Introduction

The Swedish University of Agriculture (SLU) finances a total of 13 long-term soil tillage experiments, which are run by the Division of Soil Management at the Department of Soil & Environment. The experiments are used to study the effects of different soil tillage and soil management systems on environmental and agronomic aspects. They are situated all over Sweden, although the majority are located in Uppsala.

Most of the experiments deal with various effects of reduced or non-inversion tillage to a depth of 7-15 cm compared with conventional tillage including mouldboard ploughing to a depth of 22-24 cm (Figure 29.1).

During the past 30 years the Division has also carried out a large number of short-term (1-6 year) field trials where different reduced tillage systems have been tested.

Results from long- and short-term experiments are published every year in the Annual Report from the Division of Soil Management. The results can also be found on http://www.mv.slu.se/JB/jb.htm and www.ffe.slu.se

Figure 29.1. Frequently used implements replacing the mouldboard plough in Sweden. Tine cultivator (left) and disc cultivator (right). Photo: Väderstad-Verken AB.
In the following, we discuss some of the questions to which answers can hopefully be found mainly in the long-term tillage experiments, but including some results from the short-term trials. Figure 29.2 presents the benefits and drawbacks of non-inversion tillage.

**Which Tillage Depth Should be Used in Ploughless Tillage?**

Five of the long-term experiments include different tillage depths in the ploughless tillage treatments. Figure 29.3 shows the penetration resistance in one of these experiments, and clearly demonstrates a better loosening effect for a greater tillage depth. Crop yields in all experiments are shown in Table 29.1. On average, yield effects are small. In general, on heavier soil and where ploughless tillage gives good yield relative to mouldboard ploughing, there seems to be little benefit to increasing tillage depth. Table 29.2 presents measurements of fuel consumption in two experiments at Ultuna, Uppsala, during 2005. Increasing tillage depth from 10 to 20 cm increased fuel consumption from 13 to 37 l/ha, and the deep chisel plough tillage required almost twice as much fuel as mouldboard ploughing.

**Should Ploughing or Ploughless Tillage be Continuous or Can the Systems be Mixed?**

Ploughless tillage increases organic matter content in the surface layer, which may improve seedbed properties and reduce the risk of slaking and crusting. Occasional ploughing will level out these differences in organic matter content within the topsoil, and may therefore be detrimental to soil structure. On the other hand, autumn ploughing increases the potential for wind and weather to have a positive effect on the structure. An autumn ploughed area of a heavy clay has a finer surface structure in spring than an area that was only stubble cultivated. This is because the ploughing exposes a greater surface area of soil to the effects of freezing-thawing and wetting-drying cycles.

One question often asked by farmers is whether ploughless tillage should be continuous or whether it

---

**Table 29.1. Relative crop yields in experiments with different tillage depths in ploughless tillage. From Arvidsson et al. (2003).**

| Place        | Ultuna | Ultuna | Ultuna | Ultuna | Lönns
torp | Average |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil type</td>
<td>clay loam</td>
<td>heavy clay</td>
<td>clay loam</td>
<td>heavy clay</td>
<td>clayey till</td>
<td></td>
</tr>
<tr>
<td>Exp. years</td>
<td>12</td>
<td>12</td>
<td>8</td>
<td>32</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Ploughing</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Shallow chiselling (10 cm)</td>
<td>86</td>
<td>97</td>
<td>104</td>
<td>105</td>
<td>98</td>
<td>98</td>
</tr>
<tr>
<td>Deep chiselling (20 cm)</td>
<td>92</td>
<td>99</td>
<td>100</td>
<td>105</td>
<td>101</td>
<td>99</td>
</tr>
</tbody>
</table>
can sometimes be interspersed with mouldboard ploughing. A series of experiments included these systems as treatments, where occasional ploughing meant ploughing every third to fourth year (Table 29.3). On average, the system with occasional ploughing gave the highest crop yield. The system with continuous ploughless tillage was clearly beneficial only in one experiment, which was situated on a silty soil, sensitive to crusting.

Figure 29.4 shows the number of earthworms (Lumbricus terrestris) in 2005 for one experiment at Ultuna. The number was highest for continuous ploughless tillage and approximately the same for continuous and occasional mouldboard ploughing.

**Effects of Low Tyre Inflation Pressures in Conventional and Ploughless Tillage**

In 1997, three long-term experiments were started to study the effect of low inflation pressure, primarily on soil structure and crop yield. The experiments are situated at Ultuna, on soils with clay contents ranging from 18 to 36%. There are two tyre treatments, one with single wheels at 0.9 bar inflation pressure and one with dual wheels at 0.4 bar inflation pressure, both tested in conventional (mouldboard ploughing) and ploughless tillage. The hypothesis was that improved tyre equipment would be more beneficial in ploughless compared with conventional tillage, due to a smaller depth of soil loosening in the former.

Crop yield for low inflation pressure compared with normal (average for both tillage systems) is shown in Figure 29.5. The low ground pressure was most beneficial on the heaviest soil. There also seems to be a trend for the effect of low ground pressure to increase with time, at least on the lighter soils. In contrast to the original hypothesis, no interaction has so far been found between the effect of tyre inflation pressure and tillage system on crop yield.
Is Ploughless Tillage Recommended on Certain Soil Types?

Figure 29.6 shows the relative yields of barley and winter wheat depending on soil type (Rydberg, 1992). The results of ploughless tillage were generally better with increasing clay content with the exception of results from the silty clay loam. Well structured clay soils seem to manage without yearly loosening by mouldboard ploughing. Normally a silty clay loam is very prone to soil compaction because it is rather weak-structured. The main reason for the good results on the compaction-prone silty soils is probably that the positive effects of improved self-mulching outweigh the negative effects of soil compaction. The better self-mulching ability is created by more crop residues and increasing humus content in the upper part of the topsoil, thereby reducing the risk of slaking and thus the rate of evaporation. The need for better water retention is especially great on silty soils in areas with a water deficit during the growing season.

Which Crops and Preceding Crops should be Grown?

In Table 29.4, all yield results with ploughless tillage for different crops during 1986-2002 are presented. On average, no large difference can be seen between ploughed and non-ploughed treatments. Some reduction in yield with ploughless tillage can be observed for peas, potatoes and sugar beet, all of which are prone to soil compaction.

Table 29.5 shows the importance of choosing a good preceding crop for winter wheat. Positive effects on yield, overall and with ploughless tillage, were obtained when the preceding crop was peas or an oilseed crop. The importance of a good crop rotation cannot be overestimated, especially in tillage systems with ploughless tillage. This is probably related to ploughless tillage leaving more straw residues on the surface, thus increasing the risk of fungal spread.

Will the Use of Fungicides, Herbicides and Insecticides Increase in Reduced Tillage?

Fungicides

In our trials in Sweden with reduced tillage using a tine cultivator or disc cultivator to approx. 7-15 cm instead of ploughing to approx. 22-24 cm, we have observed an increase in the incidence of leaf blotch (*Rhynchosporium secalis*) in barley in the ploughless plots. This is probably related to the ploughless tillage leaving considerably more straw on the surface, thus increasing the risk of fungal spread (Figure 29.7). Likewise, in trials with winter wheat we have found a sparser and weaker crop stand in the unploughed plots. The reason is presumably an increase in the incidence of overwintering fungi, primarily *Fusarium* species, which are found on straw residues at the surface. It could also be due to poorer covering of the seed due to the seed coulters being hampered by abundant straw masses on the surface. We also know that both eyespot (*Cercosporella herpotrichoides*) and take-all
(Gaemammomces graminis) fungi are favoured by straw being left on the soil surface. However, the international literature does not show any consistent results regarding the risk of attack from these fungi in ploughless tillage. The take-all fungus can also overwinter in couchgrass. It is generally accepted that it is more difficult to combat couchgrass in ploughless tillage than in conventional.

Herbicides
In our long-term trials on ploughless tillage, we have only occasionally increased the amount of herbicide used. In all cases, this involved an extra treatment against couchgrass. Weed counts indicate that the number of seed weeds has increased by around 25% but this has never posed a major problem. In general terms, however, the quantity of weed seeds and rhizomes decreases with increasing ploughing depth. Our ploughing trials show that ploughing to 27 cm is more effective against weeds than ploughing to 15 or 23 cm. On the other hand, energy consumption in ploughing is generally in direct proportion to ploughing depth. Advantages and disadvantages have to be weighed up. A greater ploughing depth also means a dilution of the organic matter content of the surface layer, with many negative effects as a result, see below. In tillage trials, we have found that living couchgrass is not found below the maximum ploughing depth. If a soil is ploughed to 12 cm only, couchgrass roots will not be found below this depth after a few years. It should be possible to exploit this in subsequent mechanical control strategies for couchgrass.
Insecticides
In Sweden, researchers working with reduced tillage for more than 40 years have not been able to see any major differences in the incidence of insects between ploughed and only stubble cultivated plots. In direct drilling, severe slug attacks on winter oilseed crops have sometimes been observed.

Environmental Effects of Tillage Systems
What are the environmental effects of different tillage systems? Important processes that might be affected are leaching of nitrogen, phosphorus and pesticides. All these issues have been addressed in the long-term experiments, but further research in this area is needed.

Nitrogen Leaching
The effect of tillage on nitrogen mineralisation and leaching has been studied in a large number of experiments. It has generally been found that delaying the time of tillage reduces nitrogen mineralisation. One of these experiments, on a sandy soil (Mellby) in southern Sweden, is within the long-term experiments funded by SLU. In this experiment, nitrogen leaching is studied in drained plots with three replicates in a whole crop rotation. Two treatments are included: one ‘conventional’ system and one ‘nitrogen-efficient’ system. The nitrogen-efficient system includes delayed or reduced tillage and catch crops when this is possible within the crop rotation. During the first 6 years, the measured nitrogen leaching was in total 92 kg/ha lower in the nitrogen efficient system (Figure 29.8).

Phosphorus
Tillage systems may have an impact on transport of phosphorus to surface waters, by runoff and by transport processes in the soil. In general, reduced tillage increases aggregate stability and may thereby reduce particle transport of phosphorus. In an experiment on a clay soil at Lanna, Västergötland, lysimeters were collected from treatments with mouldboard ploughing and treatments which had been direct-drilled for 22 years. The concentration of phosphorus in the drainage water from the lysimeters was significantly lower for the direct-drilled soil (Figure 29.9).
Another form of reduced tillage is shallow (10-15 cm) mouldboard ploughing. Our results from the last five years are very promising. We think that this form of ‘reduced’ tillage has many advantages both in relation to conventional and ploughless tillage.

The long-term experiments are a very valuable resource. The effects of tillage on soil structure and crop growth are very often truly long-term and cannot only be studied in short-term experiments. When new questions arise, for example new environmental issues, the long-term experiments form our natural laboratory that we use for finding answers.

**Pesticides**

At present, one research project is studying pesticide transport in two long-term experiments at Ultuna. The results are not yet published, but indicate more rapid transport of pesticides in ploughless compared with conventional tillage.

**Conclusions**

One main question concerning primary tillage is whether to plough or not. Nature strives for biological diversity but farmers wish to have uniform crop stands and high yielding crops and there is a constant struggle between those two forces. Crops can be kept uniform and high yielding by different kind of energy inputs, e.g. mechanical inputs (tillage) and chemical inputs (pesticides). The best and cheapest way for farmers to save energy and money is to use knowledge and/or experience to reduce input costs by adjusting tillage operations to current circumstances, while still obtaining a uniform and high yielding crop. So the answer to whether to plough or not is simply: *It depends*. In some cases continuous ploughing might be the best alternative. In other cases continuous ploughless tillage might be the best system. Sometimes a combination of mouldboard ploughing and ploughless tillage might be preferable.
References


Chapter 29


Chapter 30


Chapter 31


Chapter 32