Impact of ploughless soil tillage on yield and soil quality: A Scandinavian review

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Received 26 May 1999; received in revised form 8 July 1999; accepted 15 July 1999

Abstract

Ploughless soil tillage impacts on yields and selected soil quality parameters is reviewed from the Scandinavian countries of Denmark, Finland, Norway and Sweden. Soil conditions as well as climatic conditions vary widely, this resulting in variations in the length of the growing season, which is very short in the northern part of Scandinavia. The success of reduced tillage and direct drilling depends on the crop species as well as on the soil type and the climatic conditions. The best results seem to be obtained on the heaviest clay soils, which is the most difficult soils to prepare with conventional soil tillage methods. Satisfactory yields were obtained after ploughless tillage in winter wheat (*Triticum* sp.), winter oil seed rape (*Brassica* sp.) and late harvested potatoes (*Solanum tuberosum* L.). The influence of crop rotations and preceding crops in ploughless tillage systems for small grain cereals has received relatively little attention. Also, fertilization of reduced tilled crops has received too little attention, but it seems that nitrogen cannot compensate for sub-optimal tillage. One of the most striking effects of ploughless tillage is the increased density of the soil just beneath the depth of tillage. Increased soil density decreased the volume of macropores (>30–60 μm) and increased the volume of medium pores (30–0.2 μm), but the volume of small pores (<0.2 μm) was only little affected by soil tillage. Increased soil bulk density reduced the air-filled porosity, the air diffusivity and the air permeability as well as the hydraulic conductivity, and sometimes the root development. More plant residues were left on or near the soil surface after ploughless tillage, which led to lower evapotranspiration and higher content of soil water in the upper (0–10 cm) soil layer. It also led to lower soil temperature, and more stable soil aggregates which provided better protection of the soil against erosion. Nutrients and organic matter accumulated near the soil surface after ploughless tillage, and in the long run the soil reaction (pH) declined. Nearly all species of earthworms increased in number in ploughless tillage. The leaching of nitrogen seemed to increase with more intensive cultivation, particularly when carried out in autumn. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Tillage; Reduced tillage; Porosity; Soil water; Root growth; Earthworms

1. Introduction

As in many other temperate regions, the conventional tillage system in Scandinavia comprises autumn ploughing to a depth of 18–30 cm to control weeds...
and bury plant residues, followed by secondary cultivation in order to produce a seed bed. Inherent in such systems is the contradiction that the soil is first loosened and thereafter recompacted before the crop is sown. Besides wasting energy and labour inputs, this leads to a long period during which the soil is left in a condition highly susceptible to erosion and nutrient loss (Riley et al., 1994).

Ploughless tillage systems were introduced in Scandinavia in the early 1970s. Farmers’ interest in these systems was based on the possibilities of saving the costly and laborious ploughing operation, by controlling weeds with herbicides, and by reducing soil erosion and loss of nutrients.

In the Scandinavian countries today, only a small acreage is continuously tilled with ploughless systems. Normally, farmers use ploughless tillage for small grain cereals after preceding crops that have a good soil structure and a low infestation of weeds. Such preceding crops are potatoes (Solanum tuberosum L.), oil seed rape (Brassica sp.), peas (Pisum sp.), sugar beets (Beta vulgaris L.), etc. Ploughless tillage in monoculture systems often result in poor crop establishment and growth because of poor soil structure, plant diseases, etc.

By changing the soil tillage system from a ploughing system to a ploughless system with shallow cultivation or direct drilling, nearly all physical, chemical and biological properties of the soil may be affected. Changes in tillage systems may also affect the conditions for weeds, plant diseases and pests.

A difficult problem is to estimate the consequences of the changes in soil quality on the seed emergence and the growing conditions of the plants. Sometimes, changes in the same property can have different effects, depending on the dominant soil conditions and the climatic conditions (Riley et al., 1994).

This paper presents an overview of the work conducted by various Scandinavian researchers on different soil tillage systems and their effects on selected soil quality parameters as well as on crop yields. In Scandinavia, ploughing is usually made with mouldboard ploughs.

2. Tillage, soil types and climatic conditions

In the Scandinavian countries, many different soil tillage methods were used for drilling of small grain cereals, and in this review several names for tillage systems are used. Therefore, the methods described in this article are defined as follows:

- **Conventional tillage**: Mouldboard ploughing in autumn or spring to a normal depth of 18–30 cm, followed by seed bed preparation and sowing.
- **Reduced (or shallow) soil tillage**: Soil tillage to a maximum depth of 10 cm by means of cultivator, disc harrow, rotovar or the like.
- **Direct drilling (or non-tillage)**: Direct drilling in un-tilled soil where straw has been removed or burned and weeds have been killed by use of chemicals. Most sowing experiments were made by use of disc drills.
- **Ploughless tillage**: Different methods of direct drilling or reduced tillage systems, exclusive of ploughing.
- **Conservation tillage**: Plant residues have been left on the soil surface. Plant establishment is made by use of direct drilling or reduced soil tillage methods.

In most of Scandinavia the growing season for cereals is from April to September. In the period from November to April the soil is either covered with snow, frozen or very wet and therefore inaccessible for tillage operations.

Rainfall deficits are common in early summer in the major arable areas, whereas in late summer and in the autumn both harvesting and tillage are often hampered by excessive rainfall. Suitable conditions for rapid plant establishment are therefore of importance, both to ensure sufficient available moisture in spring and to avoid harvesting losses in autumn. Often, time is insufficient for the establishment of autumn sown crops. Spring-sown cereals therefore dominate, except in the southernmost areas.

Soil conditions vary widely, according to the nature and mode of deposition of the parent material.

According to the FAO soil classification, the Scandinavian soils can be classified in the following major soil types (FAO, 1988; Greve et al., 1999): Denmark: Eutriv Fluvisol; Norway: Stagnic Luvisol; Sweden and Finland: Glayic Cambisol.

Clay contents vary from 30–40 g kg\(^{-1}\) in the western part of Denmark to 600–700 g kg\(^{-1}\) in large areas of Sweden and Finland.

In the case of ploughless tillage, the influence of soil type on crop yield has usually been of minor impor-
tance, in comparison with factors such as weeds. Greater difficulties may nevertheless be expected on poorly drained, clayey soils rather than on well-drained, sandy soils. Poor results have been found in connection with early sowing on silty soil in Norway (Riley, 1985) and on silty marsh soil in Denmark (Rasmussen, 1988), probably due to waterlogging at germination. Alternatively, silty clay soil in Sweden and Finland has been one of the soil types for which ploughless tillage has been most successful (Rydberg, 1982; Elonen, 1988; Pitkänen, 1994). The latter findings are thought to be due to improved surface moisture relations during drought periods and possibly also to better rooting in unploughed soil (Rydberg, 1986).

Weather conditions in the growing season also appear to play a part in the success of ploughless tillage. In Norway, better results have often been observed in dry years than in wet years (Ekeberg, 1987; Marti, 1984; Riley, 1983). This is in accordance with the changes in soil physical conditions discussed below. However, Danish research (Djurhuus, 1985) revealed no effect of tillage on the efficiency of crop water use during the growing season.

3. Ploughless tillage impacts on crop yields

Field experiments with small grain crops were carried out in Scandinavia during the 1970s and 1980s. Most of the experiments were carried out in cereals monoculture. Some of the yield results are summarised in Fig. 1.

The most striking feature of these trials has been that the effect of omitting tillage on yields has been relatively small. Until recently, tillage has been considered essential. Average yields of well over 90% of that achieved by conventional tillage have normally been attained. Taking into account the potential savings in machinery, labour and fuel, reduced tillage will give a net benefit (Riley et al., 1994).

Experiments as well as farmers’ experience have shown that the success to be obtained from direct drilling and reduced soil tillage will depend on the crop grown, the preceding crop and the soil type. Scandinavian research shows that winter wheat (Triticum sp.) in a cereal monoculture crop rotation is the only crop with similar yields on direct drilling and on ploughing. For the other crops tested, the highest yields were obtained on ploughing (Rasmussen, 1988), e.g. winter oil seed rape (Brassica sp.) (Fig. 2) on coarse sand and sandy loam in Denmark. On an average of different soil types in Sweden...
winter oil seed rape (Brassica sp.) yields after direct drilling were only slightly less (Cedell, 1988). Direct drilling of potatoes (Solanum tuberosum L.) may be a realistic alternative to the plough-tillage-planting-method. As shown by a study in Norway, that in spite of a somewhat slower rate of development in the early growing season, potatoes planted in unploughed soil will continue to grow in the autumn, and they will often give higher final yields than conventionally tilled potatoes (Table 1). Such a system is unsuitable for the production of early potatoes, but otherwise it appears to be perfectly feasible, provided the grower has suitable equipment for planting and ridging (Riley et al., 1994; Ekeberg and Riley, 1996).

Crop rotation may indeed be of greater importance for ploughless soil tillage than for conventional systems, both in order to minimize problems associated with fungal diseases, and as a mean of reducing weed problems by resorting to herbicides. The consequences of crop rotation and the importance of preceding crops have received relatively little attention in Scandinavia.

Fertilizer requirements of crops grown with ploughless tillage have also received relatively little attention in Scandinavia. One might expect that more nitrogen would be needed in order to compensate for any suboptimal physical or biological condition resulting from ploughless tillage. On the other hand, over the long term, requirements may even be expected to decline as a result of accumulation and mineralization of organic matter, as was observed in Texas with sorghum (Sorghum bicolor L. Moench) (Franzluebbers et al., 1995) and in Kentucky with corn (Zea mays L.) without fertilization (Ismail et al., 1994). Fairly similar response curves for nitrogen fertilization have been found in both ploughed and unploughed soils (Riley et al., 1994). In a 13-year long-term trial in Norway, higher yields were found on ploughless tilled land for 10 of 13 years at low nitrogen level, whereas only a small difference between tillage methods was found at a higher fertilizer level (Riley et al., 1994). In Danish long-term trials (6 years) it was found that nitrogen cannot compensate for sub-optimal soil conditions resulting from ploughless tillage (Rasmussen, 1988).

### Table 1

Potato (Solanum tuberosum L.) tuber freshweight yields (Mg/ha) for two soil tillage systems and tree times of harvesting in Norway (Ekeberg and Riley, 1996)

<table>
<thead>
<tr>
<th></th>
<th>28 August&lt;sup&gt;a&lt;/sup&gt;</th>
<th>9 September&lt;sup&gt;a&lt;/sup&gt;</th>
<th>23 September&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Sign.&lt;sup&gt;b&lt;/sup&gt;</th>
<th>LSD&lt;sub&gt;0.05&lt;/sub&gt;&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional soil tillage</td>
<td>Direct planning</td>
<td>Conventional soil tillage</td>
<td>Direct planning</td>
<td>Conventional soil tillage</td>
</tr>
<tr>
<td>1987</td>
<td>32.0</td>
<td>28.9</td>
<td>37.0</td>
<td>36.9</td>
<td>34.9</td>
</tr>
<tr>
<td>1988</td>
<td>29.5</td>
<td>29.4</td>
<td>34.1</td>
<td>35.4</td>
<td>33.0</td>
</tr>
<tr>
<td>1989</td>
<td>26.1</td>
<td>24.9</td>
<td>28.9</td>
<td>29.6</td>
<td>29.4</td>
</tr>
<tr>
<td>1990</td>
<td>30.5</td>
<td>29.2</td>
<td>36.0</td>
<td>33.3</td>
<td>37.3</td>
</tr>
<tr>
<td>1991</td>
<td>21.4</td>
<td>19.7</td>
<td>24.7</td>
<td>22.9</td>
<td>24.8</td>
</tr>
<tr>
<td>1992</td>
<td>22.6</td>
<td>21.2</td>
<td>28.3</td>
<td>27.6</td>
<td>34.0</td>
</tr>
<tr>
<td>1993</td>
<td>28.8</td>
<td>28.4</td>
<td>32.6</td>
<td>33.1</td>
<td>35.1</td>
</tr>
<tr>
<td>Mean</td>
<td>27.3</td>
<td>26.0</td>
<td>31.7</td>
<td>31.2</td>
<td>32.6</td>
</tr>
</tbody>
</table>

<sup>a</sup> Mean harvesting dates.

<sup>b</sup> Interaction between harvest date and soil tillage; ns: not significant; *, P < 0.05; **, P < 0.01; ***, P < 0.001; +, P < 0.1.

<sup>c</sup> Between tillage systems at same or different harvest date.

### 4. Ploughless soil tillage impacts on soil properties

#### 4.1. Soil bulk density

Soil bulk density is probably the most frequently measured soil quality parameter in tillage experiments. In European work, where potential problems with excess soil moisture, decreased aeration and compaction of the soil can be important, especially for crops sown in the spring, bulk density and porosity measurements have received particular attention (Cannell and Hawes, 1994). Annual ploughing to the same depth (normally 20–25 cm) resulted in a plough pan on loamy soils. By reduction of the
ploughing depth to 10 cm (Fig. 3), the penetration resistance increased significantly in the 15–40 cm layer below the new ploughing depth, but it did not improve the density of the previous ploughing layer (Rasmussen et al., 1998).

One of the most striking effects of ploughless tillage is the increased density of the topsoil (Rydberg, 1987; Schjønning, 1988; Elonen, 1988). Increases in bulk density are particularly noticeable at about 10–15 cm depth, just beneath the depth of shallow tillage (Riley et al., 1994; Rydberg, 1986).

4.2. Soil porosity and hydraulic conductivity

On shallow tilled soil the total pore space and the volume of macropores were less than in ploughed soil — especially at a depth of 11–16 cm (Njøs and Børresen, 1988). In the soil layer at 13–25 cm depth, Comia et al. (1994) found a significantly higher soil bulk density in shallow tilled soil than in ploughed soil. In a six-year experiment with direct drilling for continuous barley (*Hordeum vulgare* L.) on two coarse sandy soils in Denmark, Rasmussen (1984) found similar pore space at a topsoil depth of 0–5 cm and decreased pore space at depths of 5–10 and 15–20 cm after direct drilling, but no differences were found at 25–30 cm depth (Fig. 4). The same trend was found by Elonen (1988).

Changes in the soil porosity may lead to changes in the pore size distribution. In the above mentioned six-year experiment, the volume of macropores (>60 μm) decreased markedly with the depth (Fig. 5). The volume was significantly higher in the topsoil (0–5 cm) than in the other depths measured. In the topsoil (0–5 cm), the highest volume of macropores was seen after direct drilling, but the difference was not significant. At depths of 5–10 and 15–20 cm, considerable significant reductions in the volume of macropores took place after direct drilling. At depths of 25–30 cm, no difference was seen (Rasmussen, 1984).

In the directly drilled treatment the volume of medium pores (60–0.2 μm) was significantly smaller in the topsoil (0–5 cm) than at depths of 5–10, 15–20
and 25–30 cm. In the ploughed treatment the volume of medium pores increased with depth, however not significantly (Fig. 6). Direct drilling increased the volume of medium pores significantly at depths of 5–10 and 15–20 cm, but not at depths of 0–5 and 25–30 cm. The volume of small pores (<0.2 mm) was not significantly affected by soil tillage (Rasmussen, 1984).

Because of increased volume of medium pores, the air-filled porosity decreased, and the volume of available water increased (Rasmussen, 1984), which was also shown by Riley et al. (1994). At the bottom of the topsoil and in the upper subsoil layer on heavy clay soil, Rydberg (1987) found that the rate of macropores (>30 µm) increased in shallow tilled soil as compared to in ploughed soil, because of a higher occurrence of earthworm channels and a better pore continuity.

Compacted soil layers lead to decreased volume of macropores, soil air, and air permeability, but also to decreased infiltration of water. On clay soils in Sweden the saturated hydraulic conductivity was significantly higher in shallow cultivated soil than in ploughed soil at depths of 25–30 cm, mainly because of better pore continuity in shallow cultivated soil (Comia et al., 1994). After ploughless tillage, Rydberg (1986) found improved saturated hydraulic conductivity and reduced rate of infiltration in field measurements in the lower topsoil and the upper subsoil. On a heavy clay soil in Finland, Aura (1988) investigated the relationship between the volume of macropores (>0.3 mm) and the saturated hydraulic conductivity (Table 2). Ploughed soil, which had the highest volume of macropores, showed the highest rate of hydraulic conductivity. The volume of macropores as well as the hydraulic conductivity were lowest in the harrowed soil.

Table 2

<table>
<thead>
<tr>
<th>Soil tillage systems</th>
<th>Infiltration of water (K, m s⁻¹)</th>
<th>Macropores &gt; 0.3 mm (% of soil volume)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ploughing and harrowing</td>
<td>159</td>
<td>13.5</td>
</tr>
<tr>
<td>Direct drilling</td>
<td>58</td>
<td>10.6</td>
</tr>
<tr>
<td>Harrowing</td>
<td>21</td>
<td>8.1</td>
</tr>
<tr>
<td>F</td>
<td>10.33**</td>
<td>3.94</td>
</tr>
</tbody>
</table>

** P < 0.01.
The importance of soil transport properties for aeration, water supply and drainage is fundamental. Unfortunately, such properties, however, typically showed a much higher degree of variability than many other soil physical properties, and they are often difficult or expensive to measure directly (Riley, 1996).

In a Danish fine loam soil, 18 years of shallow cultivation by rotovator or harrow diminished the volume of large pores as compared with annually ploughed soil. Critically low values of air diffusivity were found in the untilled layers of shallow tilled soil as well as in the plough-pan of ploughed soil. Comparative calculations of the O2 concentration at different depths using air diffusivities and respiratory activities suggested that shallow tilled soil might have a poorer aeration potential of deep layers than ploughed soil (Schjønning, 1989).

Compared with ploughed soil, an index of pore continuity, calculated as the quotient of relative diffusivity and air-filled porosity, indicated a higher degree of continuity and non-tortuosity of pores larger than about 200 \( \mu \text{m} \) in shallow tilled, loamy soil. When pores of about 30–200 \( \mu \text{m} \) were air-filled, ploughed soil appeared to have the highest continuity of air-filled pore space (Schjønning, 1989).

### 4.3. Soil moisture

In a six-year experiment with ploughing and shallow tillage for spring sown cereals in Finland, Elonen (1988) found a higher moisture content in the topsoil \((0–10 \text{ cm})\) after shallow tillage than after ploughing, but in the lower part of the topsoil \((10–20 \text{ cm})\) the water content was highest after ploughing. The same trends were found by Rydberg (1986) and Riley (1988). Plant residues on the soil surface reduced the evaporation. A lower volume of macro pores and higher volume of medium, water holding pores are also possible reasons for the higher water content in the upper soil layers after shallow tillage (Rydberg, 1988).

A higher water content in the upper soil layers and a lower evaporation are valuable in areas with low precipitation after sowing in spring, such as in the eastern part of Sweden (Rydberg, 1988). In areas with a short growing season, e.g. in Finland, and especially on clay and silt soils, a high water content in the upper soil layers may delay seeding (Elonen, 1988).

### 4.4. Soil temperature

Studies in Finland and Denmark showed that in the spring the soil temperature was 0.3–1.0\( ^\circ \text{C} \) higher at depths of 5 and 10 cm after ploughing compared to direct drilling in the period from sowing and until about 1 week after germination (Elonen, 1988; Rasmussen, 1988). Reasons for the lower soil temperature are higher water content in the topsoil and more plant residues on the soil surface, resulting in declined evaporation. The average soil temperature declined by 0.3–0.5\( ^\circ \text{C} \) per percentage point increase in soil water content (Riley, 1988). The lower soil temperature may delay plant emergence, plant development and ripening, especially in areas with late and short growing seasons.

### 4.5. Soil aggregate stability

Water-stable aggregates in the upper few mm of the soil layer may improve the germination and seedling establishment by reducing surface crusting and erosion, and by allowing water and air to enter the soil. Many reports show that the proportion of more stable aggregates in the upper 25–30 mm of the soil is greater on un-tilled land than after ploughing after 2–10 years, even on weakly structured soils. The positive influences of conservation tillage practices on aggregation can be more evident where stubble is retained rather than burned (Cannell and Hawes, 1994).

Topsoil wet aggregate stability was measured during a 13-year period in a long-term experiment with continuous growing of spring barley on a silty loam marsh soil in Denmark. Throughout the measuring period the ploughed soil had the lowest amount of water-stable aggregates, compared with rotoved soil (Schjønning and Rasmussen, 1989). Børresen (1997) found that the aggregates became coarser when the amount of straw residues on the soil surface was increased, and Rydberg (1986) found coarser aggregates in the seedbed after ploughless tillage.

### 5. Soil structure and root development

Root development is sometimes delayed by direct drilling — especially in the mid-topsoil. However, the
cracks, worm channels and large pores in the soil promote root development. Cracks were often smaller after reduced tillage, whereas the number of worm channels was often larger (Rydberg, 1987). Root density was greater in ploughed soil than in shallow cultivated soil at all depths down to 35 cm. However, the only significant difference was seen in depths of 13–25 cm (Comia et al., 1994). On coarse sand, sandy loam and silty clay soils in Denmark, Rasmussen (1991) found no significant differences in root lengths at depths of 0–95 cm after ploughing and shallow rotovating. In the coarse sandy soil where the root depth was limited to about 60 cm in depth, the highest proportion of roots was concentrated in the topsoil. More weeds were seen in the rotovated than in the ploughed treatment. Therefore, the higher root concentration in the topsoil can be caused by the weeds (Rasmussen, 1991). Thus, the influence of tillage differences on plant root development remains inconclusive.

6. Soil erosion

Soil tillage systems can affect erosion. Norwegian experiments have shown that spring ploughing, reduced soil tillage and direct drilling will protect the soil better against erosion than autumn ploughing (Børresen, 1990). Erosion occurs in the snow melt period, in the autumn after harvest, and more randomly during summer and winter. Intensive rain in the summer causes high erosion rates (Skøyen, 1988).

In a six-year experiment shallow tillage reduced water erosion by about one half to two thirds in comparison with conventional tillage (Fig. 7), although this is still well above the levels found on grasslands (Njøs and Hove, 1986; Skøyen, 1988). Unfortunately, the soils on which erosion is most severe are also the most difficult ones to manage without ploughing, owing to their low internal drainage and high susceptibility to compaction (Riley et al., 1994).

Loss of P is generally correlated with the loss of soil, but results also show that runoff from directly drilled soil and lay will have higher concentrations of water soluble P. Total P losses are not reduced to the same extent as soil losses from the investigated plots (Skøyen, 1988).

Fig. 7. Erosion of soil and total P on a silty clay soil in Norway (modified from Skøyen, 1988).

7. Soil organic matter

Soil organic matter content has important influence on soil fertility, moisture retention, structural stability and thermal properties (Riley, 1996). For most mineral soils, the structural stability will decrease when soil management methods are used to reduce the organic matter content. Such changes can lead to deterioration of the soil workability. Therefore, soil organic matter is perhaps the most important indicator of soil quality and productivity (Cannell and Hawes, 1994).

With annual ploughless tillage, plant residues will be left on the soil surface, resulting in increased organic matter in the topsoil. After some years of ploughless tillage the content of organic C in the upper 0–5 cm soil layer was increased by 3–12 g kg⁻¹ (Rydberg, 1987; Elonen, 1988; Riley, 1988; Børresen and Njøs, 1993). The increase in organic C content in the 0–10 cm soil layers was 1–2.2 g kg⁻¹ (Nielsen and Hansen, 1982; Rasmussen, 1981; Rasmussen and Andersen, 1994). At the end of six years of direct drilling in Denmark, Rasmussen (1988) found that organic C increased significantly by 7.9 g kg⁻¹ in the upper 0–2 cm soil layer after direct drilling, but in the 2–10 and 10–20 cm depths the increases were insignificant. No significant changes in the content of organic matter were found in depths below 10 cm.
8. Soil pH

Most experiments have shown that the soil reaction (pH) is normally unaffected by tillage systems and depths (Comia et al., 1994; Nielsen and Hansen, 1982; Rasmussen, 1981, 1991; Rasmussen and Andersen, 1991; Rydberg, 1987; Riley, 1988). But in long-term experiments (6–18 years) a decrease in the pH by 0.2–0.3 pH-units in the topsoil (0–5 cm) was found after shallow tillage (Ekeberg and Riley, 1997; Børresen and Njøs, 1993; Rasmussen, 1988). A significant decline resulting from no-till systems has been reported in Australia (Dalal, 1989), the US (Dick, 1983) and Canada (Arshad et al., 1990).

9. Soil nutrients

Available phosphorus increased significantly in the 0–5 cm depth in shallow tilled soil. Available P in depths of 10–20 cm on shallow tilled soil was almost constant or slightly decreased during the experimental period. Available potassium increased significantly in the toplayer of shallow tilled soil, but not in the 10–20 cm layer compared with ploughed soil (Comia et al., 1994; Elonen, 1988; Riley, 1988; Børresen and Njøs, 1993; Nielsen and Hansen, 1982; Rasmussen and Andersen, 1991; Rasmussen, 1984, 1988; Rydberg, 1986).

10. Soil fauna

Earthworms form the major components of animal biomass in arable soils of Scandinavia. Earthworms affect the soil in various ways: (1) nutrients in earthworms’ casts are readily available, (2) casts form aggregates and improve the soil structure, (3) earthworm burrows are important factors in water infiltration and transport of nutrients, (4) plant roots penetrate deeper in burrows, and (5) earthworms can incorporate large quantities of straw residues in the soil (Haukka, 1988; Pitkänen, 1993).

Soil tillage and straw management, as well as the depth of residue incorporation, seemed to affect the population of earthworms. Increased earthworm activity has usually been observed under reduced tillage in Finland (Pitkänen, 1993). It must be kept in mind that all species of earthworms do not react in the same way (Haukka, 1988). The deep burrowing surface feeder, Lumbricus terrestris, has especially been favoured by tillage systems, where soil is not ploughed and plant residues are left on the soil surface (Andersen, 1987; Pitkänen, 1993; Pitkänen and Nuutinen, 1995).

In two tillage systems in Denmark earthworms were analysed by Andersen (1987) six years after the start of an experiment located at five sites. Some of the results are shown in Fig. 8. Investigated species were: Allolobophora chlorotica, Aporrectodea caliginosa, Aporrectodea rosea, Aporrectodea longa, Lumbricus terrestris and Lumbricus rubellus. For all species counted, more earthworms were found after direct drilling than after ploughing — especially for the Lumbricus-species. The number of earthworms was significantly higher after direct drilling than after ploughing in three of five sites.

11. Nitrogen leaching

Leaching of nitrogen from arable land is one of the major environmental problems on sandy soils in
south-estern Sweden and western Denmark. On such soils, the average annual nitrogen leaching losses can be 40–0 kg ha\(^{-1}\) (Hansen and Djurhuus, 1997; Stenberg et al., 1997). Leaching increased with more intensive cultivation, particularly when carried out in the early autumn (Hansen and Djurhuus, 1997; Stenberg et al., 1997). Stubble cultivation in autumn followed by ploughing compared to stubble cultivation in spring without ploughing on a sandy loam soil gave nitrogen losses of 76 and 35 kg ha\(^{-1}\), respectively (Hansen and Djurhuus, 1997). On a coarse sandy soil no differences in nitrogen leaching between autumn ploughing and spring ploughing were seen, but direct drilling reduced the leaching by 13 kg ha\(^{-1}\), as compared to ploughing (Hansen and Djurhuus, 1997).

12. Conclusions

1. Soil conditions in Scandinavia vary from coarse sand soils with clay contents of 30–40 g kg\(^{-1}\) in the western part of Denmark to heavy clay soil with clay contents of 600–700 g kg\(^{-1}\) in large areas of Sweden and Finland.

2. Most of the experiments were conducted in monoculture of spring barley (Hordeum sp.). Winter barley (Hordeum sp.), winter wheat (Triticum sp.), winter rye (Secale sp. L.), winter oil seed rape (Brassica sp.) and potatoes (Solanum tuberosum L.) were most often grown in rotations with other crops.

3. In Scandinavia, ploughless soil tillage will be successful under a wide range of soil conditions — especially on clay soils. Most success has been obtained by growing winter wheat (Triticum sp.), winter oil seed rape (Brassica sp.) and late harvested potatoes (Solanum tuberosum L.).

4. The consequences of the crop rotation and preceding crops have received little attention.

5. Different methods of reduced soil tillage and direct drilling affected the soil parameters in the same way.

6. The soil bulk density will increase, and the porosity will decrease just beneath the depth of ploughless soil tillage — particularly in the 10–15 cm depth.

7. Ploughless soil tillage will result in decreased volume of macropores (drainable pores) and increased volume of medium (waterholding) pores, but the volume of small pores (containing non-available water) was not significantly affected by soil tillage systems.

8. Infiltration of air and water decreased after ploughless soil tillage. Critically low values of air diffusivity were found in the untilled layers of shallow tilled soil.

9. More plant residues left on or near the soil surface after ploughless soil tillage will lead to higher water content in the upper soil layer, as well as to lower evapotranspiration, lower soil temperature, and greater and more stable soil aggregates.

10. Ploughless tillage will lead to increased activity and biomass of earthworms, but the different species of earthworms will not always react in the same way.

11. Ploughless soil tillage will protect the soil against erosion of soil particles and nutrients.

12. Nutrients and organic C will accumulate near the soil surface after ploughless soil tillage, and in the long run the soil reaction (pH) will decline.

13. Leaching of nitrogen will decrease after ploughless soil tillage.

14. The influence of soil tillage methods on root development appears to be insignificant.

References


