator blades stir the soil surface, this soil takes on the concentration of oxygen in air (source of oxygen) and allows oxygen to feed into the soil.

Pairs of copper electrodes were placed symmetrically at sides of the plant root (Fig. 1). The width of the copper electrode was the thickness of the cultivated strip and widths were as follows: 1, 2, 5, 10, and 20 mm. One single copper electrode was 5.0 cm in width. With each increase in dimension of the copper electrode (strip-width cultivated), one was cultivating a wider strip of soil, and, therefore, cultivating more closely to the row of plants.

The pairs of copper electrodes, or the single 5.0-cm width copper electrode, were attached to one terminal of a Wheatstone bridge (Leeds and Northrup Model No. 4760 connected to Beede Model No. ES50UADC galvanometer and a 6-volt dry-cell battery). The uninsulated tip of the copper wire (root) extending from the insulated half of the root was attached to the other terminal of the Wheatstone bridge (Fig. 3 and 4). In the first run, the pair of the smallest copper electrodes (1-mm width each) was placed in the tap water so that they were 48 mm apart (50 - 2 = 48 mm) and the resistance in ohms was read then the smallest electrodes were removed and the next-to-smallest pair of electrodes was placed in the tap water so that they were 46 mm apart (50 - 4 = 46 mm) and the resistance was read. The same procedure was followed for all pairs of electrodes. Finally, the one 5.0-cm width copper electrode was placed in the tap water and the resistance read. The second and third runs replicated the first run. The reciprocal of ohms was calculated to obtain conductance in mhos (1/ohm = mho). (The SI unit for mho is siemen; 1 mho = 1 S.) Means of the three replications are presented.

RESULTS AND DISCUSSION

Table 1 on page 5 gives the experimental results. As the distance between cultivator blades decreased, conductance increased exponentially (Table 1). When the surface of the soil was completely open to oxygen (electrode = 5.0 cm), the conductance of oxygen to the root was at its maximum. Maximum values (51.6 and 243 μmhos) were used to compute dimensionless ratios (Table 1).
**Fig. 1.** Three-dimensional representation of model. Figure shows how active root receives oxygen from cultivated areas of soil.

**Fig. 2.** Two-dimensional representation of model.

**Fig. 3.** Top view of experimental setup.

**Fig. 4.** End view of experimental setup.
Table 1. Effect of cultivation on oxygen movement to a plant root 24 cm long. Data in parenthesis are for the situation in which the root is active over 23.5 cm of its length and data out of parenthesis are for situation in which the root is active over the 12 cm of its bottom half.

<table>
<thead>
<tr>
<th>Case</th>
<th>Width of one blade (cm)</th>
<th>Distance between two blades (distance/50 mm)</th>
<th>Conductance, G (μmhos)</th>
<th>G/51.6</th>
<th>G/243</th>
<th>Decrease in G (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.0</td>
<td>0</td>
<td>51.6 (243)</td>
<td>100.0</td>
<td>100.0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>2.0</td>
<td>1.0</td>
<td>51.3 (227)</td>
<td>99.4</td>
<td>(93.4)</td>
<td>0.6 (6.6)</td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>3.0</td>
<td>48.7 (188)</td>
<td>94.4</td>
<td>(77.4)</td>
<td>5.6 (22.6)</td>
</tr>
<tr>
<td>4</td>
<td>0.5</td>
<td>4.0</td>
<td>45.6 (163)</td>
<td>88.4</td>
<td>(67.1)</td>
<td>11.6 (32.9)</td>
</tr>
<tr>
<td>5</td>
<td>0.2</td>
<td>4.6</td>
<td>44.6 (154)</td>
<td>86.4</td>
<td>(63.4)</td>
<td>13.6 (36.6)</td>
</tr>
<tr>
<td>6</td>
<td>0.1</td>
<td>4.8</td>
<td>42.9 (117)</td>
<td>83.1</td>
<td>(48.1)</td>
<td>16.9 (51.9)</td>
</tr>
<tr>
<td>7†</td>
<td>0</td>
<td>No blade</td>
<td>100.0</td>
<td>&lt;0.1</td>
<td>(&lt;0.1)</td>
<td>99.998 (&gt;99.996)</td>
</tr>
</tbody>
</table>

† Resistance measured when no electrode in tap water and one terminal of Wheatstone bridge connected to end of plastic container. Resistance was greater than the maximum amount measurable with bridge (9,999,000 ohms). Case 7 was the situation in which the top of the soil was entirely crusted and oxygen could not penetrate the surface.
Having cultivator blades 10 mm apart was about the same as having the soil completely cultivated (compare case 1 and 2, Table 1). This result showed that, even with 20.0% of the soil surface closed to oxygen, conductance of oxygen to a root was almost the same as if none of the soil surface were closed to oxygen.

The young root which was active over 23.5 cm of its length, absorbed an average of four times more oxygen than did the old root with the top 12 cm inactive (compare G values in and out of parenthesis, Table 1). This result showed that a young root or adventitious roots close to the surface of the soil take up more oxygen than old roots active only at a distance from the soil surface. The data suggest that it is important to cultivate a plant in early stages of growth to obtain maximum benefit from aeration created by cultivation.

The model is for oxygen movement from the surface of the soil to a plant root. Oxygen diffuses in this direction because there is more oxygen at the surface of the soil than at the plant root. The model can also apply to movement of carbon dioxide. Carbon dioxide is produced as the root respires and will diffuse from the root, through the air-filled pores, to the soil surface, along a concentration gradient. Carbon dioxide diffuses in the direction opposite to that in which oxygen diffuses. Therefore, tillage is good for two reasons: It permits movement of oxygen to the plant root and movement of carbon dioxide away from the plant root.

ACKNOWLEDGEMENT: I thank Don Kirkham for discussions.

REFERENCES

DEVELOPMENT OF THE TIED RIDGED SYSTEM
BY MODELING THE INFILTRATION RAINFALL RELATIONSHIP

J. Morin¹, E. Rawitz² and W.B. Hoogmoed³

¹The Soil Erosion Research Station, The Ministry of Agriculture, Israel.
²The Seagram Center for Soil & Water Sciences, The Faculty of Agriculture, The Hebrew University of Jerusalem, Rehovot, Israel.
³The Tillage Laboratory, The Agricultural University, Wageningen, The Netherlands.

ABSTRACT

A method for predicting the quantity and discharge of runoff from cultivated areas is described. The analysis combines the soil infiltration and storage properties with the actual rainfall intensity of the rain storms in the region. The long-term runoff information allows probability analysis of the desirable storage for the tied ridged tillage system.

INTRODUCTION

Annual rainfall in the semi-arid regions is low, uncertain and patchy. Paradoxical as it may sound, however, in spite of the deficiency in rainfall enormous amounts of water are lost due to the runoff. The runoff is not only a loss of water for the crops production but very harmful also as a soil-erosion producer. Most of the engineering means to fight erosion, like water ways and broad terracing, are very expensive or not sufficient to prevent erosion at high rain storms. The most effective way to save water and to fight erosion is to prevent runoff. The rainfall water can either infiltrate, accumulate on the soil surface or form surface runoff. Increasing the infiltration capacity and/or the surface storage of the soil will reduce the runoff. Prediction of the unit-area runoff by physical models will provide the information for the desirable tillage.
The tied ridged system

The tied ridging is a simple method which can be applied by the farmer himself without special equipment for surveying the field. In many cases, it is just an extension of the bed or ridged system commonly used. The tied ridged system is described in detail in the F.A.O. informal working bulletin N 28 (1966). Since tied ridging comprises the construction of "ties" or crossdams between ridges running along the slopes, the desired storage capacity of the basin has to be known.

Runoff calculation

Surface runoff is mainly the result of crust formation on the soil surface during a rain storm. The crust impedes water infiltration. Crust formation, due to aggregates dispersion, is the result of the rain drops impact (McIntyre, 1958) and low concentration of electrolytes in the rain and in the surface soil solution (Agassl, 1981). The amount of runoff from cultivated bare soils can be calculated by combining the infiltration rates with data from the natural rain storms in the region. According to this method, the infiltration rate is expressed mathematically as a function of the rain depths by the equation (Morin and Benyamini, 1977):

\[ I_{t_i} = I_f + (I_f - I_i) e^{-\gamma p t_i} \]  

where \( I_{t_i} \) is infiltration rate as a function of time, in mm/h
\( I_f \) is final infiltration rate of the soil, in mm/h
\( I_i \) is initial infiltration rate of the soil, in mm/h
\( \gamma \) is a soil coefficient determined by the stability of the soil surface aggregate, in 1/mm
\( p \) is rain intensity, in mm/h, and
\( t_i \) is the time from the beginning of the storm, in h.

The runoff amount for a given natural rain storm containing different rain intensity segments is calculated as suggested by Morin and Jarosh by:

\[ \sum_{i=1}^{n} R_i = \sum_{i=1}^{n} (P_i \Delta t_i + SD_{i-1} - F_{\Delta t_i} - SD_m) \]  

where \( F_{\Delta t_i} \) is the total infiltration of any one segment, \( \Delta t_i \), with rain intensity \( P_i \).
\( SD_i \) is surface storage and detention for \( \Delta t_i \) segment
\( SD_m \) is maximum storage and detention, and
\( R_i \) is runoff at the \( \Delta t_i \) segment.
**Long-term analysis of runoff probabilities**

The infiltration characteristics of the soil at the Alumim experimental site were determined by a rain simulator. The prediction of the runoff amounts was calculated by those infiltration equations and the recorded rainfall data for the 1964-1979 period. Runoff probability analysis from the beginning of the season to February 1st, and for the entire winter, is presented in Fig. 1.

**Fig. 1.** Probability analysis of runoff based on Saad station.

Runoff values are presented for surface storage of 0.5 mm and for 15 mm. The 0.5 mm storage is typical of a land cultivated for small grains. The 15 mm represents storage obtainable in small grain fields with the tied ridged system.

Field experiments in Israel in cotton and wheat fields verified the ability of the infiltration-rainfall model to predict runoff and to guide the tillage system (Rawitz, Hoogmoed and Horin, 1981).
REFERENCES


The soil erosion by water detachment is a main problem in Sub-Tropical soils when mechanization is used. Because of heavy rains the top soil is sealed, the pore space is lost and the soil is carried by water erosion. The good soil management is the only way to control this phenomenon.

MATERIAL AND METHODS.

The plots were allocated on a Red Dark Latosol (Haplohumox), in Paraná State, Brasil with the following characteristics: clay textured, low fertility and high rate of Al\textsuperscript{+++}. The steep of the plots were of 10\% and the texture showed 47\% of clay.

The wheat cultivar used was IAC-5 Maringá with the seeding rate of 80 seeds per linear meter. The soybean cultivar was Bossier with the seeding rate of 28 seeds per linear meter. The fertilizer applied was 350 kg/ha of NPK (4-35-11) for both crops. For soybeans one application of pre-emergence herbicide was made.

We used the rotating-boom rainfall simulator and the accessories as detailed by BISCAIA (1). The soil concentration in the runoff was taken each 6 minutes with 1000 ml. bottles, direct at the runoff flume.

Each experimental plot had 38,5 m\(^2\) (11x3,5 m), with the bigger dimension down slope. The tillage treatments were made down slope, and consisted of:

- Conventional (disc plow + disc arrow)
- Minimum (disc arrow)
- No-tillage
- Conventional tillage: disc plow + disc arrow twice,
- Minimum tillage: disc arrow twice.
- No tillage: without soil movement.
- Conventional tillage + bare soil: disc plow + disc arrow twice, without culture.

Each treatment consisted of two replications. The results are the means of the two replications.

The simulated rain was applied with the following pattern:
- Rain I: 65 mm/h for 60 minutes.
- Rain II: 65 mm/h for 30 minutes 24 hours after Rain I.
- Rain III: 120 mm/h for 15 minutes, close after Rain II.

We used the erosion index \( EI \), presented by Lombardi Netto (2) for the rain simulator that is:

\[ EI = \frac{P \times I}{P \times 21.3 \times 10^{-3}}, \]

where
- \( P \) = erosion index
- \( I \) = maximum intensity of simulated rainfall in 30 minutes, in mm/h.

\( 21.3 \times 10^{-3} \) = rain simulator index.

RESULTS AND DISCUSSION

The simulated rainfall applied in all plots had no significant differences and showed a CV of 11% for the \( EI \) values, and was not significant for the \( F \) test at 5% level. We can say than all the treatments received the same intensity of simulated rain.

The losses for wheat and soybeans are shown on Tables n°1 and n°2.

**TABLE 1** - Soil and water losses with simulated rainfall, for wheat, in Dark Red Latossol (haplohumox), Ponta Grossa, Brasil.

<table>
<thead>
<tr>
<th>Tillage Method</th>
<th>Soil (kg/ha)</th>
<th>Water (%)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional tillage</td>
<td>11432</td>
<td>19</td>
<td>seed bed</td>
</tr>
<tr>
<td>Minimum tillage</td>
<td>1716</td>
<td>20</td>
<td>100% canopy</td>
</tr>
<tr>
<td>No-tillage</td>
<td>16407</td>
<td>19</td>
<td>seed bed *</td>
</tr>
<tr>
<td></td>
<td>1187</td>
<td>28</td>
<td>100% canopy</td>
</tr>
<tr>
<td></td>
<td>13400</td>
<td>36</td>
<td>seed bed *</td>
</tr>
<tr>
<td></td>
<td>436</td>
<td>19</td>
<td>100% canopy</td>
</tr>
<tr>
<td>Conventional tillage + bare soil</td>
<td>19274</td>
<td>31</td>
<td>Date: 11/1977</td>
</tr>
</tbody>
</table>

* Without residues
TABLE 2 - Soil and water losses with simulated rainfall, for soybeans in Dark Red Latossol (Haplohumox), Ponta Grossa, Brasil.

<table>
<thead>
<tr>
<th>Tillage Method</th>
<th>Losses Soil (kg/ha)</th>
<th>Losses Water (%)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional tillage</td>
<td>19089</td>
<td>35</td>
<td>seed bed</td>
</tr>
<tr>
<td>Minimum tillage</td>
<td>12018</td>
<td>25</td>
<td>seed bed</td>
</tr>
<tr>
<td>No-tillage</td>
<td>1120</td>
<td>16</td>
<td>seed bed</td>
</tr>
<tr>
<td>Conventional tillage + bare soil</td>
<td>22840</td>
<td>23</td>
<td>Date: 12/1977</td>
</tr>
<tr>
<td></td>
<td>13934</td>
<td>21</td>
<td>Date: 4/1978</td>
</tr>
</tbody>
</table>

The losses for the wheat crop (Table 1) are too high for minimum tillage and no-tillage treatments. This was caused by the fact that there was no mulching of a culture before the wheat. In this case these treatments have no viability.

For the soybean crop (Table 2) we can see that the losses were lower as we had less work with the soil. In this case the no-tillage method had 94% less soil losses than the conventional tillage, at the first stages of the crop. When the soybeans covered all the soil we had losses 85% smaller in the no-tillage against the conventional method. The minimum tillage system had the losses reduced by 37% as compared to the conventional, when the canopy was not completed.

In the Figure n° 1 we can see the total losses of soil for the soybean crop and the soil losses of the bare plot. These losses rose to 36.8 ton/ha for bare soil and showed the great importance of the canopy as a factor of reducing splash of the rain drops and the erosion.

The losses of surface water are shown on Table 2, for the soybean crop. We can see that the treatments that had a lower movement of top soil were able to catch more water and had a lower runoff. The same results were found by Kannering and Burwell (3).
The soil losses for the Dark Red Latossol were greater than the losses occurred in the "Latossol Roxo distrofico", tested in the same way by Mondardo et al. (4). With the conventional tillage the "Latossol Roxo distrofico" had losses of 10 ton/ha, with soybeans and the Dark Red Latossol had about 20 ton/ha. With the no-tillage method the losses had the same order of values.

FIGURE 1: SOIL LOSSES WITH SIMULATED RAINFALL, FOR SOYBEANS IN DARK RED LATOSSOL, PONTA GROSSA - BRASIL
CONCLUSIONS

With the trials of simulated rainfall made we can conclude:
- The canopy of the crop is a major factor of reducing soil losses.
- The tillage method is important for erosion control. The higher is the topsoil movement the higher are the soil losses.
- For a better erosion control, at the first stages of the crop, the mulching of the antecedent crop must be preserved.

Literature Cited


(2) LOMBARDI NETO, F. 1977 Rainfall simulations. West Lafayette, Purdue University. (mimeografado).


FURTHER DEVELOPMENT OF THE METHOD FOR MAINTAINING THE SOIL-WATER POTENTIAL IN GREENHOUSE POTS

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Abstract

By means of greenhouse experiments the influence of a differentiated but constant water supply on the development and yield of sugar beet has been investigated earlier. In order to more nearly simulate natural profile conditions in which water supply doesn't remain constant at different soil depths, columns were used in which water supply could be varied by depth.

In previous papers (Sommer 1978; Sommer 1979; Sommer 80/81) a method was described that allows one to irrigate greenhouse pots to a given soil-water potential continuously and automatically. The discussed results with sugar beet based on large 40 liter greenhouse pots. Nevertheless the root development especially into the depth was largely restricted. Therefore the method was developed further.
Three PVC cylinders of 300 mm inside diameter and 340 mm height are installed one upon another, Fig. 1.

The amount of water supplied to each soil depth can be measured by means of a scale on the storage bottles.

The daily water consumption of a sugar beet plant of the treatment 2 (upper compartment: $\gamma_1 = -0.05$ bar, middle compartment: $\gamma_2 = -0.60$ bar, lowest compartment: $\gamma_1 = -0.05$ bar) is shown in Fig. 2.
During the first 30 days the plant was small and water use consisted primarily of evaporation from the soil surface. Then water uptake from depth 1 ($\gamma_1$) increased rapidly. Depth 2 ($\gamma_2$) was tapped at a later time (point A) and five days later the water uptake from depth 3 ($\gamma_3$) increased sharply. After 74 days water consumption from depth 3 was higher than from depth 1 although the water potentials ($\gamma_1$) were the same. Corresponding results were received with other combinations of $\gamma$-levels (treatments) in different soil depths. Thus the relationship between water consumption and soil-water potential varying with depth can be studied and the development of plants can be measured. Those data are necessary for:

- making quantitative statements about actual requirements of plants to optimize water supply by irrigation (Sommer and Bramm, 1978)
- measuring the root efficiency of genotypes (El-Bassam and Sommer, 1980)
- and testing mathematic models for predicting yields by measuring evapotranspiration (Wenda and Hanks, 1981).

**Literature**


lo. NEW MACHINES AND TOOLS IN TILLAGE
ABSTRACT

The effects of various implements and tools on the quality of the prepared seedbed were investigated in a number of experiments. Drag beams produced a good soil aggregate size distribution, and rolling after sowing improved the distribution further. The ability to produce an even seedbed bottom varied considerably for the different implements and tools. The most even bottom was formed with an experimental drag-harrow implement with a small rake angle on the front beam and no tines.

INTRODUCTION

The quality of the preparation may be evaluated principally through the seedbed aggregate size distribution, the depth of the seedbed and the evenness of the seedbed bottom and the surface. The best emerging conditions occur when a high proportion of the aggregates in the seedbed is in the fraction 0.5-6.0 mm, and when the fraction of aggregates larger than 20 mm is small (NJØS 1979, HÅKANSON & von POLGAR 1976, 1977). The depth of the seedbed ought to be between 40 and 60 mm, and the coulters should place the seed on the seedbed bottom (HÅKANSON & von POLGAR 1976, KRITZ 1979). The bottom should, therefore, be as even as possible. The variations of the bottom profile are expressed by the standard deviation (mm).

EXPERIMENTS

The experiments were carried out in the spring on land ploughed in the autumn. Each field had a quite uniform soil, but the clay content in the various fields varied between 25 and 45 %. The implements used were drags, harrows,
and drag-harrows which evened and harrowed in one operation. In all, 6 drags, 3 harrows and 4 drag-harrows were used in the experiments. The drags had rigid tines, spikes, or scrapers (lugs) under the beams, Fig. 1. The harrows had one drag beam, flexible tines and crumbler rollers. The drag-harrows consisted of two drag-beams and a harrowing unit in two different versions, Fig. 2. One of these versions was an experimental implement. The effects on the seedbed of the different tools were investigated in special experiments, which comprised the use of drag-beams, tines, and rollers.

RESULTS

The Aggregate Size Distribution

The aggregate size distributions which the three types of implements produced are presented in Table 1.
Table 1. Aggregate size distributions (%) for different implements and numbers of passings (Exp. 1978-81)

<table>
<thead>
<tr>
<th>Number of</th>
<th>Depth of</th>
<th>Drags</th>
<th>Harrows</th>
<th>Drag-harrows</th>
</tr>
</thead>
<tbody>
<tr>
<td>passings</td>
<td>layer</td>
<td>Aggregate size</td>
<td>Aggregate size</td>
<td>Aggregate size</td>
</tr>
<tr>
<td></td>
<td>mm</td>
<td>&gt;20 mm</td>
<td>0.5-6.0 mm</td>
<td>&gt;20 mm</td>
</tr>
<tr>
<td>1</td>
<td>0-20</td>
<td>26</td>
<td>40</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>20-bottom</td>
<td>7</td>
<td>57</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>0-20</td>
<td>19</td>
<td>45</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>20-bottom</td>
<td>6</td>
<td>58</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 1 shows that after one passing the harrows gave a somewhat coarser structure than did drags and drag-harrows. After two passings the differences between the implements were very small. The average result from the drags was quite good. However, there were quite big differences between the 6 different drags.

The drag-beams are designed to break the soil and level the ground. The profiles of these beams vary much. Experiments concerning the profiles of these beams comprised the use of 8 understreaming profiles and 2 overstreaming profiles, Fig. 2. The main results from the experiments are presented in Table 2.

Table 2. The aggregate size distribution (%) after passings with different drag-beams (Exp. 1979-80)

<table>
<thead>
<tr>
<th>Aggregate size</th>
<th>Combinations of different numbers and profiles of beams</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>One beam understream.</td>
</tr>
<tr>
<td>&gt;20 mm</td>
<td>20</td>
</tr>
<tr>
<td>0.5-6.0 mm</td>
<td>45</td>
</tr>
</tbody>
</table>

The table shows that overstreaming beams gave a coarser seedbed structure than did understreaming beams. There was no significant effect either of the number of beams or of the profiles.

Under the understreaming beams there were scrapers with different heights (60, 90 and 200 mm), lengths (150 and 250 mm) and angles (25° and 40° with the direction of travel), Fig. 1 and 3. Scrapers at the smallest angle and of the
lowest height and the shortest length gave the finest seedbed structure. The spacing between the tracks of the scrapers varied between 0 and 100 mm, Fig. 3. Increased spacing in this area showed only a small reduction in the fineness of the seedbed structure.

The harrow tines did not have the same ability to break the soil as did drag beams with understreaming profiles. The fineness of the seedbed structure was the same as for overstreaming profiles.

The Cambridge roller had first of all an effect on shallowly prepared seedbeds. On deeply prepared seedbeds this roller only pushed the clods down through the soil. Sowing followed by packing with the Cambridge roller increased the most favourable aggregate fraction on an average with about 5 %, and possible differences in the aggregate size distribution before packing were thus eliminated.

 Depths of Seedbed and Variations of Bottom Profile

The working depth through harrowing may be adjusted with the supporting runners, wheels, and roller crumblers. The drags are not supported, but float on the soil surface, and the depth of working depends on the design of the beams. The different implements were adjusted as correctly as possible. Table 3 presents the results.

Table 3. Preparation depth (mm) and variations of the seedbed bottom profile (mm standard deviation) (Exp. 1978-81)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average preparation depth</td>
<td>38 (48)</td>
<td>48 (57)</td>
<td>44 (62)</td>
<td>46 (46)</td>
</tr>
<tr>
<td>Average variations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One passing</td>
<td>8,1 (6,9)</td>
<td>8,8 (8,1)</td>
<td>6,6 (6,6)</td>
<td>5,3 (5,3)</td>
</tr>
<tr>
<td>Two passings</td>
<td>7,0 (5,6)</td>
<td>6,8 (6,1)</td>
<td>6,3 (5,7)</td>
<td>4,3 (4,3)</td>
</tr>
</tbody>
</table>
The drag-harrows formed the bottom more evenly than did the drags and harrows. The reason was that equipment with tines and spikes formed a very uneven bottom profile as seen across the driving direction. On the drag-harrows with tines the tines were adjusted to work a little shallower than the working depth of the dragging unit. That probably explains why this implement formed a more even bottom than did drags and harrows. Nevertheless, this type of drag-harrows formed a more uneven bottom than did the type without tines.

Two passings produced a more even bottom than did one passing. When different qualities of ploughing were included in the experiments in 1981, the seedbed bottom was found to be formed more evenly on the even than on the uneven furrows. The standard deviation was 5.5 and 6.7 mm respectively ($P<0.01$). On the even ploughing two passings did not improve the seedbed bottom as compared to one passing. On the uneven ploughing, however, the bottom eveness was significantly improved with two passings instead of one. The explanation may be that the grooves between the furrows also contribute in forming the seedbed bottom after one passing. After two passings a new seedbed bottom is formed.

The working depth attained with drag-beams is related to the height of the scrapers on understreaming beams. On overstreaming beams the rake angle is probably the most important characteristic. Fig. 4. With understreaming beams the most correct depth under different conditions was obtained with 90 mm high scrapers.

![Fig. 4. The rake angle of overstreaming beams](image)

Overstreaming beams had rake angles of $5^\circ$ and $35^\circ$. Both angles gave satisfactory and equal depths. The implement with a $5^\circ$ rake angle was, however, of much heavier construction than the implement with a $35^\circ$ rake angle. This might have brought about this equality in working depth.

In order to prepare a more even bottom the attention was concentrated on the design of scrapers and overstreaming beams. Experiments were carried out with an implement which had understreaming beams with different types of scrapers, and other implements which had overstreaming beams with different rake angles, Fig. 4. The main results are presented in Table 4.
Table 4. Variations (standard deviation in mm) of the seedbed bottom for different implements with different tools

<table>
<thead>
<tr>
<th></th>
<th>Two understream beams with scrapers</th>
<th>Overstream beam 35° rake angle</th>
<th>Overstream beam 5° rake angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard deviation (mm)</td>
<td>6.6</td>
<td>7.2</td>
<td>5.3</td>
</tr>
</tbody>
</table>

Table 4 shows that the implement with the smallest rake angle of the overstreaming beam formed the most even seedbed bottom. The smallest rake angle refers to the experimental implement in Fig. 3. The results regarding the scrapers are related to scrapers at a 25° angle with the direction of travel. Bigger angles gave a more uneven bottom. The other parameters such as lengths of scrapers (150 and 250 mm) and spacing between their tracks (0-100 mm) showed no influence on the evenness of the bottom.

To make an implement work parallel to the soil surface and to a given depth, it should be supported by adjustable supports. The supporting may be effected through runners, wheels, or crumbler rollers. Crumbler rollers are probably the best alternative, because they produce no compaction of the soil. On the drag-harrow without tines the support by crumbler rollers at the rear also will regulate the transportation of soil by the second drag-beam. Without such support there may be too much soil heaped up in front of this beam.

REFERENCES


Abstract

Subsoilers and chisel plows are primary tillage implements. We propose a theoretical analysis of their respective soil resistance during uniform advancing. From our results we may conclude the subsoiler is the higher draft tools. The first tests in a farm scale experiment confirm the theoretical results. We think the subsoiler could be conveniently employed for preliminary ploughing and the chisel plow for replacement ploughing.

Foreword

Soil tillage trials carried out in Umbria, Italy, in connection with current experimental research by the Institute of Agronomy and the Institute of Agriculture Engineering in Perugia, offers the opportunity to test the performance characteristics of two implements used for primary tillage of compacted soil layers.

Both implements, three points hitched, were towed by a Fiat 1880 DT, 132 kW, 4 wheel traction tractor.

Implement in Fig. 1 has two rows of standards; they are attached to a rugged box-steel frame and spaced .45 m along the rows. The front of the lower part of the standard is protected, by a reversible steel plate, and pointed shaft end.

Implement of Fig. 2 consists of a strong tubular toolbar where three standards are steadily tilted at a distance of .90 m. The straight standards have a rectangular section and they are supplied by a wedge cutting edge shaped.

Relating to the tool's profile shape, the action mechanism is very different. However, quite apart from the work that this tool is capable of performing, the effort required for advancing depends on its shape and its pitch.
The three standards implements cut the soil and dig in depth through the terminal slab. This implement is a subsoiler.

The five standards implement can break up and lift the soil, part of which remains on the surface. This implement, which is suitable for that work, is a chisel plow.

**Soil resistance during uniform advancing**

In both cases the total soil resistance against each single standard plunged into the ground during uniform advancing is due to:

- pure soil tenacity;
- friction and adhesion on the standard faces;
- soil deformation work.
We will consider the lower part of the working tool, which is comparable to a rectangular slab, fully plunged into ground, and the top one which is the sloping standard.

About the rectangular slab Mr. Stefanelli [1] proposes separate solutions in the extreme cases: undeformable (rigid limit) and compressible soils (plastic limit).

The expressions of the horizontal and the vertical components of the resulting reaction $R_p$, in both cases (Fig. 3) are, excluding soil tenacity:

\[ R = R_p \sin (\alpha + \varphi) \]
\[ P = R_p \cos (\alpha + \varphi) \]

where $\varphi$ is the friction angle and $\alpha$ is the lift angle.

The upper part of the working tool is subject to compression forces, to external friction and adhesion on the lateral faces. As far as their analytic definition is concerned, the following simplified hypotheses should be formulated:

- the standard part examined is practically normal with respect to the ground surface by disregarding, then, its inclination effect;
- the soil exerts a constant pressure on the active faces of the standard.

We will examine the standard section outlined in Fig. 4, where are indicated, by an $a$ the mid width max and by a $d$ the height section, limitedly to the part corresponding to the active faces. The remaining part has the external profile deprived from the action of the ground.
with reference to the unit length of the standard on a segment $dl$ of the profile, the result is: $p \, dl$ vertical pressure force and $f \, p \, dl$ frictional force. The resultant of the compression forces is:

$$ F_a = 2 \int f \, p \, dl \, \cos \theta = 2 \, p \int_0^s dx = 2 \, p \, s $$

where the angle $\theta$ is defined in Fig. 4. The resultant of the frictional force is:

$$ F_a = 2 \int f \, p \, dl \, \sin \theta = 2 \, f \, p \int_0^d - dy = 2 \, f \, p \, d $$

We stated[2] that the resistance in the direction of the feed, per length unit of standard, for equal values of $p$, $s$ and $f$, is independent of the shape of the standard section, but it depends on the $d/s$ ratio:

$$ R_{pa} = F_p + F_a = 2 \, p \left( s + f \, d \right) = 2 \, p \, s \left( 1 + f \, d/s \right) $$

Chisel plow

The chisel plate lifts the soil interested with formation of mold on the surface; the behavior of the ground can be considered as corresponding to the rigidity[1]. In that case $R_p$ becomes:

$$ R_p = \tau (2 \, h - s) \cos (\alpha + \varphi) \left( 1 \, \cos \varphi + 1' \right) $$

where the shearing stress $\tau = c + p \, \tan \varphi'$ (being $c$ the cohesion, $p$ the pressure and $\varphi'$ the interior friction angle) is equal to the mean value of the tangential forces on the lateral faces of the prism soil lifted by the plate. The other parameters are defined in Fig. 3. $R_p$ appears to be an increasing function of $\varphi'$.

The resistance to the feed, excluding tenacity, is:

$$ R_0 = R_p \, \sin (\alpha + \varphi) = \tau (2 \, h \, \sin \alpha) \left( 1 \, \cos \varphi + 1' \right) \tan (\alpha + \varphi) $$

The upper part of the standard, plunged into the ground, performs in a double fashion: to favour the lifting of the soil and to break up the surface layers. The resistance in the direction of the feed, per length unit, due to compression and to frictional forces on the standard faces, in the simplified hypothesis previously mentioned, comes from (Fig. 1):

$$ R_{pac} = 2 \, p \left( a_c + f \, d_c \right) = 2 \, p \, a_c \left( 1 + f \frac{d_c}{a_c} \right) $$

(1) Though if the work is .35 + .40 m deep, this is a right approximation because the shape of the working tool favours the lifting of soil.


Subsoiler

In the subsoiler the plate works at considerable depth and unlike the chisel, has a longitudinal profile which slopes steeply from the standard for this we can argue that during advancing it will cause a partial compression of the soil in depth as well as slightly moving it towards the top.

The compression phenomenon, again excluding the soil tenacity, gives the following expression of the resistance during advancing:

\[ R_s = \frac{K \cdot l' \cdot l}{\tan \alpha \cdot \cos \phi \cdot (\alpha + \phi)} \]

where \( K \) is the ground resistance to compression, \( l' \) the width of the plate and \( l \) its length. We have to make the expression of \( R_s \) times a variable reduction coefficient \( m \) between 0 and 1 in connection with the real work conditions of partial compression.

The resistance against the standard is due to compression, to external friction and adhesion to the front and lateral faces; the definition is generated on the basis of the same simplified hypotheses previously outlined. We will consider then the faces of the standard corresponding to the unitary length; referring to Fig. 2 the compression and frictional forces are, respectively:

\[ N = p \cdot l; \quad N' = p \cdot d''; \quad S = f \cdot p \cdot l; \quad S' = f \cdot p \cdot d'' \]

The total reaction of soil against the standard in the uniform advancing is:

\[ R_{pas} = 2 \cdot p \cdot s_a + 2 \cdot f \cdot p \cdot (d' + d'') = 2 \cdot p \cdot s_a + 2 \cdot f \cdot p \cdot D = 2 \cdot p \cdot s_a \cdot (1 + f \cdot \frac{D}{s_a}) \]

Resistance \( R \) depends, as already mentioned for the chisel, on the \( D/s_a \) ratio.

Comparison of the two working tools

The direct comparison of the performances of the two working tools seems to be reasonable if limited to behavior analysis of the upper part of the standards as it is possible to detect an analogy in the action mechanism. In the hypothesis that the pressure exerted by the ground on the active faces of the standard would assume the same value, the \( R_{pac}/R_{pas} \) ratio will be:

\[ \frac{R_{pac}}{R_{pas}} = \frac{2 \cdot p \cdot s_o + 2 \cdot f \cdot p \cdot d_o}{2 \cdot p \cdot s_p + 2 \cdot f \cdot p \cdot D} = \frac{2 \cdot p \cdot (s_o + p \cdot d)}{2 \cdot p \cdot (s_p + f \cdot D)} = \frac{s_o + f \cdot d}{s_p + f \cdot D} \]

The coefficient of friction \( f \) may fluctuate between .2 and .6; consequently, referring to the standard dimensions, \( R_{pac}/R_{pas} \) ratio can reach the limit values of about 1/4.5 and 1/5.
An approximate comparative evaluation could also be expressed in connection to the performance of the two plates. We will consider admissible the hypotheses referred above in connection with the modus operandi of the two plates by assuming that the breaker tool the subsoiler presses and lets the soil partially slide and that the steel chisel plate performs the total sliding. Since the value of the shearing stress $\tau$ fluctuates in the range $0.4 + 0.6$ kg/cm$^2$, the resistance to compression $1 + 10$ kg/cm$^3$, the ratio:

$$\frac{R_c}{R_a} = \frac{2 \tau (2 h - 1 \sin \alpha) (1 \cos \varphi + 1')}{m K 1' 1^2 \sin \alpha \cos \varphi}$$

will fluctuate between $1/6$ and $1/5$ (supposing $\varphi = 27^\circ$, $h = 0.45$ m and the reduction coefficient will equal respectively to $0.6$ and $0.3$). The total resistance during advancing (excluding cutting work, breaking and soil lifting) is always greater for the subsoiler.

**Conclusions**

The first results obtained in the course of the experiment carried out on agricultural soil confirm the results achieved on a theoretical basis. By employing the chisel, the overall power was 18 kW per standard, whereas for the subsoiler the corresponding power was 35 kW per standard. The analysis of tool advancing gives only some indications of the performance of the complete implement because there is a positive mutual involvement between standards when they are working together. The chisel plow and the subsoiler are used to break through and shatter compacted soil layers. As the subsoiler performs its cleavage work by digging the ground in depth, the chisel works almost the whole tillable layer lifting to the surface the clods and is sometimes employed in stead of moldboard plows when it is soil inversion is undesirable. We think the subsoiler could be conveniently employed in the preliminary ploughing and the chisel plow in the replacement ploughing.

**Reference**


We thank: A. Cocchioni and G. Taba for their data and So.Ge.Ma, ORMA for the use of implements.
RESPONSES TO DEEP LOOSENING BY 'PARAPLOW' IN CONTINUOUS CEREAL PRODUCTION.

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(1) Agricultural Development and Advisory Service, UK; (2) ICI Plant Protection Limited, UK.

ABSTRACT

Soil and crop responses to loosening by 'Paraplow' were investigated in comparison with a range of other tillage treatments in eight field trials in eastern England. The test crops were winter wheat or barley and the sites were chosen to cover a range of soil types considered unsuitable or difficult for direct drilling. Results from the first year are reported here. Measurements of water infiltration rate and cone penetrometer resistance indicated greatly improved soil physical conditions following loosening by 'Paraplow' on the previously direct drilled treatment, and this was reflected in greater root development. The much greater soil disturbance of the conventional ploughing treatment gave no further improvement. In the relatively moist 1981 growing season, only one trial showed a yield reduction under direct drilling compared to ploughing. Three trials however showed significant yield increases after loosening by 'Paraplow', averaging 0.4 t/ha.

INTRODUCTION

Wide scale adoption of shallow cultivation (less than 10cms) and of direct drilling has taken place in England during the 1970s in order to accommodate a large increase in Autumn cereal production. By 1980, 10% of the winter cereal area was direct drilled and a further 60% established without the plough. It has been recognised by Cannell et al (1978) that these reduced cultivation techniques are more at risk of yield reduction on soil types that are particularly susceptible to compaction. The 'Paraplow' was developed specifically to alleviate compaction in such soils (Pidgeon, 1982). The experiments reported here were designed to test the hypothesis that on compacted soils, loosening by the 'Paraplow' would result in improved soil physical conditions and raise crop yield to at least the level of the best of the alternative tillage treatments. Accordingly, trial sites were selected not on major representative soil types, but on those with poor physical conditions. This paper is a report on the first year's results for the 1980/81 season.
EXPERIMENTAL METHODS

Trial Design
Most trials in eastern England comparing direct drilling, reduced cultivation and conventional ploughing for winter cereals have shown that yield does not vary with tillage method. For this study we selected six of these trials on soils considered difficult for direct drilling (Cannell, et al, 1978) and where yield reductions had occurred in one or more of the last three years. Half of each main plot was then loosened with the 'Paraplow' and the other half left with no additional treatment as a control.

Two additional trials were started in 1980. One at Knapwell on a clay soil under commercial direct drilling for three years but with extremely slow internal drainage; the second at Yeldham on a well structured clay that had been deep cultivated in previous years. At Yeldham our initial hypothesis was different, namely that on well structured soils there is no benefit from deep, or indeed, any cultivation.

All sites were loosened with the 'Paraplow' between September 20th and 30th. At two sites there were problems at the time of drilling as the farmers concerned had to contend with a wide range of soil conditions within such trials. Three sites were drilled late and outside the guideline time for successful drilling (ICI, 1976).

Soil and Crop Measurements
At all sites combine harvester yield of grain from 30m x 2m strips was recorded, as was plant population at full emergence and in early Spring. At four sites, we also measured dry matter accumulation and tiller number in May; white root counts in May at 10 cm depth intervals to 50 cm by the method of sectioning 10 cm diameter soil cores (Drew and Saker, 1980) with five cores per plot; saturated infiltration rates in March at two positions per plot using the double ring infiltrometer method (internal ring diameter 25 cm); and cone penetration resistance at ten positions per plot at 5 cm depth intervals to 50 cm using the Bush recording soil penetrometer (Anderson et al, 1980) in March when the soils were near field capacity.

RESULTS
Table 2 summarises the results for infiltration rate measurements. In this case only, statistical analysis was not undertaken because differences between treatment means were large and the data appeared unlikely to be normally distributed.
<table>
<thead>
<tr>
<th>Site</th>
<th>Wallasea</th>
<th>Beccles</th>
<th>Fincham</th>
<th>Wicken</th>
<th>Windsor</th>
<th>Agney</th>
<th>Tendring</th>
<th>Hanslope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil series</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A horizon texture</td>
<td>Silty clay</td>
<td>Sandy clay</td>
<td>Loamy sand</td>
<td>Clay loam</td>
<td>Clay loam</td>
<td>Silty clay</td>
<td>Sandy loam</td>
<td>Clay loam</td>
</tr>
<tr>
<td>% silt</td>
<td>42</td>
<td>20</td>
<td>22</td>
<td>31</td>
<td>20</td>
<td>20</td>
<td>31</td>
<td>32</td>
</tr>
<tr>
<td>% clay</td>
<td>41</td>
<td>29</td>
<td>4</td>
<td>38</td>
<td>33</td>
<td>32</td>
<td>13</td>
<td>32</td>
</tr>
<tr>
<td>% OM</td>
<td>7.0</td>
<td>3.0</td>
<td>1.6</td>
<td>2.7</td>
<td>3.8</td>
<td>2.4</td>
<td>1.7</td>
<td>3.0</td>
</tr>
<tr>
<td>B horizon texture</td>
<td>Silty clay</td>
<td>Sandy clay</td>
<td>Loamy sand</td>
<td>Clay</td>
<td>Clay</td>
<td>Silty clay</td>
<td>Sandy loam</td>
<td>Clay</td>
</tr>
<tr>
<td>Date of Drilling</td>
<td>28.10.80</td>
<td>4.11.80</td>
<td>11.10.80</td>
<td>6.10.80</td>
<td>24.11.80</td>
<td>3.10.80</td>
<td>28.3.81</td>
<td>5.10.80</td>
</tr>
<tr>
<td>No of Years</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DD yield depression</td>
<td>1 in 5</td>
<td>2 in 4</td>
<td>2 in 3</td>
<td>-</td>
<td>1 in 7</td>
<td>0 in 4</td>
<td>2 in 3</td>
<td>-</td>
</tr>
<tr>
<td>No of Years</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DD yield increase</td>
<td>3 in 5</td>
<td>0 in 4</td>
<td>0 in 3</td>
<td>-</td>
<td>4 in 7</td>
<td>0 in 4</td>
<td>0 in 3</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 2. Saturated infiltration rate, cm/hr, March 1981

<table>
<thead>
<tr>
<th>Site</th>
<th>Direct drilled</th>
<th>DD/Paraplow</th>
<th>Ploughed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>range</td>
<td>mean</td>
</tr>
<tr>
<td>Emneth</td>
<td>8.8</td>
<td>0.6-18</td>
<td>12.2</td>
</tr>
<tr>
<td>Hepmnall</td>
<td>6.1</td>
<td>0-17</td>
<td>77</td>
</tr>
<tr>
<td>Hindringham</td>
<td>0.3</td>
<td>0-0.9</td>
<td>21.6</td>
</tr>
<tr>
<td>Knapwell</td>
<td>0.2</td>
<td>0-0.4</td>
<td>41.4</td>
</tr>
</tbody>
</table>

Table 3 gives cone penetration resistance results for one site. Trends in treatment differences were similar at the other sites. In this short paper data are given for only 10 cm depth intervals. Treatment means with no letter in common are significantly different at the 5% probability level.

Table 3. Cone penetration resistance, kPa for the Hemmnall trial, March 1981.

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>Plough</th>
<th>Direct drilled</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control 'Paraplow'</td>
<td>Control 'Paraplow'</td>
</tr>
<tr>
<td>50</td>
<td>125 AB</td>
<td>185 A</td>
</tr>
<tr>
<td>150</td>
<td>412 C</td>
<td>950 A</td>
</tr>
<tr>
<td>250</td>
<td>669 B</td>
<td>1200 A</td>
</tr>
<tr>
<td>350</td>
<td>1254</td>
<td>1457</td>
</tr>
<tr>
<td>450</td>
<td>1391 AB</td>
<td>1719 A</td>
</tr>
</tbody>
</table>

Table 4 shows results from the investigation of root system development in late May when the crop was near anthesis and root system development might be expected to be near the maximum.

Table 4. Variation of white root count with tillage treatment and depth

<table>
<thead>
<tr>
<th>Site</th>
<th>White root count (no. intersecting 10cm diameter core)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10cm</td>
</tr>
<tr>
<td>Emneth</td>
<td>Direct drill</td>
</tr>
<tr>
<td></td>
<td>DD &amp; 'Paraplow'</td>
</tr>
<tr>
<td></td>
<td>Plough</td>
</tr>
<tr>
<td>Hepmnall</td>
<td>Direct drill</td>
</tr>
<tr>
<td></td>
<td>DD &amp; 'Paraplow'</td>
</tr>
<tr>
<td></td>
<td>Cultivator</td>
</tr>
<tr>
<td>Hindringham</td>
<td>Direct drill</td>
</tr>
<tr>
<td></td>
<td>DD &amp; 'Paraplow'</td>
</tr>
<tr>
<td></td>
<td>Plough</td>
</tr>
<tr>
<td>Knapwell</td>
<td>Direct drill</td>
</tr>
<tr>
<td></td>
<td>DD &amp; 'Paraplow'</td>
</tr>
</tbody>
</table>
Finally, Table 5 gives yield results for all eight sites.

**Table 5. Yield of grain t/ha at 85% dry matter.**

<table>
<thead>
<tr>
<th>Plough</th>
<th>Plough + P/plow</th>
<th>Shallow Cult</th>
<th>Shallow Cult + P/plow</th>
<th>Direct drill</th>
<th>Direct drill + P/plow</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emneth</td>
<td>7.0</td>
<td>7.4</td>
<td>6.6</td>
<td>7.2</td>
<td>6.4</td>
<td>7.0 ± 0.10</td>
</tr>
<tr>
<td>Hempnall</td>
<td>6.1</td>
<td>6.3</td>
<td>5.5</td>
<td>5.4</td>
<td>6.2</td>
<td>6.6 ± 0.16</td>
</tr>
<tr>
<td>Hindrington</td>
<td>5.2</td>
<td>5.1</td>
<td>5.3</td>
<td>5.4</td>
<td>5.1</td>
<td>5.2 ± 0.10</td>
</tr>
<tr>
<td>Knapwell</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5.2</td>
<td>5.5</td>
<td>5.5 ± 0.10</td>
</tr>
<tr>
<td>Rawreth</td>
<td>6.0</td>
<td>-</td>
<td>5.8</td>
<td>5.9</td>
<td>5.7</td>
<td>5.7 ± 0.34</td>
</tr>
<tr>
<td>Terrington</td>
<td>8.2</td>
<td>-</td>
<td>-</td>
<td>8.1</td>
<td>8.0</td>
<td>8.0 ± 0.13</td>
</tr>
<tr>
<td>Weeley</td>
<td>5.4</td>
<td>-</td>
<td>5.5</td>
<td>5.4</td>
<td>5.6</td>
<td>5.6 ± 0.18</td>
</tr>
<tr>
<td>Yeldham</td>
<td>8.4</td>
<td>-</td>
<td>8.3</td>
<td>-</td>
<td>8.3</td>
<td>8.2 ± 0.14</td>
</tr>
</tbody>
</table>

**DISCUSSION**

On these soil types, selected because of high risk of compaction problems under direct drilling, soil loosening by 'Paraplow' gave very large increases in saturated infiltration rates at all sites. In two cases the increases were much larger than those obtained with the ploughing treatment, in one case somewhat smaller but in this case lateral movement of water was very obvious for the ploughed treatment. Future work will further investigate the longevity of loosening effects.

The cone resistance results indicate that loosening by 'Paraplow' extended to 350mm depth. It is not invariably the case that loosening extends to the full depth of working (Spoor and Godwin, 1978). Cone resistance profiles following use of the 'Paraplow' were intermediate between those of continuous direct drilling and of ploughing. This result in conjunction with the infiltration results suggest better pore continuity probably associated with less vulnerability to subsequent compaction for the 'Paraplow' treatment compared to ploughing.

Total white root counts for the upper 500mm of the soil profile were significantly lower for the direct drilling compared to the plough treatment. This difference occurred mainly in the 0-200mm horizon, i.e. the plough layer.

The response to soil loosening by 'Paraplow' was to raise white root counts to the level of the plough treatment. There was no evidence that the greater soil disturbance of the plough compared to the 'Paraplow' was of any benefit in terms of greater root proliferation.

Only one site (Emneth) showed any significant crop yield loss comparing the direct drilled to the conventional plough treatment. This scarcity of yield
reductions with direct drilling on difficult soils may reflect the absence of large soil moisture deficits in this particular season, as we have demonstrated considerable differences between treatments in soil physical properties and root development.

Despite the yield results and weather pattern discussed above, small but significant yield increases for the 'Paraplow' compared to the best of the other treatments were recorded at 3 of the 8 sites (Emneth + 0.6 t/ha, Hempnall +0.4 t/ha and Knapwell 0.3 t/ha). The implication is that these may be due to improved soil water relations during the wet winter period. For example Cannell et al (1980) have shown that prolonged waterlogging of wheat in lysimeters can result in small to moderate yield depressions.

Compared with ploughing or deep cultivation, the 'Paraplow' leaves a much more level surface largely free of clods. There has been considerable discussion in the UK as to the amount of secondary cultivation then required. In these trials the 'Paraplow'/direct drill sub treatment received either no secondary cultivation or a single pass of a ringed roller. Very shallow cultivation before or after soil loosening may be required if a conventional drill is to be used.

REFERENCES


THE 9th CONFERENCE OF THE INTERNATIONAL SOIL TILLAGE RESEARCH ORGANIZATION
ISTRO, SOCIALISTIC FEDERAL REPUBLIC OF YUGOSLAVIA, OSIJEK 1982

THE ECCENTRIC DISC PITTER PLANTER - A PROVISIONAL ASSESSMENT

by John Dumelow

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and Veterinary Science, Morogoro, Tanzania

Abstract

Three tractor mechanized cultivation systems for maize were evaluated
during the 1981 growing season at the University Farm, Morogoro, Tanzania.
The three systems compared were:

1. Conventional tillage
2. Direct planting or no till planting
3. Eccentric disc pitter planting

Eccentric disc pitter planting resulted in much lower run-off and erosion
than occurred with conventional tillage. Direct planting however, was
only slightly better than conventional tillage. The costs of all three systems
were found to be almost exactly equal. However, the number of tractor
hours used in conventional tillage was much higher than for the other systems.

Tanzania has for many years been unable to grow sufficient maize to
satisfy its own human consumption and has therefore had to rely on supplementa-
tion of locally produced maize with donations from foreign aid. Such a state of
affairs is clearly undesirable and cannot be relied upon in the future. There is
therefore a need to increase Tanzania's production of maize drastically, this can
only be done on a large scale by implementation of large mechanized maize farms.

A severe limitation to maize production in many parts of Tanzania, in-
cluding Morogoro, is that the rainfall is marginal for a crop with such a long
growing cycle. Conservation of whatever moisture reaches the soil and control of runoff is therefore highly desirable. Although the annual rainfall in these areas is quite low the rainfall when it occurs can be very intense (e.g. a rainfall of 96 mm in a single day was recorded on the University Farm during 1981) and hence soil erosion is also a problem.

There is, therefore, a need to develop tillage systems and machines for dryland farming. These systems should have the following objectives:

1. Reasonable, reliable yields
2. Reasonable operating and capital expenditure
3. Effective soil and moisture conservation

The Eccentric disc pitter planter, hereafter referred to as the Edip Planter is a machine invented, designed, and constructed by the author. In the case of the prototype four rows are planted simultaneously. The machine is conventionally mounted to the three point linkage of a tractor (category 2). Fig. 1 shows a plan view of the main moving components. These are mounted on a frame made from rectangular hollow section mild steel. Eccentrically mounted disc harrow discs (eccentricity 120 mm) are fitted to two symmetrically opposite shafts interconnected by means of a connecting shaft and universal joints. In the prototype the eccentric disc shafts are mounted with their axes horizontal and at 60° to the direction of travel. As all three shafts are interconnected they all rotate in their bearings simultaneously. The eccentric disc are arranged so that they are all out of phase with each other so that when they engage in the ground the draught force remains approximately constant and continuous rotation of the shafts is assured. The connecting shaft drives the seed metering shaft through sprockets and a chain. Since the number of the teeth on the connecting shaft sprocket (12) is the same as the number of teeth on the seed metering drive shaft sprocket both shafts rotate at the same speed. The seed metering rotors mounted on their drive shaft are designed to meter seeds at the correct rate and spacing to disc type furrow openers (not shown, but situated below the rotors).

As the Edip planter is drawn over the land the eccentric discs rotate alternately digging pits in the soil. Figure 2 shows the arrangement of the pits in the ground. Figures 2 and 3 show typical dimensions of the pits. The spacing between the pits is constant for the design of the machine, but the size of the pits can be adjusted by altering the number of weights fitted to the planter and to some extent by adjusting the tractor hydraulic system controls. The
seed metering rotors are designed to drop two seeds through flexible tubes to the furrow openers at each of the positions shown in figure 2. This gives a plant population of 30,000/hectare which is quite low, but reasonable for dryland farming. Synchronization between the seed metering rotors and the discs is obtained by suitably adjusting the timing of the chain and sprockets.

Depth compensating springs automatically correct for the undulations in the soil created by the soil pits. A pivoting scraper which rests on the soil under its own weight covers the seed.

The Edip planter was constructed with a view to use in conjunction with herbicides so that no other cultivation processes would be required. The main advantages of this system over others should be:

1. The pits formed should retain rainfall thus preventing runoff and erosion and conserving moisture.

2. The seed are planted at a point where there is likely to be plenty of moisture but should not become water logged since they are planted into sides of the pits and not at the bottom.

3. The number of tractor hours should be much less than that for conventional tillage.

During 1981 growing season a field experiment was carried out to compare various tillage systems for maize at Morogoro University Farm. The following systems were compared using a plant population of 30,000/ha in every case:

a) Conventional tillage + machine planting + machine weeding

b) Direct planting + herbicide weeding

c) Edip planting + herbicide weeding
Each treatment was carried out in eight replicates.

The plots were all on a uniform slope of 3%. Equipment was constructed for collecting the runoff water from the plots.

Direct planting was carried out with a conventional tractor drawn planter with tines mounted ahead of the furrow openers. Herbicide weeding was carried out with a conventional boom sprayer. For treatments b) and c) an initial application of paraquat was made 10 days before planting and a mixture of atrazine and acetanilide was applied one month after planting. Triple super phosphate and sulphate of ammonia fertilizers were applied to all plots by hand.

Results of the field experiment were as follows:

a) Mean runoff in millimetres per growing season for each treatment:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean Runoff (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional tillage</td>
<td>2,1</td>
</tr>
<tr>
<td>Direct planting</td>
<td>1,8</td>
</tr>
<tr>
<td>Edip planting</td>
<td>0,9</td>
</tr>
</tbody>
</table>

LSD 0,05 = 0,8 mm  
0,1 = 0,6 mm

Edip planting gave a significantly lower runoff than the other treatments for the 1981 growing season. This is no doubt due to the retention of rainfall caused by the pits, and should be advantageous for soil and moisture conservation.

b) Mean soil loss in ton/hectare per growing season for each treatment:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Mean Soil Loss (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional tillage</td>
<td>2,3</td>
</tr>
<tr>
<td>Direct planting</td>
<td>1,5</td>
</tr>
<tr>
<td>Edip planting</td>
<td>0,6</td>
</tr>
</tbody>
</table>

LSD 0,05 = 1,3 t/ha  
0,1 = 1,1 t/ha

Again Edip planting gives the best result since least erosion occurs. However, the results are less significant due to the large variation in the results from different replicates.
c) Cost comparison of the different treatments:

Table I gives a cost comparison of the different systems. The cost per hectare in all three cases is almost exactly equal. However, there is a considerable saving in the number of tractor hours used with direct planting or Edip planting.

In conclusion, the results indicate that Edip planting is a promising new technique, but experiments will have to be carried out over a number of years before recommending the system to farmers.

Table 1. Comparison per hectare of different tillage systems

<table>
<thead>
<tr>
<th></th>
<th>Cost per hour (t.shs)</th>
<th>Hours/ hectare</th>
<th>Conventional planting</th>
<th>Direct planting</th>
<th>Edip planting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tractor hours</td>
<td>Cost (T. shs)</td>
<td>Tractor hours</td>
</tr>
<tr>
<td>Ploughing</td>
<td>240</td>
<td>2.0</td>
<td>2</td>
<td>480</td>
<td>-</td>
</tr>
<tr>
<td>Harrowing</td>
<td>250</td>
<td>0.5x2</td>
<td>1</td>
<td>250</td>
<td>-</td>
</tr>
<tr>
<td>Spraying</td>
<td>270</td>
<td>0.2x2</td>
<td>-</td>
<td>-</td>
<td>0.4</td>
</tr>
<tr>
<td>Conventional planting</td>
<td>260</td>
<td>0.5</td>
<td>0.5</td>
<td>130</td>
<td>-</td>
</tr>
<tr>
<td>Direct planting</td>
<td>260</td>
<td>0.5</td>
<td>-</td>
<td>-</td>
<td>0.5</td>
</tr>
<tr>
<td>Edip planting</td>
<td>260</td>
<td>0.5</td>
<td>-</td>
<td>-</td>
<td>0.5</td>
</tr>
<tr>
<td>Machine weeding</td>
<td>250</td>
<td>1.0</td>
<td>1</td>
<td>250</td>
<td>-</td>
</tr>
<tr>
<td>Herbicide</td>
<td>5 litres/hectare x 2 applications x 89/- per litre</td>
<td>-</td>
<td>-</td>
<td>890</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>4.5</td>
<td>1110</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Notes: a) These figures do not include costs common to all three systems (e.g. cost of fertilizer)

b) The use figures were calculated from the following:


Fig. 1 - PLAN VIEW OF GENERAL LAYOUT OF MAIN MOVING COMPONENTS OF EDIP PLANTER

- Eccentric disc
- Shaft
- Seed metering drive shaft
- Seed metering rotors
- Connecting shaft
- Chain
- Univerzal joints
- Bearings

Direction of travel

Fig. 2 - PLAN VIEW OF SOIL PITS DUG BY EDIP PLANTER

Fig. 3 - TYPICAL CROSS SECTION OF SOIL PITS DUG BY EDIP PLANTER
TITLE: A Slit-Plant System for Plow Pan Soils

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\textsuperscript{2}Agricultural Engineer, USDA, ARS, NTML, and Adjunct Associate Professor, Auburn University, Alabama 36849 U.S.A.

Abstract:

A slit-plant tillage system has proved to be effective in producing deep roots in soils with a plow pan. A narrow, vertical slit, cut through compacted soil layers, appears to remove low soil oxygen and high soil strength as limiting factors to depth of root growth. Pulling a knife-like blade through soil requires less energy than pulling chisel-like plows. The slit-plant concept shows promise for development for practical farm use.
Restriction of plant roots by compacted soil reduces crop yields on large areas of agricultural lands throughout the world (1,2,4). The most commonly recognized soil compaction problem is the development of a compacted layer in the soil profile immediately below the tilled surface soil. Formation and severity of this compacted layer, often referred to as a plow pan, plowsole, tillage pan, or traffic pan, are greater problems on coarse-textured soils containing nonexpanding clays. The problems increase in warm climates where soils do not freeze and where organic matter is low.

When a soil is compacted, total porosity and size of pores are reduced. Eavis and Payne (1968) studied pea (Pisum sativum var. Onward) seedling root growth in a soil at three bulk densities over a range of soil water tensions. They showed that as bulk density increased, soil strength increased while root growth decreased. However, at a particular bulk density, soil strength decreased and root growth increased as soil water content increased to a critical value. Beyond this critical value soil strength continued to decrease with increasing water content, but root growth decreased. The decrease in root growth was shown to be caused by reduced soil oxygen.

Taylor and Gardner (1963) obtained a negative correlation between soil strength and growth of cotton (Gossypium hirsutum L.) seedling taproots. Huck (1970) showed that elongation of cotton and soybean (Glycine max L.) taproots ceased when soil oxygen was depleted, and that root tips died when deprived of oxygen for 3 to 5 hours. Oxygen diffusion rates in water-free soil macropores or channels are ample to meet oxygen requirements for maximum root growth (6).

Subsoiling or other types of deep tillage are popular methods for alleviating the adverse effects of soil compaction on root growth by crop plants. Deep tillage requires large tractors, slows land preparation, and uses large amounts of energy. The objective of this research was to develop a tillage method with reduced power requirements that would alleviate the adverse effects of soil compaction on deep root penetration.

We hypothesize that whereas soil strength and deficient soil oxygen are the primary factors preventing root growth in compact soils, a 1- to 3-mm wide vertical slit cut through a layer of compact soil should eliminate both soil strength and deficient soil oxygen as deterrents to downward root growth.
Experimental Procedure

An experiment was conducted on a Harvyn sandy loam soil (Typic Hapludult, fine-loamy siliceous, thermic) with a 10- to 15-cm thick compacted layer of bulk density 1.7 g cm\(^{-3}\) beginning at a depth of 20 cm.

Soybeans (var. 'Hutton') were planted on July 16, 1979 in 2-m long single row plots, using three simulated tillage treatments. Short single-row plots were used because the 38-cm deep slits were cut by hand with a long-bladed spade. The test was replicated five times in a completely randomized block design. The three tillage treatments were (1) Conventional tillage: AP soil horizon was hand-spaded to represent conventional plowing and seed were planted 4- to 5-cm deep in rows; (2) No-till: seed were planted in narrow slits 4-to 5-cm deep; and (3) Slit-plant: seed were planted 4-to 5-cm deep over a narrow 38-cm deep slit. Weeds were controlled by contact herbicides broadcast-spray before planting and directed spray during soybean plant growth.

In other experiments, two commercially-available cable-laying vibratory plows were equipped with steel blades to mechanize the slit cutting. These plows were used to make slit-plantings for observing root response of several other plant species to the slit, and to compare slit-plant to other tillage-planting systems.

A three-row subsoiler planter was modified in 1981 to develop a practical slit-till implement. The subsoiler planter was equipped with shortened subsoil shanks with a 15-cm bladelike appendage beneath each shank (Figure 1). The implement was tested on sandy loam and loamy sand soils with dense layers beginning at the bottom of the AP horizon.

RESULTS

Slit-plant soybeans produced 1950 kg/ha of beans compared to 1680 and 1210 kg/ha for conventionally-tilled beans and no-till beans, respectively. Treatment effect was significant at the 95% probability level by F-test (7). Throughout the growth period plants on the slit-plant treatment were larger and had less visible signs of water stress than plants on conventional and no-till treatments. Excavation revealed that roots on slit-plant treatments grew rapidly down the 38-cm deep slit and proliferated in the subsoil to more than 1 m deep and more than 0.5 m to each side of the row. Roots on conventional and no-till treatments did not penetrate the plow pan and, thus, were restricted to about 20 cm in depth. Root proliferation in the AP horizon of conventionally-tilled plots was superior to...
that on slit-plant and no-till plots.

Field plot plantings for observation of root response of sunflower (Helianthus annuus), soybean, sorghum (Sorghum bicolor L. Moench), peanuts (Arachis hypogaea L.), okra (Hibiscus esculentus L.), and corn (Zea mays L.) to slit-plant were made with vibratory plows in 1980 and 1981. Roots of all species grew to the bottom of the 38-cm deep slit in about 7 days after plant emergence, and good subsoil root proliferation was observed on slit-plant treatments for all species. On no-till (without slit) roots were generally restricted to the AP horizon except for some subsoil root development by peanuts. All species had larger plants and showed less visible water stress when grown slit-plant than when grown no-till. Differences were less pronounced on peanuts than on other species. The one-row vibratory plows traffic interrow space twice, causing considerable topsoil compaction.

The modified subsoiler-planter tilled a V-shaped zone about 20-cm wide and 25-cm deep in the AP horizon, and cut a 12-cm deep slit through a dense layer of soil beneath the AP horizon. Soybeans germinated, emerged, and grew vigorously when planted with this implement. Good root growth occurred in the slit and downward into the subsoil (Figure 2).

DISCUSSION

Improved performance of soybeans grown using slit-plant compared to no-till treatment indicates that a narrow vertical slit promotes root growth through compacted soil layers. The effect of the slit on soil oxygen and soil strength was not measured; however, we can infer that the slit essentially eliminates low soil oxygen and soil strength as restrictors of root growth in compact soil because (a) oxygen diffusion in a void such as the slit is more than adequate to meet plant root needs (6); (b) slitting the soil will reduce soil strength where the incision is made; and (c) root growth rates of 4 to 5 cm per day (maximum reported in the literature) have been observed in slits.

The vibratory plows were satisfactory for cutting slits, but were unsatisfactory for yield trials comparing slit-plant to other tillage methods because their one-row design caused root restricting compaction between all rows. The modified subsoiler-planter provided good tilth in surface soil, and promoted good root growth through a dense soil layer into underlying subsoil. A shortcoming of this implement was rapid wear of the thin blade. Use of other materials and designs are being considered to
overcome the wear problem.

Superior root performance by several species grown using slit-plant, and the certitude of a lower energy requirement for pulling a knife-like blade through soil compared to chisel-like deep tillage implements, indicate that a practical farm implement should be developed for further testing of the slit-plant tillage concept.

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Figure 1. A modified subsoiler shank for slitting compacted soil layers (not to scale).

Figure 2. Response of soybean root system to slit cut through compacted soil layer.
WORKING EFFECT OF SOIL PREPARING EQUIPMENT WITH PTO-DRIVEN TOOLS AND ITS INFLUENCE ON PLANT EMERGENCE

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At nearly all crops there is a essential difference between genetic potential and really, under field conditions attainable yield. The reason for it is, that often the optimal number of plants per hectare, which is necessary for getting a high and safe yield cannot be guaranteed.

Besides other factors especially tillage conditions of soil and seedtechnics have a directly influence on emergence and basic number of plants. In this research program should be found out the working effect of different tilling tools and the relationship between tilling, seed technics and emergence at grain crops. For experimental work were only used pto-driven tilling machines with variable und movable speed of tools and for this with various working effects.

The working effect of pto-driven tools can be changed by
- forwardspeed of tractor
- circuit speed of tools
- number of tools
- length of "bit"
- Quotient of forward speed (V) and circuit speed (U) = \( \frac{U}{V} \)

For valuation of working effect at tilling implements two essential measurements are used: the wheigted approximately diameter of soil aggregates (mm) (in german called "Gewogener Mittlerer Durchmesser" = GMD) and the crumbling effect (opposite number of GMD, in german called "Zerkleinerungsgrad"= ZG).

Nr. 1: Terms for tilling effect of soil preparing equipment

<table>
<thead>
<tr>
<th>GMD</th>
<th>ZG</th>
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</thead>
<tbody>
<tr>
<td>Gewogener Mittlerer Durchmesser</td>
<td>Zerkleinerungs- Grad</td>
</tr>
<tr>
<td>= wheigted approximately diameter of soil aggregates</td>
<td>= crumbling effect</td>
</tr>
<tr>
<td>( \frac{\sum (n_i d_i)}{\sum n_i} ) [mm]</td>
<td>= ( \frac{100}{\text{GMD}} ) ( \text{[} \frac{\text{mm}}{\text{mm}} \text{]} )</td>
</tr>
<tr>
<td>( n_i ) = wheig of aggregate size class „i“</td>
<td>( d_i ) = class centre of aggregate size class „i“</td>
</tr>
</tbody>
</table>

GMD = \( \frac{\sum (n_i d_i)}{\sum n_i} \) [mm]
ZG = \( \frac{100}{\text{GMD}} \) \( \text{[} \frac{\text{mm}}{\text{mm}} \text{]} \)
At all pto-driven tools there is a strictly relationship between moving of tools in the soil and its working effect. Vertical and horizontal rotating tools show typical faces of moving. At rotary harrow and reciprocating harrow all tines are permanent in contact with the soil, knifes of rotavator only at 20 - 25% of circuit length.

Nr. 2: Typical faces of moving tools at 3 soil tilling equipments

At soil preparing equipment with horizontal and vertical rotating tools the distance between 2 faces of moving is called "length of bit". It depends on forward speed, circuit speed of tools and number of tools per holder.

It could be found out, that effect of reduction bit-length at constant circuit speed of tools means lower GMD. Besides that a higher circuit speed causes a better crumbling effect of soil aggregates. So the higher circuit speed of tools and its speed of bounce against soil aggregates has an essential importance on crumbling effect.
Nr. 3: Influence of bit-length on diameter of soil aggregates (GMD) at constant circuit speed of tools on rotary harrow and reciprocating harrow.

For getting a regular preparing of soil it is necessary, to have an optimal relation between forward speed and circuit speed. Effect of this relationship is shown at picture Nr. 4 for rotavator and rotary harrow with different circuit speeds for tools. The crumbling effect is increasing up to maximum range.

Nr. 4: Influence of relationship $\frac{u}{V}$ on crumbling effect ($ZG$)
Date for tilling

Results of research work with different rotary tillage machines on loamy soil show, that in average of 5 years the difference between different years is higher than between used machines.

<table>
<thead>
<tr>
<th>Crumbling effect of some machines</th>
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<tr>
<td>15 years, 3 cereal crops, soil LL, Dürrast</td>
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</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Winter-wheat</th>
<th>Summer-bole</th>
<th>Maize</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RH</td>
<td>RoH</td>
<td>R</td>
</tr>
<tr>
<td>G M D (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1973/74</td>
<td>14,9</td>
<td>23,2</td>
<td>25,7</td>
</tr>
<tr>
<td>1974/75</td>
<td>31,3</td>
<td>28,5</td>
<td>30,7</td>
</tr>
<tr>
<td>1975/76</td>
<td>38,1</td>
<td>32,7</td>
<td>32,7</td>
</tr>
<tr>
<td>1976/77</td>
<td>165</td>
<td>21,5</td>
<td>19,7</td>
</tr>
<tr>
<td>1977/78</td>
<td>259</td>
<td>24,8</td>
<td>27,5</td>
</tr>
<tr>
<td>Average</td>
<td>25,3</td>
<td>26,1</td>
<td>27,3</td>
</tr>
</tbody>
</table>

ReH=reciprocating harrow, RoH=rotary harrow, R=rotavator

Nr. 5: Influence of tilling date on working effect of tillage equipment

Besides that at seedbed preparing for winter cereals all machines cause more rough aggregates than in working at spring time. One of the main reasons for it can be found in different moisture content of soil in autumn an spring time.

Nr. 6: Influence of soil moisture content on crumbling effect (ZG)
In average best results of soil preparing can be found at 17 - 21 % moisture content.

**Seed and plant emergence**

Seedbed preparing may guarantee for all crops best content and distribution of pores filled with air and water. So an optimal seedbed preparing in relationship to requirements of different crops, soil and climate conditions is one of the most important suppositions for getting a high field emergence. At first uniform mixture of fine crumbled aggregates in soil causes an equal seed depth. In case of rough seedbed preparing seed depth becomes more flat and standard deviation is increasing.

![Diagram](image)

Nr. 7: Influence of aggregate diameter on seed depth

Besides that, field emergence becomes of less uniform, delayed and not satisfying. This is shown at picture Nr. 8, where different aggregates were prepared by rotavator and rotary harrow. In case of fine prepared seedbed field emergence is much higher. The difference of sprouting speed to a rough prepared seedbed is nearly 4 days. So it will be necessary to prepare a fine crumbled seedbed for getting a high and safe und fast emergence. But in practice must be made a compromise, for too fine preparing of seedbed raises dangerous problems, that soil becomes muddy and surface is crusting.
Nr. 8: Influence of seedbed preparing on sprouting speed and emergence

Summary

Besides some other factors, diameter of soil aggregates has an important influence on seed depth, speed of sprouting, emergence and safety in getting the desired number of plants per hectare. One of the main demands at soil preparing for seed is, to get a regular crumbled seedbed in relationship to planted crops and soil conditions. Results of this research work show, that is possible to gain this aim at using pto-driven tilling equipments.
MULTITILLER - SOIL TILLAGE MACHINE

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Summary
Soil preparation with conventional machines like plough and disc harrow in dry soils with high contents of clay has been a problem. An new tillage system, which can be used after ploughing and directly in the hard soil for combined tillage, is presented in this paper. This system called "Multitiller" can prepare a seedbed in one or few passes, even under extremly hard conditions. Equipped with a chisel plough, it can economize time and fuel consumption by more than 50%, and the quality of the seedbed is mostly good after the first pass. Its application is restricted by high requirements of tractor power (approx. 35 KW DIN/m), and soil moisture i.e., soils heavily moistured cannot be worked. Minimum sizes of the fields and a minimum area tilled per season are the determining factors for an economical application of the equipment.

Problems of soil preparation
Thinking of soil preparation, the aim has always been to grow plants in the best way i.e. to give them the natural conditions, they need. However until now, it is not exactly known, which conditions are required by the different plants (1). It depends on so many different factors as climate, soil type, manner of irrigation, crop, that no general statements can be made. However, there are some basic facts: Pans in the subsoil or soil avoid the roots penetrating - soils with too big clods with few fine particles are not considered as an optimum seedbed.
There are soils in Europe, on which the correct tillage methods are well proved - and on which the proper machines are used. It is a fact: The more clay is contained in the soil, the more engine power is necessary and the less effective is the operation, if the soil is dry.

In many regions people plough the land at a depth of 40-50 cm - and then have to do a lot of passes with disc harrows, rollers and other more or less effective machines. Often, the clods are so hard, that they cannot be cut by the disc harrow to a diameter smaller than 8 cm. So, the best effect is produced by the tracks of the caterpillar.

An alternative can be p.t.o. - driven implements like rotary harrows or rotary cultivators. Their tools run at high speed (up to 30 km/h) in the soil, so in the humid Central European conditions they can cut the soil to a rather fine size of the particles. The problems of those machines are the handling by the driver and the wear and tear of the tools. The soil is not good enough settled after tillage.

**Design of the Multitiller**

The task was to design an implement, not driven by p.t.o., but having about the same or even a better effect under hard conditions. Tines can enter into the soil, their effect is depending on their shape, distance between the tines and the forward speed. They can work at optimum in compacted soils with regard to loosening and breaking - if the soil is already broken, the effect is rather low.

For cutting clods, discs are required. But the discs of the disc harrow leave the soil too rough. So a company started in 1974 to design a new sort of discs, constructed in a chassis. Those discs have a diameter of 600 mm in the first row, 500 mm in the second row. Firstly the company tried tri-sets of discs. Tests have proved two double-sets achieving better results.

The shafts of the double-sets work one into the other, the smaller discs are provided with angled spikes. So the clearance between the discs is always less than 85 mm.
Every chassis has two double-sets of those "Rotostars", as the company calls those special-shaped discs. The "Rotostars" are combined with a leveller in front and a tine set between the "Rotostar"-sets for work in ploughed or chiseled land, see fig. 1.

![Diagram of Multitiller configuration I](image)

**Fig. 1** Multitiller, configuration I for seedbed preparation after ploughing or chiseling.

Forward speed, weight of the machine and spikes are the main supporting units for the performance of the "Rotostars". The weight is approx. 1.4 tons per meter of working width. The power requirement is rather high. To get the speed of 5 km/h as minimum, better are 7 km/h, approx. 35 KW/m of working width are required.

It is recognized, that especially on ploughed land the adhesion of the tractor wheels is rather small. Further more, on chiseled land the Multitiller I requires nearly 40% less draft power, see fig. 2, thus providing the opportunity of chiseled land to be worked at a speed of 2 km/h exceeding that obtainable for doing the job on ploughed land.

Whenever an implement has to work on ploughed or chiseled land, the tractor has a drawback of running on loosened soil, so draft power is limited. Therefore, the next step was the combination of the "Rotostars" with a chisel plough in front, see fig. 3.

With this combination, primary and secondary soil preparation in a depth of 10 cm up to 30 cm is possible. In the tests with different points at the chisel plough, we realized, that a good seedbed can be prepared in a single pass even under very hard conditions.
Fig. 2 Power requirement of Multitiller I (3m) on ploughed and chiseled land.

Fig. 3 Multitiller, configuration III for combined primary and secondary soil preparation.
Power requirement, fuel consumption and performance depend considerably on the working depth of the chisel tines. The following question has to be answered: Making a seedbed in a single pass - which working depth is really necessary for the different crops?

Tests with the Multitiller

The Multitiller was tested with configuration I after ploughing and chiseling (2,3,4,5,6,7). If it is compared with the rotary harrow (345 rpm) in a loamy soil of high moisture contents (25-28%), the Multitiller requires more energy and achieves about the same effect (7).

Tests in CSSR, Yugoslavia and Hungary (2,3,4,5) showed, that the number of passes with the Multitiller compared with traditional methods (disc harrow and roller) is 1:3. Fuel consumption is reduced by 50%. Total costs with Multitiller are about 60%, compared with the traditional systems (5). Yields of wheat on the Multitiller-plot increased 1,5 - 2,0 dt/ha (6).

The Multitiller with chisel plough prepares the seedbed with less than half of the time and fuel consumption. The chisel plough produces smaller clods, which are crashed immediately, having still an acceptable moisture content. So the relation between energy input and effect is better than with traditional systems (5,7).

The trend, which is shown in fig. 4, has also been confirmed by other tests (5).

On light soils, traditional implements can achieve a good seedbed, so that the use of Multitiller and other special tillage systems is not justified, because of their high investment. In extremely humid conditions, tractor slippage inhibits work with the Multitiller, and the "Rotostars" stick up with soil. On the other hand, work in those conditions is limited to few implements like plough and p.t.o. - driven tillers.

To be justifiable on economic grounds the Multitiller needs a minimum size of the plots and a minimum area, worked per season, depending on soil conditions and crop requirements.

Considering the different systems for one-pass combined soil preparation implements, the Multitiller proves its advantages especially on hard, dry soil and large scale farming operation.
Fig. 4  Energy input and weighted average diameter (WAD) of different soil tillage systems: Multitiller III (MT III); plough and Multitiller I; plough and rotary harrow (345 rpm); plough and 2 x disc harrow. Soil: clayey loam 25 - 28 % moisture content.

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MULTITILLER - A SOIL TILLAGE SYSTEM APPROPRIATE TO TROPICAL CONDITIONS?

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Summary
Under tropical conditions, soil tillage problems are different to those in moderate climate. Solutions with a new system called "Multitiller" are being tested in laterite soils of Western Africa and in clayey loam soils of Portugal and Turkey.
The Multitiller has high power requirement and needs large plots for economical work. In most tropical countries those requirements can be fulfilled only by cooperative work.
This paper is particularly taking care of technical and plant cultivation questions.
In the laterite areas, problems of timeliness of seeding, fuel consumption and weed control can be solved. On dry loam and clay soils, ploughing can be avoided and a seedbed can be made in a single pass, soil layers are not turned.

Introduction
First results of a current study about the use of the Multitiller (MT) in tropical and subtropical countries are being shown in this paper. This study is aiming to gain practical experience and the input - output - relation of the MT in comparison to traditional tillage systems.
This study is promoted by the German Agency for Technical Cooperation (GTZ).
The locations, where the MT are being tested, are shown in fig. 1.

Fig. 1
Multitiller on location x in test
- tested by national authorities

Three of the machines are stationed in the laterite areas of Western Africa, the other two machines work in clayey loam soils of the Menderes river valley in Turkey and Mondego river valley in Portugal. Another one is in test by the University of Evora in Allentejo/Portugal, which has dry conditions with clay soils. In the Medjerda valley of Tunesia Dr. Kopp tested a Multitiller prototype in 1977/1978.

Methods of the test
For the time of myself being a member of the project-team, the MT is compared with different conventional implements. Performance, slippage of the tractor and fuel consumption are measured. The soil resistance should be measured before tilling. This can be done by a penetrometer, but I think, that a shear vane can give the more comparable data.
The effect of tillage is measured by particle size analysis with three sieves with round holes of 80 - 40 - 20 mm of diameter. In light soils with high contents of roots, a big part of the soil is stuck to the roots. Those parts affecting the weed growth have been weighted - see fig. 2.

For normal work during the year, I get the data of performance, fuel consumption and effect. Germination and shooting of the plants is observed then, germination and shooting of the weeds, too. At the locations, where it is possible, yields of the MT-plots and conventional tilled plots are measured. Knowing, that this is a very rough scaled method to observe the effect of a machine, I hope to get a number of data very shortly by this method.

Experiences in the laterite soils of Western Africa

In Ferkessedougou, Northern Ivory Coast, the task is to prepare a seedbed for grassland (Brachiaria ruciciensis, panicum maximum and stylosanthes) for fattening cattle. At 170 ha every year grassland was ploughed by disc plough and then tilled by disc harrow. In the future, approx. 250 ha of corn will be planted, too. The problem was, that "Kenaf", a fibre plant, was planted there 10 years ago and now is multiplied by discing, as well as imperata cylindrica, a weed grass. The soil, loamy sand, is in good conditions with about 25 cm deep Ah - horizon (1,5% humus). It can easily be tilled by the disc plough if it is not too dry, but the roots of weeds and grass hold the soil. During rainy weather the plants go on growing. Further more, use up of the discs is extremely high.

The aim of tillage is:
1. Cutting weeds and grass.
2. Incorporation of weeds and grass in the top soil.
3. Preparing a seedbed for fine seeds.

The Multitiller with built - in chisel plough (MT III) is able to meet these requirements, but the requirement of tractor performance is very high. The smallest MT III (2,5 m working width) needs a tractor of 81 KW (110 hp DIN), while the 3-furrow disc plough works with a tractor of 52 KW (71 hp DIN). Fig. 2 shows the difference of input and output, affected by the two machines.
The difference of the particle size (wad) is obvious: 34 mm with the disc plough, 17 mm with the MT III. Even more important under those conditions is the percentage of rootballs in the samples. It shows, that the roots hold 60% less soil after tillage with the MT III. So the weeds and grass are not easily able to grow again, but are loosened in the soil and die. If seeding has to be made very late in rainy season (Panicum maximum in July) two passes of MT can be necessary for weed control.

Fig. 2
Comparison of performance, fuel consumption, particle size (wad) and rootballs (rs), affected by disc plough (71 hp-tractor) and MT III (110 hp-tractor).

At the first view, the soil seems to be prepared for direct seeding after tillage with the MT. But the last records showed, that seeding one week later results in better shooting.
In Central Togo, a seed producing farm of 240 ha has been working with the MT since 1979. The first tests were made by MIDOHOE (1). A test, which has to run 5 - 10 years, started in May 1981 on new cultivated land.

The comparison will be:
1. Multitiller-chisel plough with one Rotostar-set
2. Disc plough and disc harrow
3. Heavy disc harrow
4. Mouldboard plough
5. Animal pulled implements

Especially in the light laterite soils the question of the required working depth and working quality is very important. At a depth up to 10 cm the heavy disc harrow can do a good job with high performance and few fuel consumption. For deeper work, a chisel plough combined with leveller and crumbler, as it is used in Central Europe for stubble-breaking, could prepare a rougher seedbed than MT in a single pass, too, if the soil is not too dry - and the investment costs for this implement would be approx. a quarter of the costs of the MT.

It has been true for laterite soils, that the Multitiller with chisel plough prepares a seedbed in a single pass. A problem is, that long rests of plants block the tines of the chisel plough. Therefore the company is designing cutting tools in front of the chisel plough.

Experiences in clayey soils

In clayey loams, as they are in Söke/Turkey or Quinta do Canal/Portugal and in dry conditions tillage with plough and disc harrow is a problem. The plough produces big clods, which can only be cut in numerous passes by disc harrow and roller - so the lower layers of the soil are repressed as well, and the seedbed quality is poor. After harvesting the first crop during early summertime a second crop can be seeded provided the soil is tilled very quickly. So high performance and water-saving tillage is required. In Söke we stated, that the MT III leaves the humid layer below and does not turn the soil, wad was 21 mm. So moisture can be saved for the plants.
After ploughing, wad was 41 mm; even two passes of the seedbed combination could affect not less than 34 mm.

In Quinta do Canal first results are encouraging with the MT. In 1980 Dr. Kopp made intensive measures of performance, fuel consumption and effect (wad) (2). In 1981, Dr. Speetzen continued the studies (3). Three systems are compared: No. 1 Multitiller with 2-bar-chisel plough; No. 2 2-bar-chisel plough with rotary cultivator; No. 3 plough and disc harrow.

The energy input of No. 1 and No. 2 seems to be approximately the same, the plough needed 50% more. The yields of millet showed a significant difference only between No. 1 and No. 3 (lower).

With regard to the use of the Multitiller under tropical conditions, still many questions are open. It is not only an new tillage machine, but also a member of a new tillage system which has to be applied. Technically, the Multitiller especially in configuration III (chisel plough built-in) seems to be appropriate to the difficult soil conditions, we find in tropical zones. The question is, whether it is appropriate as well according to the social conditions in those countries, where the average farm size is often less than 3 ha. So I hope, that it can promote the cooperation between the farms.

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FORCE MEASUREMENT ON TILLAGE IMPLEMENTS

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Abstract

Design considerations and solutions for systems to measure the forces acting upon tillage implements and their component parts, are discussed for both two and three dimensional force situations.

Introduction

In addition to the measurement of the total force system acting upon a tillage implement it may be necessary to simultaneously measure the forces acting upon particular components of the implement such that future design may be concentrated upon the most critical components.

This paper aims to give detailed information regarding the selection and use of strain gauge techniques for the measurement of total and component forces and moments acting on tillage implements in one or more of the principal planes shown in Fig 1.

Force and Moment Requirement

Transducers for the measurement of the forces are remote from the point of force application, the exact position of which is often unknown. The transducers, therefore, need to be capable of accurately monitoring the forces independent of force position and also of supporting and if necessary measuring the resulting moment, such that the point of application of the resultant force can be determined.

Where force components in more than one principal direction act upon an implement it is critical to ensure that the application of a load in one direction does not cause a significant output from transducers measuring loads in the directions.

Types of System

The above measurement requirements can be met with either of the following strain gauge techniques:

i. dynamometer suspension system, Rogers and Tanner (1955) Fig 1

ii. cantilever beam, Rogers and Tanner (1955) Fig 2a

iii. extended octagonal ring transducer, Godwin (1975) Fig 2b
The dynamometer suspension system can be used to measure the forces in either one, two or three principal planes. Construction of the system is relatively easy and data recording and analysis simplified by the use of commercially available tension/compression dynamometers each with identical calibration characteristics. Providing the ball end bearings of each dynamometer are free to move in all planes, cross sensitivity errors are acceptable, see Table 1 (A). The summed outputs of each force are independent of the position of the applied force, Seig (1982). The major limitations are the space requirements for construction of the main and subframes and the errors involved should one of the ball end joints of a dynamometer become constrained, see Table 1 (B).

Problems of friction in ball end joints do not occur with the cantilever beam and the extended octagonal ring transducer. Both of these devices offer a big advantage in that they can be made sufficiently compact for use when not wishing to significantly change the implement and its attachment system.

The strain gauge positions and bridge circuits for measuring the forces and moments acting upon these transducers are shown in Fig 2. The cantilever beam is generally used for the measurement of a force and a moment in one dimension, although, Rogers and Tanner (1968) describe a two dimensional application. Calibration with static loads shows that cross sensitivity and position sensitivity errors over the designed working range are less than 2% and 3% respectively.

The extended octagonal ring transducer was initially designed for the measurement of forces $H$ and $V$ and their resulting moment, $MHV$, with both cross sensitivity and position sensitivity errors less than 2%.

Additional gauges 13, 14, 15 and 16 positioned according to Friend (1980) enable $MH$ to be measured independently from the effects of $MHV$ with less than 2% cross sensitivity, between the two channels.

Construction Details

In cases where cantilevers and extended octagonal rings are used to measure the forces on component parts, they can be conveniently machined directly into the material from which the implement is constructed, see Fig 3 a and b, which overcomes the problems of attachment when resisting the applied loads.

Non-integral force measuring transducers may be constructed from a choice of materials the two most common being the high strength alloys of steel and aluminium. Steel is used where compactness together with high strengths are required i.e. yield strength of EN24 steel alloy is of the
order of 650 MN/m² in comparison with 83% of the 0.1% proof stress of 200 MN/m² for HE15 aluminium alloy. Where lightness is required, however, large capacity transducers are better constructed from aluminium as the density is one third of that of steel. A second advantage of aluminium is the smaller elastic modulus which, therefore, produces a more sensitive transducer. To ensure that problems of non-linearity due to mechanical overloads do not occur. Factors of safety of no-less than 2 should be used for design purposes. It is worthwhile noting that the moments acting upon an implement may be greater as it is lifted from the soil than under normal conditions and the instrumentation should be designed accordingly.

The strain gauges and the associated circuit connections must have the highest level of moisture protection to combat both rainfall and soil moisture. Mechanical protection is also critical to protect gauges from soil damage and also human errors when handling the equipment. Where transducers are machined into the implement the dimensions of the implement is restored by the use of steel plates with the joints filled with a flexible compound to prevent soil from entering the cavities.

Selection of Force Measuring Systems for Particular Applications

1. Draught and vertical forces and the resulting moment acting upon implements causing symmetrical soil failure such as subsoilers, mole ploughs and chisel tines.

i. Overall forces. Techniques (i) and (iii) would both be acceptable, the choice being dependent upon space constraints in which case a 28 kNm capacity extended octagonal ring transducer constructed from aluminium alloy is sufficiently light for manual attachment in the field, yet sufficiently compact to mount onto existing tool bars, Fig 3a.

ii. Foot forces. Simultaneous measurement of the forces acting upon the foot of the implements can be obtained by a second extended

<table>
<thead>
<tr>
<th>Applied Load</th>
<th>$V_1 + V_2$</th>
<th>$V_3 + V_4 + V_5$</th>
<th>$S$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1850N</td>
<td>444N</td>
<td>445N</td>
<td></td>
</tr>
<tr>
<td>1800N (-1.3%)</td>
<td>472N (+6.0%)</td>
<td>484N (+3.0%)</td>
<td></td>
</tr>
<tr>
<td>1810N (-2.2%)</td>
<td>489N (+10.5%)</td>
<td>506N (+18.7%)</td>
<td></td>
</tr>
</tbody>
</table>

Figures in brackets are ± error
Fig 2

$H_T$ = total horizontal force
$V_T$ = total vertical force
$M_T$ = moment due to $H_T$ & $V_T$

$H_Y$ = foot horizontal force
$V_Y$ = foot vertical force
$M_Y$ = moment due to $H_Y$ & $V_Y$

Fig 3

Fig 4
octagonal ring transducer (4.0 kNm capacity) machined into the leg as shown in Fig 3a, Godwin et al (1981). Where only the draught force is required, this can be determined using a cantilever beam machined into the leg as shown in Fig 3b, Asrafali (1980).

2. Draught, Vertical and Side forces and the resulting moments acting upon implements causing asymmetrical soil failure, such as mouldboard ploughs and side inclined tines.

i. Overall forces of a mouldboard plough.

Six dynamometer suspension systems are the most appropriate on the grounds of simplicity, ease of construction and reliability, where space is available.

ii. Share point forces of mouldboard ploughs.

Separation of the forces on the share of the plough from the remaining mouldboard assembly can be achieved by mounting the share on a steel extended octagonal ring transducer (7.5 kNm capacity) via a cantilever beam, as shown in Fig 4. The combination of these two devices produces a compact unit for measuring the three mutually perpendicular force components and their associated moments under conditions where space would prevent the construction of a six dynamometer suspension.

iii. Side inclined tines and other asymmetrical implements.

Where space is restricted for the construction of a 6 dynamometer suspension and where only minimal changes can be made to the existing equipment the combination of an extended octagonal ring transducer and cantilever extension welded to the tine is a suitable method.

The problems of subjecting the transducer to large eccentric loads to the right of the transducer as shown in Fig 5a, for which it was not designed can be remedied by monitoring the transducer such that the major axis is not vertical but inclined in the place of the face of the tine i.e. $\alpha = 23^0, \beta = 45^0$ as shown in Fig 5b, Thake (1981). The extended octagonal ring transducer will therefore measure $H^1$, $V^1$, $M_H^1$ and $M_H^1$ and the cantilever beam $S^1$ and $N_S^1$ about axis xx.

Details of dimensions and sensitivities for the transducer mentioned are given in Tables 2 and 3.

Conclusions

The techniques discussed are acceptable for the measurement of forces on complete or component parts of tillage implements with linear outputs and low cross sensitivity and position sensitivity errors.
Table 2 Cantilever Beam Dimensions and Sensitivities

<table>
<thead>
<tr>
<th>Moment Rating (kN)</th>
<th>0.3</th>
<th>7.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section b x b (mm)</td>
<td>25 x 25</td>
<td>250 x 25</td>
</tr>
<tr>
<td>Linearity of circuits (r²)</td>
<td>&gt;0.99</td>
<td>&gt;0.99</td>
</tr>
<tr>
<td>Sensitivity of channels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S$ (μV/N)</td>
<td>0.14</td>
<td>0.01</td>
</tr>
<tr>
<td>$W_{bg}$ (μV/NmV)</td>
<td>3.88</td>
<td>0.39</td>
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References


ABSTRACT

Two major developments in soil management in Britain over the past ten years have been the growth in understanding and practice of direct drilling and of deep soil loosening. These two developments are brought together in a new rational approach to soil management with the 'Paraplow' soil loosener. The implement design criteria are based on a growing multi-disciplinary understanding of the mechanics of soil loosening, of natural processes of soil structure improvement and of the requirements of crops in terms of soil physical conditions for optimum yield potential. The implement itself, a slant legged soil loosener, is briefly described. Finally a rational approach to tillage is proposed whereby weeds are controlled by herbicides and crops are established without tillage where appropriate but with occasional or annual soil loosening where this is required due to soil structure limitations.

INTRODUCTION

Historically, tillage practices have always been determined by the need to control weeds and by the technology available to provide tractive power to pull implements through the soil. The need to kill weeds through inversion of the soil ensured the dominance of the mouldboard plough, in humid regions at least, while depth of ploughing was largely a function of technology. Animal power meant shallow working, steam power allowed deeper tillage and then small tractors meant a reversion to shallow ploughing. Thus tillage practices in general responded rationally to the two dominant factors of weed control and limiting technology and were not determined by consideration of the soil conditions needed for optimum plant production. They were however often mistakenly rationalised in such terms.

In the two decades from 1950-1970 the advent and increasing effectiveness of herbicides and the development of more powerful tractors simultaneously undermined the rationale of tillage practices. Tillage methods, and by now traditions, which once had a rational basis needed re-evaluation in the changed circumstances. In the 1970s the real cost of energy and labour rose sufficiently to provide considerable motivation for this re-evaluation in
terms of soil conditions, largely physical, for optimum crop production.

RECENT DEVELOPMENTS IN SOIL MANAGEMENT

In Britain, tillage practices of progressive farmers and the emphasis of research studies have shown two main changes over the last decade in response to the changed circumstances already outlined. The first change was the steady increase in direct drilling or very shallow surface cultivation and the second was the growth in deep loosening or 'subsoiling'. Relevant advances in knowledge in both areas are reviewed briefly here as fundamental to 'Paraplow' design and use.

The provisional classification of soil suitability for direct drilling in Britain (Cannell et al, 1978) is the most relevant summary of current knowledge for direct drilling. Two points emerging from this should be stressed here. First, Category 3 soils occupying some 30% of the cereal growing area are unsuited to continuous direct drilling as compaction causes a high risk of yield reductions. Second, it is important on Category 2 soils that the soil is in good physical condition before a sequence of direct drilling is begun. Thus while in many cases there is no need for tillage, we are beginning to be able to define certain soil types and situations where there is a rational requirement for soil loosening either once only or annually to provide optimum conditions for crop growth.

The main contribution to understanding of deep soil loosening in the UK has come from Spoer and Godwin (1978) and other work by these authors. They have shown that soils have a characteristic critical depth; working below this with any draft implement gives no useful loosening and may result in additional compaction at depth, while energy consumption increases rapidly below the critical depth. Hence soil loosening implements should be used at a depth suitable to remove an identified soil compaction problem or at the critical depth, whichever is the shallower. Soils are most effectively loosened when they are in a moist condition (i.e. pF2-4). From an implement design point of view, their work shows that considerable reductions in specific draft compared to conventional straight leg subsoilers can be achieved by the use of 'wings', the correct spacing between legs and by loosening the soil from the top downwards. Correct leg spacing is also of prime importance in achieving a level finish. The need to avoid recomposition after loosening is now better appreciated, with several workers (e.g. Raghavan et al, 1977) having shown that most recomposition occurs in the first few passes over a soil, while Pidgeon
and Soane (1978) demonstrated that recompaon occurred to the full depth of the previous loosening operation.

THE 'PARAPLOW' SYSTEM

Direct drilling or very shallow cultivation and efficient deep soil loosening are not mutually incompatible systems, but are brought together in a rational system of soil management with the 'Paraplow'. The approach advocated here is claimed to be rational because it is based on three principles of:

(i) loosening the soil as much as actually needed for optimum crop potential
(ii) loosening only when actually required
(iii) loosening efficiently, both in the light of current understanding of design and loosening processes and by complementing natural processes of soil structure improvement

By contrast, many other tillage systems loosen the soil too much and subsequently recompact it, and one of the many examples of this is given by Pidgeon (1981), Figure 1. Also they must invariably be used annually or before each crop, and disrupt or oppose natural improving processes, e.g. by inverting the surface tilth and bringing unweathered clods to the surface.

In order to meet these principles, it is necessary to have a multi-disciplinary understanding of soil conditions in relation to crop development and yield. Sound engineering, economic and marketing criteria though necessary are not sufficient. We do not at present have the necessary quantitative understanding of soil conditions - a formidable task for ISTRO members to tackle within the rest of this century. However qualitatively there is growing acceptance that three aspects of this complex topic, comprehensively reviewed by Russell (1978), are important. Plants require a continuous pore system adequate for root development and drainage but not necessarily large in volume since for example a well developed cereal root system occupies only 5% of the soil volume near the surface and around 0.5% at say 50cm depth. Second, such a pore system should be combined with adequate bearing strength. The less vulnerable it is to compaction by traffic the better and more long lasting it will be. Third, an adequate seedbed is required.
'PARAPLOW' DESIGN CRITERIA

The six main criteria for design are listed below with little further discussion in this short paper, since they effectively summarise the ideas outlined above.

1. The implement should crack the soil along natural patterns, rather than disrupt or invert it, and should do so efficiently.

2. The implement should loosen the soil just as much as needed - not more and not less.

3. The implement should leave a level surface suitable for drilling, so that subsequent cultivations, which recompact the soil due to traffic, are not necessary.

4. The amount of soil loosening by the implement should be adjustable to suit soil type and moisture conditions, rather than the farmer needing to wait until conditions suit the machine.

5. The implement must be operationally attractive in terms of costs, rate of work, reliability, power requirements and other practical economic and engineering aspects.

6. In many countries, but not Britain, the implement must be able to work through heavy trash, so as to retain the many advantages associated with trash cover in many agricultural regions.

Some further comment on the first criterion is perhaps appropriate. Cracking the soil rather than total disruption and/or inversion is the mode of soil loosening most likely to give the desired result of a small volume of vertical continuous fissures considered appropriate for drainage and root growth. Cracking the soil along natural planes of weakness is also an inherently less energy consuming process than other modes of soil failure. Natural 'fissures' are likely to be longer lasting than others and possibly reform naturally in subsequent dry seasons. The absence of disruption of small natural aggregates also has several potential benefits to stability and durability of soil structure (Greenland, 1981). In addition, the surface tilth formed by many types of soils is maintained and enhanced as the basis of the seedbed for the following crop, eliminating the need for further tillage.

The logic of weed control by herbicides is also evident, since further cultivation to control weeds can cause recompaction due to traffic, reduce pore continuity and aggregate stability and disrupt any surface mulch cover.
THE IMPLEMENT

The 'Paraplow', an implement embodying these design criteria, has been developed from a slant legged implement invented by Dr A N Ede and originally intended for conventional drainage and subsoiling work. When the implement is pulled through the ground, soil flows over the slant legs, is loosened by failure in tension and lifted but not inverted, thus giving the type of 'natural' cracking desired. The leg spacing (50cm) and working depth (25-35 cm) have been chosen so as to give loosening over the whole soil volume down to about the critical depth (Spoor and Godwin, 1978) for most British soils. The slant leg configuration ensures that no damaging horizontal smear can occur and that, considering any vertical cross section, the soil is loosened from the top downwards. Each slant leg is fitted with replaceable wear parts and a foot. Cutting discs are fitted in front of each leg to enable the implement to work through trash and to assist in leaving a level surface by parting the soil in front of the leg, particularly on clay soils. Behind each leg an adjustable flap is fitted which enables the user to regulate the effective thickness of the slant leg and thus alter the amount of lift and soil cracking to the desired amount. The current implement has three legs with an optional fourth leg extension to give a working width of 2m, but a range of models to suit different tractor sizes will be produced.

THE 'PARAPLOW' IN FARMING SYSTEMS

Where and when the 'Paraplow' soil loosener should be used is of course, as with any cultivation method, a matter of judgement for individual fields. However, broad guidelines can be given which, together with some examination of soil profiles in the field, assist in making that judgement on a rational basis. One can envisage perhaps five types of situation in Britain:

1. If the soil structure is suitable for the next crop - only weed control by herbicides is required.
2. If the soil structure is suitable generally, but headlands have been compacted - loosen the headlands only before drilling.
3. If the soil has a good stable structure generally suited to reduced cultivation or direct drilling, but has been damaged by compaction or a plough pan - loosen the whole field the first year and then only in subsequent years if it is damaged again.
4. On soil types inherently not suited to shallow cultivation or direct drilling to poor or unstable structure, loosen each year.
5. If grassland production is being restricted because of poor soil physical conditions, loosening can be carried out without destruction of the sward, or may be followed by direct re-seeding if necessary.

This paper has perforce been restricted to a consideration of rational tillage in the predominantly arable or mixed farming areas of Britain. It is of interest to consider the adoption of such ideas to other agricultural regions where traditional tillage is being questioned. For Britain at least, one may conclude thus:

when in doubt, get the 'Paraplow' out
if the soil is OK, put it away.

REFERENCES


Pidgeon, J.D. 1981. A preliminary study of minimum tillage systems (including broadcasting) for Spring Barley in Scotland. Soil & Tillage Research 1, 139-151.


ACKNOWLEDGEMENT

This work owes a very great deal to the inspiration of the late Mr Paul Koronka.

* 'Paraplow' is a trademark of the Howard Rotavator Company.
Abstract

The characteristics of friction-loss due to compaction effect of the Japanese rotary blades to the untilled soil were discussed. As a result, the single-edged blades were more effective to decrease the tillage resistance than the double-edged ones. Indoor test conducted to compare the performance of single and doubleedged blades under the usual tillage conditions. The reduced tillage resistance energy of the single-edged blades were obtained from the tilling resistance torque curves. The single-edged blade decreases about 20% of tillage power from the results of field experiments. Design method of the single-edged knife of Japanese rotary blades were geometrically analysed. The cross-section of lengthwise blade to soil exists on the trochoid locus curve of the blade motion. And the equations to be used for examining angle operations of the blades were obtained.

I. Introduction

The Japanese rotary blade as shown in Fig. 1 is an important tool for the cultivation of paddy rice field in Japan. It differs from the European rotary blade "L type-blade", in the design for cross-section of blade. The relief angle at untilled side-surface of the lengthwise blade is an important parameter for the design of rotary blade. Their cross-sections were designed as the double-edged blade on the Japanese market. The decrease in tillage resistance of these cross-sections were studied for the saving of energy. The objects of this paper are:

- to discuss the soil cutting mechanism of single and double-edged blades.
- to compare the advantageous tillage resistance (reduced tillage energy) of single-edged blades with double-edged ones.

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to present a design for relief and cutting angles at lengthwise blade. Recently in Japan, most new rotary blades are designed to be single-edged ones.

II. SOIL CUTTING MECHANISM OF SINGLE AND DOUBLE-EDGED BLADES

The cross-sectional shape of the blades has influence on the torque characteristics of tilling resistance, because of frictional resistance between the blades and the untilled soil. In the case of Japanese rotary blade, there are two portions to consider as follows:

A) Lengthwise Blade Portion

Fig. 2 shows the cutting patterns of soil surface with the Japanese rotary blades. The vertical section "dd" was observed. The friction between the tilled soil and the single-edged blade is not large. This is because most of the free moving action of the uncohesive soil clods and particles as shown in Fig. 3-a. On the contrary, the friction which occurs between the untilled soil and the double-edged blade is much greater than the single-edged one. It can be said that, this friction is an immediate cause of the energy-loss as shown in Fig. 3-b.

B) Tip Blade Portion

Although the tilling conditions and the lip angle of two types of edged blades were observed to have the same values, the cutting angle ϕ at the second scoop-surface with the single-edged blade was smaller than the double-edged one as shown in Fig. 4(a-b). That means, the scoop-surface with single-edged blade is able to
reduce soil cutting resistance, and the pressing phenomenon due to its back surface to unttled soil hardly occurs.

III. PERFORMANCE OF SINGLE-EDGED BLADE

The tillage resistance characteristics of single-edged blade were obtained through indoor test as shown in Fig. 5. The work of single-edged blade which was presented by an area of torque resistance curve, was smaller than the work of double-edged one.

That means, the tilling energy for single-edged blades decreases in the Japanese rotary blades. Fig. 6 shows the relationship between the tillage pitch (apparent pitch) and peak torque under the tillage conditions: Tillage depth H=12cm, tillage width Wb=4cm, revolution of rotary axle n=180rpm, and radius of blade R=22cm. The relationship between the tillage pitch and the decreasing percentage of tilling resistance in comparison of single-edged blade with double-edged one was obtained as shown in the top of Fig. 6, too. As the tillage pitch increases the peak torque of single and double-edged blades increases. The decrease in tillage resistance for single-edged one was obtained from 22% to 27% when the tillage pitch increased from 3cm to 12cm.

Field test was conducted to compare the performance of two types of edged blades. Seven complete sets of rotary blades were used. These were designed as follows:
A: Standard double-edged blades in the market.
B: Single-edged blades with bigger cutting angle \( \phi \) (see Fig. 4) than A blades for better raking to soil.
C: Single-edged blades made from A blades.
Fig. 7

KINDS OF ROTARY BLADE FOR EXPERIMENTS

<table>
<thead>
<tr>
<th>Blade</th>
<th>Torque (peak)</th>
<th>Torque (mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
<td>B</td>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td>C</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>D</td>
<td>60</td>
<td>20</td>
</tr>
<tr>
<td>E</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>F</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>G</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

D: Smaller angle $\phi$ than C blades.
E: Reverse single-edged blades.
F: Bigger angle $\phi$ than A blades.
G: Reformed blades with single-edged blades.

There were 12 blades in one complete set. The radius of blades was 22 cm. The field was clay loam (well drained paddy field) having soil hardness at surface of 5.5 - 9 kg/cm$^2$, and hard-pan of 20 - 25 kg/cm$^2$. The tilling conditions were constant as tillage depth $H=14$ cm, forward speed of machine $v=31$ cm/sec, revolution of rotary axle $n=203$ rpm. The "C" and the "G" blades required tilling energy less than the standard blade "A" about 20% as shown in Fig. 7. And an advantage in the tilling resistance for single-edged blade increases in the hard soil, but it is not obtained in the soft soil.

This advantage was clearly obtained in the first half term of the blade's life from the wear-out test, too. Then in the last half it decreases, because the form of lip angle of single and double-edged blades becomes the same as shown in Fig. 8.

III. THEORETICAL DESIGN OF CROSS-SECTIONAL SHAPE

As the shape of Japanese rotary blades before a bending process in the production-line of blades has a changing thickness from the shank to the tip of blade as shown in Fig. 12. The cross-section of lengthwise is usually designed in the radius direction of the edged curve. This cross-section is called the apparent one as shown in Fig. 9 (section "nn"). The actual cross-section which is shown in Fig. 9 as section "vv", exists on the trochoid locus curve of the blade motion. Therefore the actual one has a relief angle $\psi$ as shown in Fig. 9, too. However this relief angle is not important factor in
the design for European rotary blades, because the thickness at shank and tip of European ones are the same values.

Then the apparent cross-section is advised to be of uniform thickness with the single-edge, depending upon the basic idea to give a reasonable relief angle between the blade and the material to be cut, for the decrease of cutting resistance.

In 1979 Sakai presented theoretical analysis for examining angle operations of a blade which has an edge of acute angle. In this paper, analysis was tried on a blade which has a round cornered edge having radius \( r \) as shown in Fig. 11. The blade model and angle operations are shown in Fig. 10. The equations for the examining angle operations of the blades were obtained as follows:

Actual relief angle \( \psi \) of the lengthwise blade to soil is calculated by

\[
\psi = \tan^{-1}\left(\frac{(t_1-t_2)\tan(\beta+\alpha-90)}{2L_1\sqrt{1+\tan^2(\beta+\alpha-90)}}\right)
\]

Actual lip angle \( \varepsilon \) of cutting edge is calculated by

\[
\varepsilon = \tan^{-1}\left[\frac{t}{(M+y)\sqrt{1+\tan^2(\beta+\alpha-90)}} - \tan\psi\right] - \psi
\]

Actual cutting angle \( \varepsilon_1 \) is calculated by

\[
\varepsilon_1 = \tan^{-1}\left[\frac{t}{(M+y)\sqrt{1+\tan^2(\beta+\alpha-90)}} - \tan\psi\right]
\]

Since, the function \( y \) in the equations (2) and (3) is calculated by

\[
y = r\left[\cot(\varepsilon_4/2) - 1\right]
\]
Thickness tolerance of plus relates closely to the tillage resistance of back portion of the blade, and must be determined through calculation of the following equation:

\[ e = \frac{h_1 - h_2}{2L_1} \tan(\beta + \alpha - 90) \]

where

\[ \beta = \cos^{-1} \left[ \frac{30v}{R} \sqrt{\frac{H(2R - H)}{(30v)^2 - 60\pi v(R-H)+(R\pi)^2}} \right] \]

The lengthwise blade of Japanese rotary blade which is designed with these equations, may have rational soil cutting characteristics for minimizing friction-loss due to the soil compaction by the blade.

REFERENCES

MOLE DRAINAGE OF DIFFICULT LAND

Peter Smart
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Abstract. Theory for design of mole drainage schemes when a few small collapse-inducing features are present.

It is frequently said that mole drains cannot be used when stones or sand pockets are present, since these cause the mole drains to collapse. If these features are small enough to affect only one mole drain each, this view may be over-cautious, provided that collector drains are installed at sufficiently close intervals. This situation is illustrated in Fig. 1 and discussed below.

In effect, the mole drains occupy a layer between certain depths, and each collapse-inducing feature will affect a small area of this layer. For the sake of argument, it is assumed here that the proportion of the total area containing such features, \( a \), may be estimated with sufficient accuracy. For example:

\[
a = \frac{\text{number of auger holes with features}}{\text{total number of auger holes}} \quad (1)
\]

If the auger is comparable in size with the features, a better estimate is obtained by dividing the value obtained from Eqn. 1 by the factor:

\[
1 + \frac{gP}{A} \quad (2)
\]

where \( g \) is the radius of the auger, and \( P \) and \( A \) are the perimeter and area of a typical feature. \( P \) and \( A \) may be estimated from pits dug at the positions of auger holes which encountered features. The proportion of the total area affected by the features, \( a' \), will be greater than \( a \). Thus:

...
Fig. 1. Idealised plan. Mole drains, spacing s. Collector drains, spacing D. Collapse-inducing features, black. Areas of potential collapse, outlined. Collapses, black.
Fig. 2. Picture of mole drain, showing collapse of length \( l \) in a run of length \( L \).

\[ a' = (1 + c) a \]  

(3)

where some reasonable assumption must be made, such that \( c = 0.1 \) or \( 0.05 \). The value of \( a' \) so found is an estimate of the total length of mole drain which will be affected and collapse, i.e.:

\[ a' = 1/L \]

(4)

where \( l \) is the average length of a collapse, and \( L \) is the average length containing one collapse, Fig. 2.

The average length of a collapse may also be estimated from the field investigation. Assume that the features are circular, and that their average radius is \( r \). Then, the affected areas will also be circles, whose average radius, \( r' \) is given by:

\[ r' = (1 + 0.5 c) r \]

(5)

Because the mole drains intersect the features along random chords, assume that the average length of a collapse may be estimated by the mean chord of a semi-circle:

\[ l = \pi r' / 2 \]

(6)

The spacing of the collector drains, \( D \), should be chosen such that a sufficient proportion of the individual mole drains is unlikely to collapse. This may be done by requiring that:

\[ D = L/K \]

(7)
where $K$ is a factor which must be chosen by the designer. For example, it may be desired that, on average, each mole drain containing a collapse should be flanked by a pair of intact mole drains. This is approximately equivalent to specifying $K = 3$. A higher value of $K$ would give a higher standard of drainage.

Collecting formulae:

$D = \frac{\pi}{2K} \frac{1 + 0.5c}{1 + c} \frac{r}{a}$ \hfill (8)

Assuming $c$ to be small:

$D = \frac{\pi r}{2K} \frac{r}{a}$ \hfill (9)

Let $n$ be the number of features per unit area, i.e. their frequency. Then:

$a = n \pi r^2$

Therefore, $D = \frac{\pi r}{2K} \frac{1 + 0.5c}{1 + c} \frac{1}{n r}$ \hfill (10)

Assuming $c$ to be small:

$D = \frac{1}{K n d}$ \hfill (11)

where $d = 2r$ is the average diameter of a feature. Thus, the spacing of the collector drains may be estimated from the standard of drainage required, through the choice of $K$, and from the size and frequency of the collapse-inducing features. The spacing of the mole drains, $s$, will have a negligible effect, provided that the size of the collapse-inducing features is less than $s$.

Fig. 3 is a graphical representation of Eqn. 11 using $K = 3$. For example, if there is one feature per 10 sq. metre, $n = 0.1$; and, if these have diameter $d = 0.4$ m, then, the collector drain spacing, $D = 8$ m. In this case, any attempt to draw mole drains might perhaps be better regarded as sub-soiling, provided shatter is achieved. However, if the features were only half as large, say, then collector drains 16 m apart would seem permissible; in which case, mole drainage would seem to be satisfactory despite a few collapses.
Fig. 3 Chart for collector drain spacing, $D$, from diameter and frequency of features, $d$ and $n$, using Eqn. 11 and assuming $K = 3$.

I thank Mr. R. H. Hewitt for suggesting the correction to Eqn. 1.
TILLAGE FOR IMPROVED DRAINAGE

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ABSTRACT

Implement design parameters controlling crack development and mole channel formation are discussed to aid selection of appropriate tillage techniques to overcome impeded drainage within soil profiles.

INTRODUCTION

Temporary waterlogging resulting from the development of perched water tables above compacted layers in a soil profile can frequently retard crop development. These compact layers may develop naturally or result from the action of soil working implements or surface traffic. Tillage operations can be used to improve the drainage status in these situations by creating larger conducting pores in the compacted layers and in certain soils by forming a mole drain at depth to remove excess water rapidly. This paper discusses the implement design parameters which control crack development and channel formation under different soil conditions.

Nature of soil disturbance required

The creation of larger pores in a compacted zone can be achieved in two ways:

a. by complete disruption of the zone with reorientation of the soil units produced, leaving large pores between these units.

b. by opening up the existing profile along existing planes of weakness, increasing pore size between the peds, but without significant ped re-orientation.

The method chosen will be dependent upon other husbandry considerations. Extensive soil reorientation at depth is difficult to achieve without disturbing the surface layers and hence the first technique is only appropriate in situations where surface disturbance is acceptable or required. Loosening with minimal surface disturbance requires the second technique and this is often the situation in grassland and in continuously direct drilled or shallow tilled cereal areas. The second approach produces fewer large pores, leaving the soil in an almost undisturbed state, but the soil is very prone to recompaction if trafficked soon after loosening.
Implement parameters influencing the nature of soil disturbance

To meet field requirements, control is needed over the number of large pores produced, the degree of soil unit reorientation and the degree of soil surface disturbance and clod production. These aspects are controlled by the following implement geometry parameters, illustrated in Figure 1 for current equipment, Spoor and Godwin (1978): share width $a$, working depth $d$, leg width $b$, leg sideways inclination $\beta$, wing lift height $h$, wing inclination $\delta$. The use of discs or shallow working tines ahead of deep tines also influences disturbance.

FIGURE 1 Basic tine shapes

![Basic tine shapes](image)

Soil failure is progressive, the soil responding first to the share, followed by the leg and where appropriate, the wing. The influence of tine geometry changes on disturbance will be discussed in terms of:

a. share aspect ratio $\left(\frac{\text{share width}}{\text{working depth}}\right)$

b. leg width and inclination

c. wing lift height and inclination

d. presence of leading tines or discs

Share disturbance

Two types of soil failure are possible:

1) With low aspect ratios, crescent disturbance with the soil moving forwards and upwards ahead of the share, Figure 2(i).

2) With high aspect ratios, local disturbance at depth with failure boundaries similar in section to shape of share, see Figure 2(ii).

Surface disturbance is more extensive with crescent failure than local

**FIGURE 2** Share disturbance

![Diagram of share disturbance with labels](image)

**b. Leg disturbance**

1) **Vertical leg** \( \beta = 90^\circ \) (Figure 1 (i, ii, iii, iv))

With crescent share disturbance, the leg splits the loosened crescent zone of soil causing soil reorientation and some surface clod production. Surface disturbance increases with increasing leg width.

With local share disturbance, the leg, working in almost undisturbed soil, creates a series of cracks angled to the direction of travel, see Figure 3. These cracks extend from the surface to the channel at depth. Surface disturbance is small.

**FIGURE 3** Leg disturbance

Isometric sketch

![Isometric sketch of leg disturbance](image)

i) **Inclined leg** \( \beta = 45^\circ \) (Figure 1 (v))

With crescent share disturbance, the leg runs within the sideways failure plane, Figure 2 (i). The disturbed crescent flows over the leg and...
some fissuring occurs with minimal surface disturbance or ped reorientation.

With local share disturbance, the leg opens up an angled slot at depth connecting with the share channel. Minimum surface disturbance occurs.

c. Wing disturbance

With crescent share disturbance, further soil loosening occurs at depth, see Figure 4. Soil reorientation and surface disturbance increases with increasing wing lift height and flap inclination, Figure 1 (v). Reorientation can be considerable with high wing lift heights.

With local share disturbance, undisturbed soil flows over the wing and vertical tensile cracks are formed as the soil leaves the wing. The number of tensile cracks formed increases with increasing wing lift height and wing inclination. A minimum lift height is required for tensile crack formation, this minimum height being dependent upon working depth and soil conditions.

FIGURE 4 Wing disturbance

[Diagram of Wing disturbance]

d. Leading shallow tines or discs

The use of shallower working leading tines loosening the surface layers first, causes considerable surface disturbance and increases the chances of crescent share disturbance, with greater soil reorientation by both the share and the wing. Surface disturbance of this type allows loosening with reorientation to much greater depths.

The use of a shallow working flat disc running ahead of the leg and crescent failure zone, significantly reduces the chances of clods being brought to the surface as a result of the tine leg action.

Soil factors influencing the nature of soil disturbance

The two major soil factors influencing the nature of disturbance are, the surcharging effect of the surface soil layers on the soil at working depth and the soil cohesion. The surcharging effect is dependent upon soil shear strength.

The lower the shear strength of the surface layers relative to those
at depth, the lower the surcharging effect and the greater the chances of crescent share disturbance with greater soil reorientation. Surface surcharging effects are particularly severe at the extremes of dry conditions on the surface and wet conditions at depth.

Soil cohesion influences soil breakup and reorientation as soil flows over wings and affects the number of tensile cracks created by wing action after local share disturbance. The lower the cohesion between the soil peds, the greater the ped reorientation and the greater the number of tensile cracks produced. Inter-ped cohesion is a maximum near the plastic limit. Extensive root systems such as in grassland effectively increase the total soil cohesion.

Although channels can be formed at depth through local share disturbance under many soil conditions, mole channels will only be stable in soils with an appreciable clay content and when formed under appropriate moisture conditions, see Spoor et al (1982).

Selection of equipment and techniques

Equipment selection for work under specific soil conditions will be dependent upon the requirements for working depth, degree of loosening, degree of reorientation, surface conditions and the need for a drainage channel at depth.

In situations where there are no constraints imposed by the surface conditions and loosening with reorientation is required, the use of shallow leading tines, with a wide share and high lift wings on the deep tines, will allow satisfactory loosening over the widest possible range of depths and soil conditions. At the other extreme where surface disturbance must be minimal, tines with narrower shares, lower lift wings or flaps, and narrow legs preceded by flat discs will be required. The wing lift height needed will be dependent upon the working depth and soil conditions; the greater the working depth, the greater the wing or flap lift height required.

The levelness of the soil surface after any operation is dependent on the uniformity of loosening across the field. Level surfaces can be achieved with all tine configurations providing an appropriate tine spacing is used. Wide spacings cause uneven soil surfaces.

Where both a drainage channel and soil loosening are required, it is important to form the channel first, before loosening. A cylindrical cross section share is required, Figure 1 (ii) for mole channel formation and wings may be attached to the leg to loosen above the channel, see Godwin et al (1981). The leg disturbance above a mole channel provides
adequate cracking with minimum surface disturbance to allow the rapid movement of excess water in the surface layers to the drainage channel.

References


FIELD MEASUREMENT OF SOIL SHEAR STRENGTH AND A NEW DESIGN OF FIELD SHEAR METER

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Abstract
Six techniques for measuring soil shear strength have been compared in six different soils. It was concluded that the choice of techniques must be determined by the application to which the shear parameters are to be applied. Because of the variability of shear strength in the field, considerable numbers of tests have to be conducted to obtain statistically significant values of shear parameters. A new design of shear meter, that simplifies the gathering of large quantities of shear data, is outlined.

Introduction
Workers in tillage and soil mechanics have long recognised the importance of shear strength in determining the reaction of soil to mechanical disturbance. The forces exerted by soil on soil working equipment, the shattering of soil and the nature of soil failure are largely determined by the soil's shear strength. Thus the impetus to measure shear strength has been high and a number of different types of measuring equipment have been designed. The principle types include triaxial cell, direct shear box, torsional shear box, shear annulus and shear vane. There are many variations on these basic types as well as instruments, such as the penetrometer, which measure some compound strength parameter of the soil. It has become clear that the various types of instrument do not yield the same value of shear strength for a given soil sample. A number of comparative tests have been carried out between different types of instruments and even these comparisons have not been consistent with each other.

The study reported here was commenced for two reasons. Firstly, in developing a model of implement/soil reaction, it was necessary to measure shear strength to a reasonable degree of confidence (Stafford, 1979a). It was found that triaxial and torsional shear box methods gave very different shear strengths, making model validation difficult. A comparison between test methods in widely differing soils was therefore required. Secondly, in field experiments, the measurement of shear strength is very labour intensive and there is frequently the temptation to take insufficient readings to yield statistically significant results. A new field shear rig was therefore designed to enable measurements to be made much more quickly. Again, a comparison of methods was needed to decide on the most appropriate shear device.

Previous comparative studies
The fact that there are discrepancies between the shear values measured by different types of equipment has been widely observed, but studies to rationalise these differences have often contradicted each other or been conducted
under a limited range of conditions. Osman (1964) concluded that the shear devices that he investigated yielded identical shear parameters. Dunlap et al. (1966) however found that different devices all yielded different cohesion (c) and internal friction angle (φ) values when used in remoulded soils. Similarly, Bailey and Weber (1965) measured different values of c and φ with different devices in two remoulded artificial soils.

Experimental details

A comparison of a number of shear devices was carried out in a range of soil types and conditions. Tests with six different soils included undisturbed field soils and remoulded soils. Details of the soils are given in Table I.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Textural analysis, %</th>
<th>organic content %</th>
<th>moisture content % d.b.</th>
<th>plastic limit % d.b.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>Classification</td>
<td>Clay &lt;2μm</td>
<td>Silt 2-60μm</td>
<td>Sand 60-2000μm</td>
</tr>
<tr>
<td>1</td>
<td>Sandy clay loam</td>
<td>22.8</td>
<td>21.4</td>
<td>55.8</td>
</tr>
<tr>
<td>2</td>
<td>Clay</td>
<td>51.0</td>
<td>20.4</td>
<td>28.6</td>
</tr>
<tr>
<td>3</td>
<td>Clay with stone</td>
<td>42.3</td>
<td>21.4</td>
<td>26.3*</td>
</tr>
<tr>
<td>4</td>
<td>Peat mineral fraction</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Sandy loam</td>
<td>19.8</td>
<td>26.4</td>
<td>53.8</td>
</tr>
<tr>
<td>6</td>
<td>Sandy loam</td>
<td>19.8</td>
<td>26.4</td>
<td>53.8</td>
</tr>
</tbody>
</table>

Remoulded soils

5 Clay 23.0 17.0 60.0 - 47.9(2.3) 39
6 Sand 0 0 100 0 6.6(2.4) -

*Mean value for top 80 mm. +10% > 2 mm. s.d.'s in brackets.

Shear tests and soil sampling on the 4 field soils were carried out in as small an area as possible to minimise differences in soil strength. The remoulded clay was prepared in a laboratory soil tank (Stafford, 1979b). The remoulded clay was prepared by saturating in a metal bin (370 mm diameter by 370 mm deep) and then allowing free drainage from the base for 15 minutes. The wet sand was reconstituted directly in the triaxial cell and the direct shear box. The shear devices tested were:

i Torsional shear box of 125mm diameter and 45mm height.
ii Torsional shear annulus of 120 mm external and 80 mm internal diameter. The annulus was fitted with 6 grouser plates and side shields of 20mm depth.
iii Shear vane of the cruciform type, of length 30mm and diameter 19 mm.
iv Direct shear box of the conventional type using 60 mm square soil samples and a strain rate of 3.3 x 10^-4 s^-1 (sliding speed 1.17 mm/min).
v Triaxial fast undrained test. The axial strain rate was 3.3 x 10^-4 s^-1 (loading ram speed 4 mm/min).
vi Triaxial slow drained test. The axial strain rate was 10^-5 s^-1 (loading ram speed 0.12 mm/min).
For the laboratory tests, soil samples were taken from the field and stored in polythene bags in a cold room until required. For the direct shear measurements, either 60 mm square samples were cut directly or 150 mm cubes were cut and stored and then cut to the requisite size immediately prior to a test. For the triaxial tests, 100 mm diameter cores were cut by a tractor-mounted corer. The length of a core was about 250 mm which was trimmed to 200 mm prior to a test.

Results

Peak torques from the torsional shear box and annulus were converted to peak shear stresses using Payne's (1952) assumption of uniform normal stress distribution on the shear surface. Values were obtained at 6 normal stresses (up to 80 kPa for the annulus and 40 kPa for the box), and linear least squares fits were made between shear (τ) and normal (σ) stress using the classical Coulomb model:

\[ \tau = c + \sigma \tan \phi \]

Values of cohesion (c) and friction angle (ϕ) were thus determined for each soil. The peak reading from the shear vane was converted to shear strength. The value obtained was the soil cohesion if normal stress could reasonably be taken as zero. Results from the direct shear box were treated in the same way as those from the torsional box and annulus to yield cohesion and friction angle values. Tests were made at 6 normal stresses up to 150 kPa. Both triaxial tests yielded a series of axial loads to produce failure in the samples at 6 different cell pressures. The maximum major principle stress was about 300 kPa. The Mohr circle construction was used to determine the failure envelope and an analysis developed by Stafford et al (1982) was used to fit a least squares tangent line to the circles. Cohesion and friction angle could then be determined.

Up to 5 sets of tests were made with each method in each soil, but it was found that in a number of cases, particularly for the shear box and the annulus, regression analysis did not yield a significant (P>95%) linear fit. In each case, the lack of fit was due to experimental scatter and not due to curvature of the shear-normal stress relationship. The number of sets of tests and the number that yielded significant fits are shown in Table II.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Torsional shear box</th>
<th>Torsional shear annulus</th>
<th>Direct shear box</th>
<th>Direct shear undrained</th>
<th>Triaxial test drained</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1/5</td>
<td>5/5</td>
<td>2/2</td>
<td>3/3</td>
<td>2/2</td>
</tr>
<tr>
<td>2</td>
<td>1/5</td>
<td>3/5</td>
<td>2/3</td>
<td>2/3</td>
<td>3/3</td>
</tr>
<tr>
<td>3</td>
<td>4/5</td>
<td>2/5</td>
<td>3/3</td>
<td>1/3</td>
<td>2/4</td>
</tr>
<tr>
<td>4</td>
<td>4/5</td>
<td>5/5</td>
<td>4/4</td>
<td>3/3</td>
<td>2/3</td>
</tr>
<tr>
<td>5</td>
<td>3/3</td>
<td>1/2</td>
<td>3/3</td>
<td>3/3</td>
<td>1/3</td>
</tr>
<tr>
<td>6</td>
<td>2/2</td>
<td>5/5</td>
<td>3/3</td>
<td>3/3</td>
<td>1/1</td>
</tr>
</tbody>
</table>

All measurements for a given soil and test were then lumped together and a straight line fitted to the data. The fits were significant in each case and the values of cohesion and friction angle are shown in Table III.
TABLE III Values of cohesion and friction angle

<table>
<thead>
<tr>
<th>Soil</th>
<th>Torsional shear box annulus</th>
<th>Direct shear box</th>
<th>Triaxial test undrained</th>
<th>Triaxial test drained</th>
<th>Shear vane</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a. cohesion, kPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>28.5</td>
<td>39.3</td>
<td>14.8</td>
<td>6.5</td>
<td>17.4</td>
</tr>
<tr>
<td>2</td>
<td>36.3</td>
<td>41.9</td>
<td>54.3</td>
<td>11.1</td>
<td>14.4</td>
</tr>
<tr>
<td>3</td>
<td>86.9</td>
<td>88.6</td>
<td>50.1</td>
<td>33.5</td>
<td>41.9</td>
</tr>
<tr>
<td>4</td>
<td>33.0</td>
<td>36.1</td>
<td>19.9</td>
<td>11.3</td>
<td>15.5</td>
</tr>
<tr>
<td>5</td>
<td>40.4</td>
<td>62.3</td>
<td>28.2</td>
<td>10.3</td>
<td>21.1</td>
</tr>
<tr>
<td>6</td>
<td>(1.6</td>
<td>(4.2)</td>
<td>6.2</td>
<td>4.9</td>
<td>3.1</td>
</tr>
<tr>
<td>b. friction angle, deg.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>28.2</td>
<td>33.2</td>
<td>33.2</td>
<td>25.4</td>
<td>29.7</td>
</tr>
<tr>
<td>2</td>
<td>20.2</td>
<td>13.7</td>
<td>21.4</td>
<td>17.3</td>
<td>26.4</td>
</tr>
<tr>
<td>3</td>
<td>38.1</td>
<td>22.9</td>
<td>24.0</td>
<td>11.3</td>
<td>11.3</td>
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<tr>
<td>4</td>
<td>29.0</td>
<td>30.8</td>
<td>34.4</td>
<td>16.9</td>
<td>21.9</td>
</tr>
<tr>
<td>5</td>
<td>20.5</td>
<td>21.3</td>
<td>8.3</td>
<td>6.0</td>
<td>2.8</td>
</tr>
<tr>
<td>6</td>
<td>(14.8</td>
<td>(8.8)</td>
<td>31.6</td>
<td>31.8</td>
<td>33.3</td>
</tr>
</tbody>
</table>

Both the torsional box and annulus became unstable in the wet sand at onset of shear and sank unevenly. The relevant figures in Table III must therefore be treated with caution.

Conclusions from shear tests

The results for both $c$ and $\phi$ in Table III show quite clearly that the test method affects the measured soil shear strength. There are a few cases of agreement between two methods but generally each test method produces different strength values whether undisturbed or remoulded soils are being considered. A number of observations and conclusions can be drawn -

i. Test methods may be grouped into those where the shear plane is (nominally) defined by the shape of the measuring equipment and those (the triaxial tests) where the soil is free to fail along a distinct shear plane or fail in flow. In the former tests, the soil is generally failing under confined conditions and the strength parameters may be expected to be higher than from triaxial tests on the same soil.

ii. The shortcoming of the torsional shear box is that shear strain varies from zero at the centre to some value at the periphery. Failure thus occurs progressively from the periphery inwards as the box is turned. The range of shear strain for a given angular displacement of the annulus is much less and so the peak stress is greater than for a box. Cohesion values would therefore be higher with the annulus and this is confirmed from the Table.

iii. Although use of the shear vane is generally restricted to saturated clays, the results show that the apparent cohesion values from the vane were in reasonable agreement with values from the annulus for the undisturbed mineral soils.

iv. The triaxial drained test yielded higher values of friction angle than the undrained test in most soils. This was due to pore water pressure carry-
ing some of the normal stress in the undrained test. The exception was the freely draining sand where the angle was the same for both tests.

v. There were less significant results from the regression analysis of the stony soil than from the other five soils.

vi. 45% of the regressions for the torsional box were not significant compared with 14% for the annulus if the stony soil was excluded. In the latter case, stone would have occupied a significant proportion of each annular sector.

vii. The general practice with the torsional shear box and annulus is to measure shear stress for about 6 normal stresses. The results from this study clearly show that to obtain a reasonable number of significant results, shear stress must be measured for a larger number of normal stresses.

vii. The choice of test method must be determined by the particular application for which shear strength is required. Thus, a different method would be chosen when considering a soil traction problem than when considering a problem of soil-impliment interaction.

Measurement of shear strength in the field

Shear strength may be measured in situ using a shear box, annulus or vane or by taking 'undisturbed' samples and using direct or triaxial machines. In situ methods are to be preferred as minimum disturbance is caused to the soil under test. The vane only yields an apparent cohesion value although the results of this study suggest that it may be used more widely than generally accepted. The results here also show that an annulus is to be preferred to a box and so for obtaining both shear parameters, c and $\phi$, the annulus is recommended.

The collection of in situ shear data in the field is a laborious task and frequently insufficient measurements are made to yield significant values of c and $\phi$. Field equipment was therefore designed which would enable shear measurements using an annulus to be made quickly and easily by one man. The aim was to design equipment that was as convenient to use as a shear vane or penetrometer.

A simplified diagram of the equipment is shown in Fig. 1. It is completely self-contained with instrumentation for measuring shear stress and strain incorporated with the shear head and drive in a wheeled carrier that can be handled by one man. At a test site the equipment is levelled and the shear annulus jacked into the ground. Side shields around the annulus are withdrawn automatically before a test so that there is no friction component between the sides of the annulus and the soil. A shear stress/strain curve is recorded automatically as a test proceeds and the peak shear stress is indicated on a digital readout. The annulus is cleared of soil automatically at the end of a test so that the equipment is ready for the next test.

The shear meter has been compared with other shear annulus equipment in the field, and has been found to give similar results. The time taken for a test however is considerably reduced and the meter is much more convenient to use.
Fig. 1. Field shear equipment. A - annulus and shield in ground
B - loading lever
C - torque transducer
D - mechanism for withdrawing shields
E - reduction gear box and manual drive
F - shear angle transducer
G - instrumentation and recorder
H - lift handles
I - support legs
J - transport wheel

References


11. TILLAGE AND FERTILIZING IN INTENSIVE CROP PRODUCTION
EFFECT OF TILLAGE DEPTH AND FERTILIZATION ON THE YIELD OF WINTER WHEAT AND SOME WATER-PHYSICAL PROPERTIES OF HEAVY SOILS

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Dr. Boriša Spasojević, Dr. Svetimir Dragović,
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ABSTRACT

We studied the effect of different tillage depths, from disk harrowing to the plowing at 45 cm, and the level of mineral fertilization on the yield of winter wheat and physical properties of hydromorphic smonitsa soil of poor physical, water-air, and thermic characteristics.

It was concluded that the differences in the depth of basic tillage did not affect the yields of wheat.

The higher dose of NPK nutrients brought highest wheat yields in all variants of tillage depth. The differences in relation to the control and the lower dose of NPK were highly significant.

The analysis of water-physical properties of the soil showed that the plowing at 45 cm and the subsoiling in combination with plowing did not bring significant changes in the values of the volumic weight of the soil in relation to shallow tillage.

INTRODUCTION

Hydromorphic smonitsa soil has very unfavorable physical properties: heavy mechanical composition, low effective porosity, high compaction and mechanical resistance, and poor water permeability. Its water-air and thermic properties are equally unfavorable. Hydromorphic smonitsa soils have very short optimum dates of tillage and they are classified accordingly into "minute soils". The basic objective of the cultivation of these soils is a lasting improvement of the unfavorable properties which diverge considerably from the optimum values (Molnar et al., 1977). However, this objective cannot be achieved by conventional tillage but by resorting to ameliorative, i.e., agrotechnical and hydrotechnical practices.
METHOD

In an attempt to solve the problems of tillage depth and fertilization for heavy soils and their effects on wheat yields, we established an experiment in fall 1977 in one locality in Vojvodina, on hydromorphic amonita soil. The experiment was stationary and it lasted for three years. The experiment included the following variants:

a) Tillage: 1. disk harrowing, 2. plowing at 15 cm, 3. plowing at 30 cm, 4. plowing at 45 cm (stratified, in two turns), 5. subsoiling at 45 cm combined with plowing at 30 cm.

b) Fertilization: 1. control, 2. medium dose of fertilizers (120:80:40 kg/ha of NPK), 3. high dose (140:100:60 kg/ha of NPK).

The preceding crops for wheat were soybean in 1977, silo corn in 1978 and 1979.

According to its mechanical composition, the soil belonged to heavy clays. The mineral fertilizers were distributed in the following manner: with the disk harrowing and the plowing at 15, 30, and 30+15 cm, total P and K fertilizers and one third of N fertilizers were used. With the plowing at 45 cm, one half of P and K fertilizers was applied before the first plowing, another half of P and K and one third of N before the second plowing. The remaining portion of N fertilizer was used for top-dressing, at the end of winter, before the beginning of the vegetative season.

Water-physical properties were conducted before the establishment of the experiment, i.e., before plowing, and after the wheat harvest in the third year. Conventional analytical methods were used to examine samples of undisturbed soil taken by 100 cm³ cylinders.

WEATHER CONDITIONS

1977/78 was unfavorable for wheat production. There was a period of drought in October. Winter was long and cold. Cool and humid spring, with late frosts in April and May, protracted considerably wheat vegetation to the stage of heading which was 14-15 days later in relation to the previous year. A few hot days in June accelerated to an extent the maturation of early wheat varieties.

1978/79 was unfavorable from planting to harvest. An extreme drought in October and November, when there were only 8 mm of rain, caused poor and non-uniform germination and emergence and a low percentage of emerged plants. Low temperatures in December, January, and the second half of February brought further reductions of wheat stand.
Moisture deficiency occurred again from February and it became pronounced in April and May, during the intensive growth and heading of wheat. Furthermore, medium daily and maximum air temperatures (20 times over 30°C) started to grow abruptly in mid-May, during the stage of flowering. Moisture deficiency occurred again between heading and wax maturity. It was combined with an uncommonly low air humidity which precipitated wheat maturation. The harvest started as early as June 25, 1979. The combination of unfavorable effects brought absolutely lowest wheat yields both in the experiment and the commercial production.

In 1979/80, fall and winter were favorable for wheat growth and development. However, the rainfall in the period from March to the end of the vegetative season of wheat was above the long-term average. The consequences were excess moisture and extensive swamping on heavy and low soils. Since the experimental plot was not exposed to water excess, the yields of wheat were higher to significantly higher than those obtained in the previous two years.

RESULTS AND DISCUSSION

Table 1 shows the effects of tillage depth and doses of NPK nutrients on the yields of wheat.

In 1978, the variants of shallow tillage, i.e., disk harrowing and plowing at 15 cm, brought somewhat higher yields than the variants of deep tillage. The differences were not statistically significant except between the variants of plowing at 30 cm and 15 cm. Fertilization brought considerable increases in wheat yields, both on the average and per individual variants. Highest yields were secured by the highest dose of NPK nutrients with the probability of over 99%.

In 1979, there were no differences in the average wheat yields among the variants of tillage. Furthermore, no differences were observed within the variants of fertilization. However, fertilization had a higher effect on wheat yield than tillage depth in that year too. Within the variants of tillage, the medium dose of NPK nutrients brought considerably higher yields than the control whereas the higher dose brought considerably higher yields than the medium dose.

In 1980, shallow tillage (disk harrowing and plowing at 15 cm) brought significantly higher wheat yields than deep tillage. However, the reason for it were low LSD differences; otherwise, the differences would not exist. Fertilization was even more effective than in
the previous two years. The high dose of NPK nutrients rendered significantly higher wheat yields than the medium dose.

Considering the data for all three years, we could see that the variants of disk harrowing and plowing at 15 cm had slightly higher wheat yields than the variants of plowing at 30, 45 and 30+15 cm. The reduced tillage, therefore, secured an economically more profitable production requiring lower investments in labor and energy.

Similar results were reported by Stojanović (1981), Konstantinović (1980), and Holmar (1981). Our results are identical with those of Holnar (1981) who, conducting an experiment on heavy hydroorphic black soil, at the same time and under the same climatic conditions, obtained the same results as ours for the shallow tillage (disk harrowing and plowing at 15 cm) as well as for the deep tillage (plowing at 30 and 45 cm). According to the results of Konstantinović (1980), obtained in an experiment conducted on chernozem soil, there were no significant differences in wheat yields among the variants of tillage from disk harrowing to the plowing at 45 cm.

Simultaneously with the study on the effect of tillage depth on the yields of wheat, we studied changes in the water-physical properties of the soil. Since we dealt here with the soil of a heavy mechanical composition, poor and unstable structure, we turned our attention to only those properties which we expected to show reaction to the tillage practice in a short period of time. This paper includes only a portion of these results (Table 2).

The values of volumic weight and total porosity were not improved considerably by deepening the plowing layer. On the contrary, the variant of disk harrowing had a lower volumic weight and a higher total porosity, on account of a lower soil compaction caused by agricultural implements, than the variants of conventional tillage, especially in the soil layers of 15-30 cm and 30-45 cm. In the variant of plowing at 45 cm, the values of volumic weight in the surface layers (0-15 cm and 15-30 cm) were lower than in the other variants of tillage. This may be explained rather as the result of turning up lighter materials from deeper layers than as the result of soil tillage itself because the same phenomenon was not encountered in the variant of tillage at 30 cm.
Tab.1 - Effect of tillage depth and fertilization on the yield of wheat (t/ha)

<table>
<thead>
<tr>
<th>Year</th>
<th>Fertilization (B)</th>
<th>Tillage (A)</th>
<th>Average for fertilization (B)</th>
<th>LSD</th>
<th>LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control (NPK1)</td>
<td>Disk harrowing at 15 cm</td>
<td>Subsoiling at 45 cm + plowing at 30 cm</td>
<td>2.97</td>
<td>A 0.08 0.11</td>
</tr>
<tr>
<td>1978</td>
<td>(NPK2)</td>
<td>6.04 6.14 6.00 6.03 6.09</td>
<td></td>
<td>5.77++ B 0.06 0.08</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average for tillage (A)</td>
<td>4.93 4.98+ 4.89- 4.92 4.94</td>
<td></td>
<td>4.93</td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td>Control (NPK1)</td>
<td>2.55 2.55 2.55 2.56 2.56</td>
<td></td>
<td>2.55− A 0.05 0.06</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(NPK2)</td>
<td>4.02 4.03 4.05 4.04 4.03</td>
<td></td>
<td>4.03++ AB 0.07 0.10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average for tillage (A)</td>
<td>3.42 3.42 3.43 3.43 3.42</td>
<td></td>
<td>3.42</td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td>Control (NPK1)</td>
<td>3.30 3.27 3.25 3.22 3.20</td>
<td></td>
<td>3.25− A 0.02 0.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(NPK2)</td>
<td>7.02 7.03 7.00 7.01 7.00</td>
<td></td>
<td>7.01++ AB 0.04 0.06</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average for tillage (A)</td>
<td>5.45+ 5.43+ 5.41− 5.41− 5.40−</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The rate of water permeability was positively affected by the deepening of the plowing layer. In the variants of plowing at 45 cm and subsoiling at 45 cm plus plowing at 30 cm, the rate of water permeability was increased in relation to the variants of shallow tillage both in the analyzed soil layers and the entire soil profile. The variant of disk harrowing, which had most favorable values of volumetric weight and total porosity, had the least favorable rate of water permeability. This is characteristic for heavy soils unstable structure in which the improvement in some physical properties lasts for a short time.

In an earlier study on the correlations between some physical and some water properties of soil, Dragović et al. (1972) found these properties to depend mainly on the contents of silt and clay. Regarding the rate of water permeability, Erhov et al. (1975) classified the agrotechnical condition of soil and the resistance of structural aggregates as the most important factors.
### Tab.2: Effect of tillage depth on the changes of some water-physical properties of the soil

<table>
<thead>
<tr>
<th>Tillage depth</th>
<th>Sampling depth, cm</th>
<th>Volumic weight, g/cm³</th>
<th>Total porosity, %</th>
<th>Rate of water permeability, cm/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before the experiment</td>
<td>o-15</td>
<td>1.38</td>
<td>48.9</td>
<td>3.9 x 10⁻²</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>1.36</td>
<td>49.6</td>
<td>2.8 x 10⁻²</td>
</tr>
<tr>
<td></td>
<td>30-45</td>
<td>1.52</td>
<td>44.9</td>
<td>8.5 x 10⁻²</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>1.42</td>
<td>47.8</td>
<td>1.3 x 10⁻²</td>
</tr>
<tr>
<td>Disk harrowing</td>
<td>o-15</td>
<td>1.44</td>
<td>46.5</td>
<td>3.9 x 10⁻²</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>1.35</td>
<td>50.8</td>
<td>2.6 x 10⁻²</td>
</tr>
<tr>
<td></td>
<td>30-45</td>
<td>1.32</td>
<td>51.8</td>
<td>3.1 x 10⁻²</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>1.37</td>
<td>49.3</td>
<td>2.2 x 10⁻²</td>
</tr>
<tr>
<td>Plowing at 15 cm</td>
<td>o-15</td>
<td>1.41</td>
<td>47.6</td>
<td>4.6 x 10⁻²</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>1.43</td>
<td>47.6</td>
<td>2.1 x 10⁻²</td>
</tr>
<tr>
<td></td>
<td>30-45</td>
<td>1.56</td>
<td>43.2</td>
<td>1.7 x 10⁻²</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>1.46</td>
<td>45.8</td>
<td>8.9 x 10⁻³</td>
</tr>
<tr>
<td>Plowing at 30 cm</td>
<td>o-15</td>
<td>1.47</td>
<td>45.3</td>
<td>1.3 x 10⁻²</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>1.39</td>
<td>48.3</td>
<td>2.6 x 10⁻²</td>
</tr>
<tr>
<td></td>
<td>30-45</td>
<td>1.45</td>
<td>47.8</td>
<td>2.9 x 10⁻²</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>1.43</td>
<td>47.2</td>
<td>2.6 x 10⁻²</td>
</tr>
<tr>
<td>Plowing at 45 cm</td>
<td>o-15</td>
<td>1.38</td>
<td>48.9</td>
<td>1.1 x 10⁻³</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>1.36</td>
<td>49.6</td>
<td>2.8 x 10⁻³</td>
</tr>
<tr>
<td></td>
<td>30-45</td>
<td>1.51</td>
<td>44.9</td>
<td>8.9 x 10⁻³</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>1.43</td>
<td>47.8</td>
<td>1.6 x 10⁻²</td>
</tr>
<tr>
<td>Subsoiling at 45 cm + plowing at 30 cm</td>
<td>o-15</td>
<td>1.46</td>
<td>45.9</td>
<td>6.3 x 10⁻⁴</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>1.45</td>
<td>46.2</td>
<td>7.3 x 10⁻⁴</td>
</tr>
<tr>
<td></td>
<td>30-45</td>
<td>1.55</td>
<td>44.8</td>
<td>2.3 x 10⁻⁴</td>
</tr>
<tr>
<td></td>
<td>50 cm</td>
<td>Average</td>
<td>1.49</td>
<td>45.7</td>
</tr>
</tbody>
</table>

### Literature Cited


SCANDINAVIAN PRINCIPLES FOR FERTILIZER PLACEMENT.

UTILIZATION OF FERTILIZER-N.

Ake Huhtapalo
Department of Soil Sciences, Swedish University of Agricultural Sciences,  S-750 07 UPPSALA, Sweden.

ABSTRACT

Rationalization and effectivisation in crop production often means that compromises must be made between the biological requirements of crops and the technical demands. A discussion is given of the utilization of fertilizer-N in spring cereals. The results originate from three different series of experiments conducted in eastern parts of central Sweden during 1963-1981. Comparisons were made between fertilizer placement and broadcasting (harrowed in before sowing).

At placement, the fertilizer is normally placed deeper than the seed. This implies that the tillage action of the fertilizer coulters may negatively influence germination conditions and crop development. The experimental results thus illustrate the biological effect of fertilization, including the tillage effect of the coulters on production.

INTRODUCTION

In cooperation with the Department of Agricultural Engineering and Rationalization a new technique for fertilizing and sowing - combi-drilling - was developed in the late 1960's. The method implies that the fertilizer is placed in the MIDDLE of ALTERNATE ROW SPACES and some centimeters deeper than the seed.

Following the results of our initial experiments, combi-drills are now made by seven Scandinavian machinery manufacturers.

When fertilizer placement gives higher yields than broadcasting, this may depend on at least two causes:

1. The placement effect

   a) The dominating reason for fertilizer placement giving a more reliable yield than broadcasting is that the fertilizer is placed in "untilled" moist soil under the loose seedbed. Below the seedbed there is generally water enough for the nutrient uptake to continue even during longer periods of drought.
b) The distance between the rows of fertilizer and the rows of seed is also of importance. The most reliable methods are to place the fertilizer 3-6 cm to the side and 3-6 cm below EACH ROW of SEED, or in the MIDDLE of ALTERNATE ROW SPACES 3-6 cm deeper than the seed (Figs. 1A and 2A). This applies up to at least 12-13 cm row spacing (probably also to band sowing with unchanged coulter spacing and seed rates).

2. The concentration effect

a) When the fertilizer is concentrated in rows, less soil and fewer microorganisms will come into immediate contact with the fertilizer pellets - immobilization is delayed.

b) When water moves in the soil a smaller amount directly influences the fertilizer when concentrated in rows than when it is broadcast.

Fig. 1.

UTILIZATION OF FERTILIZER-N

Successful broadcast fertilization and good nitrogen effect will result in about 70% of the supplied fertilizer-N reaching the cereal crop. Half of this amount (35%) should be recovered in the grain and the rest in straw, stubble and roots (Jansson, 1966).

Combi-drilling can give considerably higher yields of spring sown crops than broadcasting (Figs. 1A, 2A and 3A).

Figs. 1B, 2B and 3B show the amount of nitrogen in the grain. Broadcasting of 119 kg N/ha in the experiments (Fig. 1) increased the grain yield by 810 kg/ha and the amount of N in the grain by 23 kg/ha which corresponds to 19% of the fertilizer-N. Optimum placement gave yield increases of 1280 kg/ha and 34 kg N/ha, which corre-
Comparison of effects when the fertilizer was BROADCAST (I), placed in EACH ROW SPACE (II) and placed in ALTERNATE ROW SPACES (III). Means of 19 experiments in spring cereals, 1967-1970. N-rate on average, 103 kg N/ha.

Broadcasting gave a fertilizer-N utilization of 26%, placement in each row space 33% and placement in alternate row spaces 39% utilization of the 103 kg N/ha supplied. In intensity trials presented in Fig. 3, broadcasting of 60, 120 and 180 kg N/ha increased the yields by 980 kg grain/ha (19 kg N), 1370 kg (33 kg N), and 1530 kg (41 kg N). Corresponding values for combi-drilling (placement in alternate row spaces) were 1310 (25 kg N), 1740 (43 kg N) and 1740 (51 kg N). 120 kg N/ha broadcast only increased the yield by 60 kg/ha more than combi-fertilizing with 60 kg N/ha. 120 kg N/ha with the combi-drill gave, however, 370 kg larger yield than the same amount of N when broadcast.
If it is assumed that similar proportions of the fertilizer-N are recovered in straw, stubble and roots as in the grain, this implies that when broadcasting 60, 120 and 180 kg N/ha the crop has taken up 64, 54 and 46% respectively. A combi-drilled crop has utilized 82, 72 and 56% respectively of the supplied fertilizer N.

Combi-drilling always gives early and uniform fertilizer effect which noticeably stimulates the vegetative development at the start of the growing period. In trials it can often be observed in early summer that a combi-drilled crop is more vigorous than a corresponding broadcast crop. Measurements of crop height have shown that these differences can remain until harvest, which might cause differences in the distribution of fertilizer-N between the grain and the straw, stubble and roots depending on the method of application.

TILLAGE EFFECT OF FERTILIZER COULTERS

The task of the fertilizer coulters now used in practice is to place the fertilizer in the middle of alternate row spaces, at least 3 cm deeper than the seed. On Swedish clay soils, a firm bottom is formed when harrowing. The fertilizer coulters rip up the bottom so that the conditions for seed germination might be influenced.

An investigation has been conducted to study how the tillage effect of the fertilizer coulters influences crop development and yield. We did not intend to find out how a fertilizer coulter should be designed, just simply to compare the effects of four standard coulters for different combi-drills and a special coulter. All the coulters were tested on the same combi-drill in order to achieve similar conditions regarding the delivered quantity and distribution of fertilizer and seed. The coulters were used at only one working depth, about 4 cm deeper than the 5 cm harrowing depth. The trials were carried out on soils with clay contents ranging from 20-50%.

Fig. 4.

The working part of the coulters on a Scandinavian combi-drill.
Table 1 contains details of the coulters used: the make, the width of the tip, the width 4 cm above the tip, the design of the front edge, and the rake angle of the lower part of the coulter (when stationary, and approx. working angle). The tillage effect was studied without fertilizer. The fertilizing effect + the tillage effect was studied at one rate of fertilizer application.

Tab. 1. Combi-drilling - Tillage effect of fertilizer coulters. Data on the coulters studied. All coulters were s-tine types.

<table>
<thead>
<tr>
<th>Coulter Make</th>
<th>Tip width mm</th>
<th>Width, 4 cm above the tip mm</th>
<th>Profile of front edge</th>
<th>Rake angle ( \alpha ) Stationary ( \leq 70 )</th>
<th>At work ( \leq 60 )</th>
<th>Direction of travel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Nordsten</td>
<td>22</td>
<td>28</td>
<td>35</td>
<td>75</td>
<td>100</td>
<td>( \alpha )</td>
</tr>
<tr>
<td>2. Special</td>
<td>17</td>
<td>17</td>
<td>28</td>
<td>50</td>
<td>60</td>
<td>( \alpha )</td>
</tr>
<tr>
<td>3. Tume, before 1980</td>
<td>20</td>
<td>20</td>
<td>24</td>
<td>65</td>
<td>75</td>
<td>( \alpha )</td>
</tr>
<tr>
<td>4. Tume, 1981</td>
<td>20</td>
<td>20</td>
<td>24</td>
<td>65</td>
<td>75</td>
<td>( \alpha )</td>
</tr>
<tr>
<td>5. Juko</td>
<td>17</td>
<td>17</td>
<td>28</td>
<td>50</td>
<td>60</td>
<td>( \alpha )</td>
</tr>
</tbody>
</table>

Results of the trials are given in Table 2. It can be seen that all types of coulters can influence sowing depth, crop establishment (plant counts early and finally) and that they may reduce the yield by one or two percent.


<table>
<thead>
<tr>
<th>Coulter Make</th>
<th>Fertilization kg N/ha</th>
<th>Yield kg/ha</th>
<th>Sowing depth cm</th>
<th>Plants/m² Early</th>
<th>Finally</th>
<th>N in grain kg N/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Broadcast&quot;</td>
<td>-</td>
<td>3970</td>
<td>4,0</td>
<td>207</td>
<td>412</td>
<td>70</td>
</tr>
<tr>
<td>Nordsten</td>
<td>-</td>
<td>3940</td>
<td>4,1</td>
<td>193</td>
<td>431</td>
<td>70</td>
</tr>
<tr>
<td>Special</td>
<td>-</td>
<td>3950</td>
<td>4,2</td>
<td>204</td>
<td>426</td>
<td>69</td>
</tr>
<tr>
<td>Tume, before 1980</td>
<td>-</td>
<td>3910</td>
<td>4,2</td>
<td>198</td>
<td>443</td>
<td>69</td>
</tr>
<tr>
<td>Tume, 1981</td>
<td>-</td>
<td>3940</td>
<td>4,6</td>
<td>213</td>
<td>436</td>
<td>69</td>
</tr>
<tr>
<td>Juko</td>
<td>-</td>
<td>3880</td>
<td>4,4</td>
<td>210</td>
<td>463</td>
<td>68</td>
</tr>
<tr>
<td>Broadcast</td>
<td>86</td>
<td>4370</td>
<td>3,6</td>
<td>248</td>
<td>428</td>
<td>80</td>
</tr>
<tr>
<td>Nordsten</td>
<td>86</td>
<td>4540</td>
<td>4,0</td>
<td>248</td>
<td>428</td>
<td>84</td>
</tr>
<tr>
<td>Special</td>
<td>86</td>
<td>4620</td>
<td>4,0</td>
<td>248</td>
<td>428</td>
<td>87</td>
</tr>
<tr>
<td>Tume, before 1980</td>
<td>86</td>
<td>4530</td>
<td>4,2</td>
<td>248</td>
<td>428</td>
<td>86</td>
</tr>
<tr>
<td>Tume 1981</td>
<td>86</td>
<td>4590</td>
<td>4,4</td>
<td>248</td>
<td>428</td>
<td>87</td>
</tr>
<tr>
<td>Juko</td>
<td>86</td>
<td>4540</td>
<td>4,6</td>
<td>248</td>
<td>428</td>
<td>87</td>
</tr>
</tbody>
</table>

The fertilizer effect was, however, considerably better with all types of coulters when placements was used.

The coulters, 20 mm or wider, always disturbed an area from the edge of the coulter tip and about 45° diagonally outwards and upwards in addition to the coulter's own width (Fig. 4, within the area enclosed by the broken line). The special coulter apparently tilled the soil only slightly outside its own width.

The Juko coulter partly worked in the same way as the special coulter, but most-
ly as the wider coulters. All the standard coulters used brought up to the surface moist clods from the "untilled" bottom, but never the special one.

CONCLUSIONS

Combi-drilling of spring-sown crops gives considerably better fertilizer effect than broadcasting (harrowed in before sowing) in most places in Sweden. Fertilizer placement gives a more effective utilization of the supplied fertilizer-N. In the three series of experiments reported here the crops with fertilizer placement have taken up 24-48% more fertilizer-N than crops grown with broadcast N supply.

As a crop with fertilizer placement utilizes a larger part of the supplied fertilizer-N, compared with broadcasting, a smaller amount might find its way into the environment.

Placement in alternate row spaces is a good compromise between biology and technology. However, it can not be excluded that placement in each row space, closer than 6 cm to the rows of seed, might give a slightly better fertilizer effect. Problems with seed placement and thus crop establishment due to the tillage effect of the fertilizer coulters are more difficult to avoid the closer the fertilizer is placed to the rows of seed.

In order to avoid negative effects of the fertilizer coulters to the greatest possible extent, the lower part of the coulter should be narrower than 17 mm with a rake angle when working of approx. 90°, and with a sharp front edge.

LITERATURE


Abstract

We investigated the effect of the time of fertilizer application and seedbed preparation on maize yield on chernozem type of soil in a field trial in 1974-1977.

Results of four years of investigation showed that in a semi-arid climate higher amounts of nitrogen (up to 300 kg/ha) on chernozem type of soil do not always give significantly justified differences in yield. There was no difference in yield when the total amount of fertilizers was applied in the fall with primary tillage compared to applying fertilizers using the standard method.

Seedbed preparation can also be carried out in the spring without danger of reducing the yield.

Introduction

The wide range of different types and subtypes of soil in Yugoslavia as well as the diversity of agroecological conditions for growing maize indicate that factors such as fertilizer and fertilizer application must be viewed regionally or even locally.

According to some authors, the increase in maize yield is mostly attributed to fertilizers (Stojković, 1972; Barna, 1972; Božić and Milojić, 1977; Tomas et al. 1980, and others). The time and mode of fertilizer application, primarily complex fertilizers, was investigated by many authors (Milić et al. 1974; Drezgić et al. 1974; Milojić et al. 1971; 1975; Jekić et al. 1974; Jovanović, 1973; Popović et al. 1974, and others).

Recently, and particularly since the energy crisis, the trend is to rationalize and economize fertilizer application by reducing the number of operations to a minimum, two or possibly one, when the total amount of fertilizers is incorporated into the soil.

There are trial results to this effect showing possibilities in applying fertilizers in such a manner (Mihalić et al.

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- 675 -
The aim of our investigations was to establish whether there is any difference in maize yield between the standard method of fertilizer application and seedbed preparation in the spring, and incorporation of the whole fertilizer amount once during primary tillage and seedbed preparation in the fall.

Material and Method

Investigations were conducted during 1974-1977 on the trial field of the Maize Research Institute in Zemun Polje on a chernozem type of soil. On the basis of agrochemical analyses, the arable soil layer contained: 0.14-0.19% N, 3.72-6.15 mg P$_{205}$ and 19.20-22.30 mg K$_{20}$ per 100 g of soil. The trial was set up according to the split-split plot design in three replications on an area of 19,323 m$^2$.

The plot was divided in two equal parts. On one part (treatment A) fertilization was carried out in the fall with primary tillage and seedbed preparation. The nitrogen fertilizer urea also applied in the fall with primary tillage. On the other part of the plot (treatment B) the same fertilizer treatment was investigated, except that the time of application was as follows: 1/3 of P and K were applied in the fall with primary tillage and 1/3 P and K and 2/3 of N were applied before planting. The remaining 1/3 of N was used for side-dressing of plants in the 6-7 leaf stage. The nitrogen applied in this way was in the nitrate form (KAN). This part of the plot was conventionally tilled: after harvesting wheat (the preceding crop in all years of investigation was wheat), the stuble was plowed under to 10-15 cm. In October, primary tillage was carried out to a depth of approximately 30 cm. In the spring, March-April (depending on meteorologic conditions) seedbed preparation was conducted with the rau-combi system.

The following treatments and amounts of fertilizer (kg/ha) were investigated:

<table>
<thead>
<tr>
<th></th>
<th>N$_{0}$</th>
<th>N$_{100}$</th>
<th>N$_{200}$</th>
<th>N$_{300}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>P$<em>{100}$ K$</em>{50}$</td>
<td>P$<em>{100}$ K$</em>{50}$</td>
<td>P$<em>{100}$ K$</em>{50}$</td>
<td>P$<em>{100}$ K$</em>{50}$</td>
</tr>
<tr>
<td>2.</td>
<td>P$<em>{200}$ K$</em>{50}$</td>
<td>P$<em>{200}$ K$</em>{50}$</td>
<td>P$<em>{200}$ K$</em>{50}$</td>
<td>P$<em>{200}$ K$</em>{50}$</td>
</tr>
<tr>
<td>3.</td>
<td>P$<em>{100}$ K$</em>{90}$</td>
<td>P$<em>{100}$ K$</em>{90}$</td>
<td>P$<em>{100}$ K$</em>{90}$</td>
<td>P$<em>{100}$ K$</em>{90}$</td>
</tr>
<tr>
<td>4.</td>
<td>P$<em>{200}$ K$</em>{90}$</td>
<td>P$<em>{200}$ K$</em>{90}$</td>
<td>P$<em>{200}$ K$</em>{90}$</td>
<td>P$<em>{200}$ K$</em>{90}$</td>
</tr>
<tr>
<td>5.</td>
<td>P$<em>{100}$ K$</em>{135}$</td>
<td>P$<em>{100}$ K$</em>{135}$</td>
<td>P$<em>{100}$ K$</em>{135}$</td>
<td>P$<em>{100}$ K$</em>{135}$</td>
</tr>
<tr>
<td>6.</td>
<td>P$<em>{200}$ K$</em>{135}$</td>
<td>P$<em>{200}$ K$</em>{135}$</td>
<td>P$<em>{200}$ K$</em>{135}$</td>
<td>P$<em>{200}$ K$</em>{135}$</td>
</tr>
</tbody>
</table>
The hybrid ZPSC 1A was investigated in three plant densities:
1. $D_1 = 30,300$ plants/ha ($75 \times 44$ cm + 1 plant/hill)
2. $D_2 = 38,100$ plants/ha ($75 \times 35$ cm + 1 plant/hill)
3. $D_3 = 45,900$ plants/ha ($75 \times 29$ cm + 1 plant/hill)

Yield was calculated using the factorial analysis of variance.

Meteorological conditions

Mean monthly temperatures and rainfall during the maize growing season for the years of investigation are given in Table 1.

Table 1. Mean monthly temperature and precipitation during the growing seasons 1974-1977.

<table>
<thead>
<tr>
<th>Month</th>
<th>1974</th>
<th>1975</th>
<th>1976</th>
<th>1977</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV</td>
<td>10.2</td>
<td>11.3</td>
<td>11.4</td>
<td>10.4</td>
</tr>
<tr>
<td>V</td>
<td>14.7</td>
<td>17.7</td>
<td>15.9</td>
<td>17.4</td>
</tr>
<tr>
<td>VI</td>
<td>18.2</td>
<td>19.0</td>
<td>18.1</td>
<td>19.6</td>
</tr>
<tr>
<td>VII</td>
<td>20.5</td>
<td>20.9</td>
<td>21.3</td>
<td>20.9</td>
</tr>
<tr>
<td>VIII</td>
<td>22.3</td>
<td>19.8</td>
<td>18.3</td>
<td>19.9</td>
</tr>
<tr>
<td>IX</td>
<td>18.0</td>
<td>18.9</td>
<td>16.5</td>
<td>15.1</td>
</tr>
<tr>
<td>Average</td>
<td>17.3</td>
<td>17.9</td>
<td>16.9</td>
<td>17.2</td>
</tr>
<tr>
<td>IV</td>
<td>45.7</td>
<td>30.1</td>
<td>52.4</td>
<td>75.2</td>
</tr>
<tr>
<td>V</td>
<td>87.1</td>
<td>89.9</td>
<td>20.0</td>
<td>33.4</td>
</tr>
<tr>
<td>VI</td>
<td>77.5</td>
<td>111.7</td>
<td>60.5</td>
<td>40.8</td>
</tr>
<tr>
<td>VII</td>
<td>36.2</td>
<td>129.3</td>
<td>24.5</td>
<td>58.6</td>
</tr>
<tr>
<td>VIII</td>
<td>38.7</td>
<td>166.4</td>
<td>43.4</td>
<td>85.4</td>
</tr>
<tr>
<td>IX</td>
<td>109.8</td>
<td>66.4</td>
<td>63.2</td>
<td>66.6</td>
</tr>
<tr>
<td>Sum</td>
<td>395.0</td>
<td>593.8</td>
<td>264.0</td>
<td>360.0</td>
</tr>
</tbody>
</table>

Although there was only 264.0 mm of precipitation in 1976, due to a reduced evapotranspiration particularly in July and August, this year was not counted as a poor production year (see yield results). During 1975, there was too much precipitation in some months (August 166.4 mm).

Results and Discussion

Results of yields are given in Table 2, 3 and 4.
Table 2. Effect of seedbed preparation and application of nitrogen on maize yield (t/ha)

A. Seedbed preparation and nitrogen application in the fall

<table>
<thead>
<tr>
<th>Year</th>
<th>N₀</th>
<th>N₁₀₀</th>
<th>N₂₀₀</th>
<th>N₃₀₀</th>
<th>Average</th>
<th>LSD 5%</th>
<th>LSD 1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>10.44</td>
<td>9.88</td>
<td>9.94</td>
<td>10.48</td>
<td>10.19</td>
<td>0.25</td>
<td>0.33</td>
</tr>
<tr>
<td>1976</td>
<td>10.41</td>
<td>10.40</td>
<td>10.55</td>
<td>10.56</td>
<td>10.48</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>1977</td>
<td>10.16</td>
<td>11.05</td>
<td>11.25</td>
<td>10.93</td>
<td>10.85</td>
<td>0.21</td>
<td>0.29</td>
</tr>
<tr>
<td>Average</td>
<td>10.24</td>
<td>10.28</td>
<td>10.37</td>
<td>10.49</td>
<td>10.35</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

B. Seedbed preparation in the spring, standard nitrogen application

<table>
<thead>
<tr>
<th>Year</th>
<th>N₀</th>
<th>N₁₀₀</th>
<th>N₂₀₀</th>
<th>N₃₀₀</th>
<th>Average</th>
<th>LSD 5%</th>
<th>LSD 1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>10.84</td>
<td>10.25</td>
<td>10.38</td>
<td>10.92</td>
<td>10.59</td>
<td>0.26</td>
<td>0.35</td>
</tr>
<tr>
<td>1976</td>
<td>10.30</td>
<td>10.43</td>
<td>10.49</td>
<td>10.44</td>
<td>10.41</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>1977</td>
<td>9.74</td>
<td>10.42</td>
<td>10.55</td>
<td>10.38</td>
<td>10.27</td>
<td>0.23</td>
<td>0.31</td>
</tr>
<tr>
<td>Average</td>
<td>10.22</td>
<td>10.25</td>
<td>10.37</td>
<td>10.42</td>
<td>10.31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>10.23</td>
<td>10.27</td>
<td>10.37</td>
<td>10.45</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2 shows that there was no difference in yield on the average for four years (10.35 and 10.31 t/ha) with seedbed preparation and nitrogen (urea) application in the fall and standard seedbed preparation and nitrogen application.

Higher amounts of nitrogen increased yields, but not significantly in all years (Table 2A and B, 1974 and 1976). Yield was obviously affected by meteorological conditions in individual years.

Janković et al. (1974) investigated on sandy carbonate soil the effect of various amounts of nitrogen (90-180 kg/ha) on yield. They found that differences in yield were small and that the best ratio of NPK for this type of soil was 1.0:0.5:1.7.

Barna (1972) found that nitrogen highly affected yield on chernozem type of soil in south-east Bačka. Phosphorus had only a tracing role especially in drought years. Mihalić et al. (1980) established that the highest maize yield on pseudoglei soil was obtained when nitrogen was applied in the fall and for side-dressing. On pseudoglei soil Kolčar (1971) obtained a higher yield by applying a higher amount of nitrogen. Even with the highest amount of nitrogen (180 kg/ha), the yield was lower than with the NPK treatment.

Statistically significant differences in yield were found between fertilization in the fall and seedbed preparation (treatment A), while using the standard method (treatment B) statistically justified difference were not found (table 3).
This leads to the conclusion that maize production on chernozem type of soil in a semi-arid climate can be profitable if the total amount of fertilizer is applied and seedbed preparation carried out in the fall.

Milojić et al. (1975), Milić et al. (1974), Drezgić et al. (1974), Popović et al. (1974), Marković et al. (1974) and others also reported that the efficiency of complex fertilizers is highest when these are applied in the fall or in some other way and time and that differences in yield are statistically non-significant. Jovanović (1967) reported higher maize grain yields on chernozem soil when the fertilizer was applied deeper in the soil in the fall.

Table 3. Effect of seedbed preparation and application of NPK fertilizer on maize yield (t/ha)

<table>
<thead>
<tr>
<th>Treatment A</th>
<th>N₀</th>
<th>N₁₀₀</th>
<th>N₂₀₀</th>
<th>N₃₀₀</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>P₁₀₀ K₅₀</td>
<td>10.30</td>
<td>10.12</td>
<td>10.41</td>
<td>10.55</td>
<td>10.34</td>
</tr>
<tr>
<td>P₂₀₀ K₅₀</td>
<td>10.07</td>
<td>10.16</td>
<td>10.56</td>
<td>10.63</td>
<td>10.35</td>
</tr>
<tr>
<td>P₁₀₀ K₉₀</td>
<td>9.92</td>
<td>10.13</td>
<td>10.17</td>
<td>10.37</td>
<td>10.15</td>
</tr>
<tr>
<td>P₂₀₀ K₉₀</td>
<td>9.96</td>
<td>10.18</td>
<td>10.26</td>
<td>10.32</td>
<td>10.18</td>
</tr>
<tr>
<td>P₁₀₀ K₁₃₅</td>
<td>10.32</td>
<td>10.50</td>
<td>10.39</td>
<td>10.72</td>
<td>10.48</td>
</tr>
<tr>
<td>P₂₀₀ K₁₃₅</td>
<td>10.36</td>
<td>10.38</td>
<td>10.65</td>
<td>10.40</td>
<td>10.45</td>
</tr>
<tr>
<td>Average</td>
<td>10.15</td>
<td>10.24</td>
<td>10.40</td>
<td>10.50</td>
<td>10.32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment B</th>
<th>N₀</th>
<th>N₁₀₀</th>
<th>N₂₀₀</th>
<th>N₃₀₀</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>P₁₀₀ K₅₀</td>
<td>10.13</td>
<td>10.18</td>
<td>10.18</td>
<td>10.36</td>
<td>10.21</td>
</tr>
<tr>
<td>P₂₀₀ K₅₀</td>
<td>10.17</td>
<td>10.38</td>
<td>10.33</td>
<td>10.29</td>
<td>10.29</td>
</tr>
<tr>
<td>P₁₀₀ K₉₀</td>
<td>10.06</td>
<td>10.10</td>
<td>10.68</td>
<td>10.22</td>
<td>10.26</td>
</tr>
<tr>
<td>P₂₀₀ K₉₀</td>
<td>10.24</td>
<td>10.33</td>
<td>10.33</td>
<td>10.44</td>
<td>10.33</td>
</tr>
<tr>
<td>P₁₀₀ K₁₃₅</td>
<td>10.25</td>
<td>10.10</td>
<td>10.18</td>
<td>10.62</td>
<td>10.29</td>
</tr>
<tr>
<td>P₂₀₀ K₁₃₅</td>
<td>10.38</td>
<td>10.25</td>
<td>10.56</td>
<td>10.50</td>
<td>10.42</td>
</tr>
<tr>
<td>Average</td>
<td>10.20</td>
<td>10.22</td>
<td>10.38</td>
<td>10.40</td>
<td>10.30</td>
</tr>
</tbody>
</table>

Treatment

LSD A B
5% 0.34 n.s.
1% 0.44 n.s.

The investigated factor plant density highly affected the yield and was statistically highly significant in all years of investigation (Table 4).
Table 4. Effect of plant density on the yield of hybrid maize
ZPSC 1A (t/ha)

<table>
<thead>
<tr>
<th>Treatment A</th>
<th>1974</th>
<th>1975</th>
<th>1976</th>
<th>1977</th>
<th>Average</th>
<th>Relative (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant density (plants/ha)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30.300</td>
<td>8.82</td>
<td>9.52</td>
<td>9.65</td>
<td>10.14</td>
<td>9.53</td>
<td>100.00</td>
</tr>
<tr>
<td>38.100</td>
<td>9.95</td>
<td>10.31</td>
<td>10.55</td>
<td>10.95</td>
<td>10.43</td>
<td>109.44</td>
</tr>
<tr>
<td>45.900</td>
<td>10.85</td>
<td>10.73</td>
<td>11.24</td>
<td>11.46</td>
<td>11.07</td>
<td>116.16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment B</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant density (plants/ha)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30.300</td>
<td>9.00</td>
<td>9.79</td>
<td>9.64</td>
<td>9.43</td>
<td>9.46</td>
<td>100.00</td>
</tr>
<tr>
<td>38.100</td>
<td>10.05</td>
<td>10.65</td>
<td>10.52</td>
<td>10.36</td>
<td>10.39</td>
<td>109.83</td>
</tr>
<tr>
<td>45.900</td>
<td>10.92</td>
<td>11.35</td>
<td>11.09</td>
<td>11.02</td>
<td>11.09</td>
<td>117.23</td>
</tr>
</tbody>
</table>

| LSD 5% | A 1.69 | 2.15 | 1.31 | 1.82 |
|        | B 1.57 | 2.28 | 1.42 | 2.02 |

| LSD 1% | A 2.23 | 2.84 | 1.73 | 2.38 |
|        | B 2.07 | 3.01 | 1.80 | 2.65 |

The average four-year yield shows that the yield both in treatment A and B increases with increasing plant density. In treatment A, the difference in yield between the lowest and highest plant density was 16.16%, while in treatment B this difference was 17.23%.

Conclusion

On chernozem type of soil in the semi-arid region, seedbed preparation can be completed in the fall, without a reduction in maize yield.

Higher amounts of fertilizers increase the yield, but not always within limits of statistically significant differences.

The total amount of PK fertilizers may be applied in the fall without a decrease in maize yield.

The total amount of nitrogen (urea) can be applied in the fall with primary tillage without a reduction in yield compared to the standard application of nitrogen nitrate (KAN).

The plant density is a very influential factor on yield. A single or standard application of fertilizers as well as the timing of seedbed preparation did not affect the yield.
References

Barna, Dj.: Norme NPK hraniva kod kukuruza na jednom delu Šajkaške. Agrohemija, br. 5-6, 175-186, 1972.


EFFECT OF FLOWING DOWN STRAW AND DIFFERENT AMOUNTS OF NITROGEN ON GRAIN YIELDS IN A THREE-CROP ROTATION WHEAT-CORN-SPRING BARLEY

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ABSTRACT

Effects of a periodical plowing down of straw and different amounts of nitrogen, on the yields of corn, spring barley, and wheat were examined in a stationary field trial. Wheat straw (5 t/ha) was plowed under once every three years. The analysis of variance was used to process the results of second and third rotation (1976-1980).

INTRODUCTION

Cereals straw and corn stalks are the byproducts that are most frequently plowed under in Vojvodina. Their C:N ratio is quite wide, rendering additional nitrogen fertilisation a compulsory practice aimed at the prevention of nitrogen depression (Menglel, 1976; Rajkovic, 1978).

There are numerous indications of positive effects of plowing under harvest residues on the yields of staple crops when grown on fertile soils (Mihalid et al., 1979; Marković et al., 1979). The effects were further enhanced by combining the plowing under of harvest residues with nitrogen fertilisation.

Contrarily to the previously employed procedures, we applied straw and additional nitrogen only once each three years in order to define direct effect of this practice on the crops grown immediately afterwards as well as the extended action of the practice in subsequent years.
METHOD

A stationary field trial was established on chernozem soil in 1971/72. Wheat, corn, and spring barley were rotated in the trial and 5 t/ha of wheat straw were added in one portion of the trial each three years.

The trial included also the following variants of nitrogen fertilization: 0, 90 and 160 kg/ha for wheat, 0, 100, and 180 kg/ha for corn, and 0, 40, and 80 kg/ha for spring barley. There was a total of six variants, three with and three without plowing under straw; 50 kg/ha of nitrogen were plowed down together with straw in the first three variants. All variants were fertilized also with 80 kg/ha of P₂O₅ and K₂O. The results discussed in this paper pertain to second and third rotation (1975-1980). They were processed by the analysis of variance, years of growing being taken as a factor.

RESULTS

The paper discusses the results obtained following the sequence of the crops after the plowing under of straw.

Corn yields varied in dependence of the examined treatments and weather conditions of the experimental years (Table 1).

On a long-term average, corn yields were significantly affected by nitrogen. Differences in relation to the controls (with and without straw) were highly significant. The plowing down of straw and additional nitrogen brought significant yield increases. The largest differences were registered between the controls - 1.2 t/ha, highly significant. The differences were lower in the variants with 100 and 180 kg/ha N - 0.6 and 0.5 t/ha, respectively, but they were nevertheless significant at 5%. No significant differences could be found among the variants with nitrogen fertilization, either with or without plowed under straw.
Significant interactions were observed between the examined treatments and weather conditions of the experimental years. The plowing under of straw affected positively the yield of the control in the majority of the years. There were no significant differences in yield between the variants with and without straw when 100 kg/ha N were added. A significant difference appeared only in 1978 in the variant of nitrogen fertilization with 180 kg/ha.

The plowing under of straw affected the yield of spring barley grown in the subsequent year. On the six-year average for the controls, the variant with straw was highly significant in relation to the variant without straw. The positive action of plowed under straw was considerably lower (0.2 t/ha), but still significant, in the variant with 40 kg/ha N, to disappear completely in the variant with 80 kg/ha N. Generally, nitrogen affected positively the yield of spring barley to the dose of 40 kg/ha (Table 2).

Weather conditions had the decisive impact on the yield of spring barley. The yield decreased almost in exact proportion with the duration of the trial.
Tab. 2 - Yields of air-dry spring barley grain (t/ha)

<table>
<thead>
<tr>
<th>Year</th>
<th>Kg/ha N + straw</th>
<th>Kg/ha N without straw</th>
<th>Average</th>
<th>LSD 5%</th>
<th>LSD 1%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>40</td>
<td>80</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>1975</td>
<td>5.5</td>
<td>5.4</td>
<td>5.2</td>
<td>4.5</td>
<td>5.4</td>
</tr>
<tr>
<td>1976</td>
<td>4.0</td>
<td>5.0</td>
<td>4.8</td>
<td>3.7</td>
<td>4.6</td>
</tr>
<tr>
<td>1977</td>
<td>3.9</td>
<td>4.4</td>
<td>4.0</td>
<td>3.3</td>
<td>4.2</td>
</tr>
<tr>
<td>1978</td>
<td>3.2</td>
<td>4.5</td>
<td>4.3</td>
<td>3.0</td>
<td>4.3</td>
</tr>
<tr>
<td>1979</td>
<td>2.3</td>
<td>3.6</td>
<td>3.9</td>
<td>2.1</td>
<td>3.6</td>
</tr>
<tr>
<td>1980</td>
<td>2.6</td>
<td>3.6</td>
<td>3.2</td>
<td>1.9</td>
<td>3.1</td>
</tr>
<tr>
<td>Average</td>
<td>3.6</td>
<td>4.4</td>
<td>4.2</td>
<td>3.1</td>
<td>4.2</td>
</tr>
</tbody>
</table>

The plowing under of straw affected positively the yield of spring barley in the controls in all years, but the differences were significant in the first, third, and sixth year. Differences in yield between the variants with and without straw became lower already at 40 kg/ha N. At that nitrogen level, a significant difference was found in 1980 only. At the level of 80 kg/ha N, there were no significant differences in any year.

Spring barley yields were positively affected by nitrogen in the majority of the experimental years. The differences in relation to the control were significant and highly significant. The yields in the controls decreased with the duration of the trial, which made the differences between the controls and the fertilized variants still larger.

The extended action of plowed under straw was considerably reduced or disappeared completely in the third year, as illustrated by the yields of wheat (Table 3). The plowing under of straw increased the yield of wheat only in combination with 90 kg/ha N.

There were no statistically significant differences between the controls in any year. In one year only was the yield of wheat significantly higher in the variant with 90 kg/ha N and straw than in the variant without straw. The yields were also similar with the highest dose of nitrogen with the exception of 1977 when the variant without straw brought a significantly higher yield than that with straw.

- 686 -
Tab. 3 - Yields of air-dry wheat grain (t/ha)

<table>
<thead>
<tr>
<th>Year</th>
<th>Kg/ha N + straw</th>
<th>Kg/ha N without straw</th>
<th>Ave-</th>
<th>L S D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>20</td>
<td>150</td>
<td>0</td>
</tr>
<tr>
<td>1975</td>
<td>3.7</td>
<td>5.6</td>
<td>5.4</td>
<td>3.6</td>
</tr>
<tr>
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<td>7.0</td>
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<td>6.8</td>
<td>6.0</td>
<td>3.6</td>
</tr>
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<td>5.5</td>
<td>6.1</td>
<td>3.5</td>
</tr>
<tr>
<td>1979</td>
<td>3.1</td>
<td>5.1</td>
<td>5.3</td>
<td>3.0</td>
</tr>
<tr>
<td>1980</td>
<td>4.3</td>
<td>6.4</td>
<td>5.2</td>
<td>4.1</td>
</tr>
<tr>
<td>Ave-</td>
<td>3.8</td>
<td>6.1</td>
<td>5.8</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Nitrogen affected positively the yield of wheat in all years, but to the level of 90 kg/ha N, with and without straw.

DISCUSSION

The plowing under of straw in combination with nitrogen fertilization brought significant increases in the yields of corn. The results confirm those of other authors (Mišković et al., 1972; Šeravica et al., 1974; Markovíč et al., 1979). The effects were less pronounced at the beginning (Drešig et al., 1976), when the amounts of mineral fertilizers were larger, and when the period from the plowing under of straw was longer. The control variants displayed largest differences in yields but a low level of the yields diminished the importance of the positive action of plowed under straw. All crops brought highest yields with the medium doses of nitrogen. The differences between the variants with and without straw were statistically significant. It ensues that the plowing under of straw is commendable only in combination with appropriate doses of nitrogen fertilizer.

The examined practice did not bring changes in the volume weight of the soil (Drešig et al., 1980), nor it caused large changes in the ratio of organic matter and total nitrogen (preliminary results). The number of actinomyceses and dehydrogenase activity increased in the year of plowing under straw (Mišković et al., 1977). The results obtained so far are insufficient to try to give a reliable answer on the mode of action of this cultural practice. It might be assumed that it steadied the supply of mine-
nal nitrogen to plants, as hinted at by other authors (Rajkovic, 1978).

CONCLUSIONS

The plowing under of straw affected positively the yields of the examined crops.

The effect of plowing under straw was highest in the first year to become insignificant or non-existent in the last year of the rotation.

Nitrogen affected positively the yields of all crops but to the medium level only.

The plowing under of straw is recommendable only in combination with the quantities of nitrogen which will ensure high yields.

LITERATURE


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THE INFLUENCE OF TILE DRAINAGE SYSTEM ON AGROTECHNICAL PRACTICES AND YIELDS OF MAIN FIELD CROPS

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Abstract

Soil water regime is one of the limiting factors in achieving stable and high yields on 15,000 ha of Vinkovci Agricultural and Processing Plant (in further text - PIK Vinkovci). The main target of tile drainage usage in Čeretinci area was the lowering of water table level to a necessary level and regulation of excess surface water. According to undertaken measures the favourable conditions for performing agrotechnical practices on time were achieved and for safer crop production and higher yields.

Introduction

In Yugoslavia's agricultural regions the plant production in relatively developed, but there are also potential possibilities for it's further development. Taking advantage of existing favourable possibilities depends upon various factors, but mainly upon the possibility of qualitative undertaking of agricultural practices and performing the same on time. Greater part of arable land in our country have unregulated soil water regime and consequently the modern soil tillage practices are sometimes difficult, and sometimes even impossible to perform. Thus the soil water regime is one of the pronounced limiting factors in achieving the stable and high yields of crops in many agricultural areas of Yugoslavia and especially Croatia (Tomić, 1976).

The land structure of our agricultural regions shows that 1/3 of them remain uncultivated. Each year great harm is being done to our agricultural production by the excess of water in soil at about 70 % of arable land (Simundić 1974, Tomić 1976). Because of this in first place it is necessary to regulate the excess water in search of optimal agricultural land's usage by means of drainage. Tile drainage is one of the most intensive meliorative measures in regulation of water regime of productive areas. The application of that practice is being spread widely in our country. PIK Vinkovci is one of the leading organizations in tile drainage usage. Till now it put under systematic tile drainage 36 % of its productive area. The aim of this paper is to show (on the basis of the obtained results and acquired experiences at Čeretinci area) the necessity of regulating the excess water in soil, in first place because of making possible qualitative and on time soil tillage as well as other agrotechnical practices in plant production.
Method of survey

The basis of our investigation is field macro-trial in Čeretinci area. Yields of winter wheat and maize were measured from area of 330 and 258 ha respectively in eight-year period.

In 1976 tile drainage with a tile spacing of 22 m was laid out. The data of yields from remaining five years (1977-1981) are related to postme- liorative phase - drained areas.

In statistic processing of obtained results the method of difference was used (tab. 4 and 5).

Discharge of water from five tile outlets was measured from December of 1977 to May of 1981. In the same period in the drained and undrained area (two plots) the level of water table was measured in plastic tiles on three positions.

Principal data concerning climate

Vinkovci area (where PIK Vinkovci is situated) have moderate continental climate with long term average rainfall of 668 mm and average annual temperature of 11.2°C. For years in which the water table level and discharge of water from drainage tiles was measured (1978-1981) and for average year (1931-1980) the precipitation per month is given in table 1.

Principal data concerning soil

According to Škorić et al (1973) the soil belongs to hydromorphic gley soils respectively amphigley type. For amphigley type of soil the combined influence of excessive wetting by surface and ground water is characteristic. The soil is until 0.6 m depth of silty - clayey - loamy texture; deeper to 2 m is loess-like silty - clayey aquifer layer. Under it is again silty - clayey - loamy layer about 1.3 m thick which deeper transits into a loess material. The content of clay in silty - clayey loam is 30 - 35 %, while in silty - clayey loess about 20 %.

Drain tiles were mostly put into silty - clayey loess material which has average values of permeability between 1.4 and 3.0 m/day. Silty - clayey loam layers have smaller water permeability (0.026 to 0.13 m/day). Other physical properties are given in table 2. The soil is acid, has low hydrolitic acidity but alkali saturation is high. Loess material has neutral to alkaline reaction.

Results and discussion

PIK Vinkovci had in past been trying to stabilize the yields of field crops on areas deteriorated through excess water by surface drainage - open ditches and bedding system. However, through those undertakings in spite of depth and spacing of open ditches the expected results were not obtained (Levaković, 1976). Detailed hydrogeological investigations which started in 1967 pointed out to necessity of applying the subsurface drainage at 60% of total area of 15,000 ha. The main target of tile drainage is reducing of groundwater fluctuation to a necessary level and regulation of excess water on the surface of a soil. For some meliorative areas (pseudogleyed soil, hipogley and alkaline soils) additional measure which consists of subsoiling was recommended; for amphigley it was mole drainage and contact filter in order of achieving efficient and fast
run off of surface water which stagnates on the surface or in the subsurface layer of soil (Vidaček and Vukušić 1967, Tomić and Marišić 1979). Tomić et al (1980) state that the draining of excess surface water and groundwater amounts to improving physical properties of soil. Porosity is being increased and aerobic processes in soil are being pronounced. Water permeability of soil is significantly increased. In soil of better structure and lower water table the roots are getting deeper. These changes in drained soils are the reason of many advantages, i.e. easier performing of agricultural practices and doing them on time, easier and more efficient organization of plant production by lesser costs.

These conclusions are affirmed by a number of other authors (Pejović 1974, Plamenac 1976, Levaković 1976, Concaret et al 1976, Thomasson et al 1975, Thomasson and Spoor 1981).

So far is drained an area of about 8,800 ha of PIK Vinkovci. Through applying this meliorative measure some experiences were attained and positive results in relation to creating favourable conditions for tillage and other higher yields of crops were achieved.

| Table 1: The monthly rainfall in mm for the period of 1978-1980 and the long term average values for 1951-1980 for Vinkovci |
|---|---|---|---|---|---|---|---|
| Month | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | Year | Average |
| 1978 | 80 | 96 | 87 | 76 | 90 | 80 | 94 | 78 | 90 | 78 | 74 | 82 | 1978 | 80.4 |
| 1979 | 85 | 87 | 90 | 90 | 92 | 90 | 87 | 87 | 80 | 78 | 74 | 82 | 1979 | 82.6 |
| 1980 | 85 | 87 | 90 | 90 | 92 | 90 | 87 | 87 | 80 | 78 | 74 | 82 | 1980 | 82.6 |
| Long term average | 84 | 87 | 90 | 90 | 92 | 90 | 87 | 87 | 80 | 78 | 74 | 82 |

| Table 2: Main physical properties of soil |
|---|---|---|---|---|---|
| Depth, cm | Porous soil moist | Air dry bulk density, g cm⁻³ | Bulk density, g cm⁻³ | % Water content, % | % Vol. water, % |
| % | vol | vol | vol | vol | vol |
| 0-50 | 45.0 | 37.2 | 26.1 | 26.3 | 12.6 |
| 50-100 | 42.1 | 36.3 | 26.1 | 26.3 | 12.6 |
| 100-200 | 42.9 | 36.2 | 26.1 | 26.3 | 12.6 |
| 200-400 | 38.4 | 33.8 | 26.1 | 26.3 | 12.6 |
| 400-800 | 36.2 | 32.6 | 26.1 | 26.3 | 12.6 |

| Depth, cm | Porous soil moist | Air dry bulk density, g cm⁻³ | Bulk density, g cm⁻³ | % Water content, % | % Vol. water, % |
| % | vol | vol | vol | vol | vol |
| 0-50 | 45.0 | 37.2 | 26.1 | 26.3 | 12.6 |
| 50-100 | 42.1 | 36.3 | 26.1 | 26.3 | 12.6 |
| 100-200 | 42.9 | 36.2 | 26.1 | 26.3 | 12.6 |
| 200-400 | 38.4 | 33.8 | 26.1 | 26.3 | 12.6 |
| 400-800 | 36.2 | 32.6 | 26.1 | 26.3 | 12.6 |

Attained experiences and results on drained areas

Our experiences have shown that drained areas are giving significantly higher yields. On some areas the yield increase was even stated as over 100%. The undertaking of all agricultural practices on time was made possible, especially the sowing in spring in its optimum period. However, before the tile drainage was done agrotechnical practices were often being late for two or more weeks.

The soil in drained areas is easily being tilled and less energy is being consumed. It is also possible to reduce the number of working operations.

On bigger part of drained area of PIK Vinkovci subsoiling was itself an effective additional measure to pipe drainage. However, on undrained areas soil is often saturated with water and subsoiling alone gives no significant results.

In 1980 on two neighbouring plots (one drained, one undrained) the preparations for wheat sowing...
were being done. On drained plot the plowing was easier and of more quality. On undrained plot furrows were more compacted and higher number of working operations were needed, consequently the working time was 30\% higher.

In 1981 in Ceretinci area on plot of 22 ha (a half drained and the other half without pipe drainage) spring barley was sown. On drained part all agrotechnical practices were done on time, while on undrained half this became possible 12 days later. The yield on drained half was 42 dt/ha while on undrained 36 dt/ha; at the same time expenses were comparably higher on undrained plot.

On drained areas of PIK Vinkovci it is possible to apply reduced tillage (2 harrowings crosswise and one pass with combined tools). In relation to classic tillage for seedbed preparation (plowing, harrowing and final seedbed preparation) 50\% less of working time and energy were consumed in reduced tillage system. However, on plot without pipe drainage reduced soil tillage is impossible. Significant advantage of drained areas over undrained shows also itself in possibility of plowing in so called "figure". Using this method of plowing "empty passes" are minimized and energy is saved.

On drained areas more economical and safer plant production is possible. After pipe drainage was applied higher safety for sensitive seed production was achieved, so this is also one of important advantages and justification for the pipe-drainage (Levaković and Vukušić, 1979).

Principal indications of water regime

Long-term average quantities of precipitation through investigation period, level of water table on drained and undrained plots and water discharge from pipe-drainage are shown in figure 1. Because of the unequal precipitation distribution in quantity and intensity and hydropedological properties the problems concerning soil water regime are appearing. The present pedological conditions promote quick rhizosphere water saturation by relatively smaller quantities of rainfall. As this happens frequently, the conditions for soil tillage and other agrotechnical practices are also often unfavourable.

At the time of the worse state of water regime the curve of ground water level on drained area is considerably lower in comparison to undrained conditions. On drained areas water table was never higher than 50 cm, what was predicted by the projecting. However, on undrained plots water sometimes remains under the very surface of soil, and thus it is possible to measure SWC data (Sieben 1964). Levaković (1970) is frequent depressions in yield of crops on undrained areas of PIK Vinkovci explaining by the very high SWC data. High ground water level in many areas is appearing during winter with prolonged negative effects on spring crops. However, on PIK Vinkovci area high ground water level mainly appears in between January and June, and so it is harmful for all field crops and especially spring ones. Because of this Levaković (1977) states that for stable and high yielding plant production it is necessary to regulate ground water levels by means of pipe drainage.

The discharge of water from pipe drains in observed period (1978 - 1981) appeared from December to June. However, according to intensity and disposition of water discharge there were considerable differences in four years observation (figure 1, table 3). These differences are identical to differences in quantity and intensity of precipitation. In relation to rainfall in 1979 the smallest quantity of water was discharged from soil - 8,3\% of rainfall, than in 1978 25,3\%, in 1980 37,9\% and in 1981 even 45,5\% of total rainfall. Sufficiency of water as the consequence of bigger quantity or stronger intensity of rainfall appeared in observed years, except in 1979, in winter spring period and thus in undrained conditions it made seedbed preparation and sowing of spring crops.
FIGURE 1- PRECIPITATION, DISCHARGE OF WATER FROM TILE DRAINS AND WATER TABLE LEVEL

[Diagram showing annual precipitation and water table levels from 1971 to 1981, with data for decades and years indicated.]
Table 3. Average data of water discharge from pipe drains at Čeretinci area

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1/min</td>
<td>1/sec/ha</td>
<td>l/m²</td>
<td>days</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td>XII</td>
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<td>0.96</td>
<td>0.043</td>
<td>2.76</td>
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<td></td>
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<td>III</td>
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<td>0.78</td>
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<td>II</td>
<td>0.09</td>
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<td>158.12</td>
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</table>
more difficult. It also negatively influenced the planted winter crops.

Achieved yields of main field crops

Favourable influence of pipe drainage can be also expressed through yields of cultivated crops. In this case the yields of winter wheat and maize achieved before and after the drainage was laid out on Čeretinci area are revealed. The results show (tab. 4) that the yields of winter wheat (330 ha) and maize (258 ha) achieved after drainage are highly significant in comparison with yields in undrained conditions. Taking into consideration that considerably bigger increase was achieved in maize (94%) in relation to winter wheat (31%) it is obvious that high saturation of soil with water is performing more unfavourable effect upon crops which are being sown in spring.

Table 4. Average grain yield of wheat and corn on field plots before and after drainage - PIK Vinkovci, Čeretinci area, 1973 - 1981

<table>
<thead>
<tr>
<th>Crop</th>
<th>Period</th>
<th>Total area harvested, ha</th>
<th>Average yield of grain, dt/ha</th>
<th>Difference, dt/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>1 1973-1975</td>
<td>330</td>
<td>43,27</td>
<td>13,44++</td>
</tr>
<tr>
<td></td>
<td>2 1977-1981</td>
<td>330</td>
<td>56,71</td>
<td>31</td>
</tr>
<tr>
<td>Corn</td>
<td>1 1973-1975</td>
<td>258</td>
<td>43,78</td>
<td>41,25++</td>
</tr>
<tr>
<td></td>
<td>2 1977-1981</td>
<td>258</td>
<td>85,03</td>
<td>94</td>
</tr>
</tbody>
</table>

1 - Before drainage, 2 - after drainage
++ - significant at 0,01 level based on LSD

Table 5. Comparative performance of maize grown on eight plots before drainage (1975) and after drainage (1979) - PIK Vinkovci, Čeretinci area

<table>
<thead>
<tr>
<th>Plot No.</th>
<th>Plot size ha</th>
<th>Grain yield dt/ha</th>
<th>Difference, dt/ha</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>1975</td>
<td>1979</td>
</tr>
<tr>
<td>15</td>
<td>18</td>
<td>16,46</td>
<td>78,15</td>
</tr>
<tr>
<td>16</td>
<td>22</td>
<td>18,20</td>
<td>78,00</td>
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<tr>
<td>26</td>
<td>15</td>
<td>14,33</td>
<td>87,40</td>
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<td>27</td>
<td>22</td>
<td>69,70</td>
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<tr>
<td>28</td>
<td>50</td>
<td>13,09</td>
<td>82,15</td>
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<td>29</td>
<td>22</td>
<td>27,95</td>
<td>86,70</td>
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<tr>
<td>30</td>
<td>26</td>
<td>49,22</td>
<td>85,20</td>
</tr>
<tr>
<td>31</td>
<td>17</td>
<td>46,23</td>
<td>81,10</td>
</tr>
</tbody>
</table>

Average 31,90 83,10 51,24++
C.V. % 65 5 16 %
Total area 192 ha
++ - Significant at 0,01 level based on LSD

The achieved results of maize yields after applying tile drainage are highly significant in relation to 1975 yields on undrained plots.
It also has to be taken into consideration that upon highly significant differences in yields some other factors could have also performed some influence (climatic conditions, variety of hybrid, differences in technology) because different time periods respectively years are being compared. However, the maize yields data from 1979 show decidedly that the yields in drained conditions are more uniform in comparison to yields from 1975 in undrained conditions. We look upon it as it was mostly influenced by regulated soil water regime and this results are sufficient proof of need of applying the pipe drainage, as a most economical measure for increase in production of main field crops.

Conclusions

The most important conclusions of our investigations are as follows:

On bigger part of productive areas in our country there is unregulated soil water regime and therefore it is difficult and sometimes impossible to apply modern farming practices. Consequently the soil water regime is one of expressed limiting factors in achieving stable and high yields on about 15,000 ha of PIK Vinkovci.

Pipe drainage is one of the most intensive meliorative practices in regulating soil water regime on productive fields. The main target of using the pipe drainage in PIK Vinkovci area is lowering of water table level to a favourable depth and regulation of excess surface water.

On drained areas improving of water - air relationship in soil occurs. It becomes possible to do all agrotechnical practices on time. Soil is easily being tilled, stoppages are lesser and expenditures are smaller. On drained areas it is possible to apply reduced soil tillage, "figure" plowing and subsoiling.

In conditions of regulated soil water regime it is possible to realize a pattern of intensive crops growing including seed production.

Obtained yields of winter wheat and maize after applying tile drainage are highly significant in relation to yields before tile drainage was laid out. In conditions of regulated soil water regime significantly higher and more stable and uniform yields of field crops were achieved, and therefore it is also the proof of the benefit caused by water management projects with enlarged agricultural production and additional improvements in soils.

References