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Non-inverting soil tillage as a means of optimising soil tilth

A field experiment was initiated in 1997 with non-inverting soil tillage compared to conventional tillage with annual mouldboard ploughing to either 20 cm depth (CT) or 10 cm depth (RCT). The new system included a non-inverting mechanical loosening of the soil to approximately 35 cm depth combined with a shallow cultivation of the top 5 cm soil by either a rotovator (NIT) or an S-tine harrow (RNIT). The experiment was located on a sandy loam at the organic farmed Rugballegård Experimental Station.

A plough pan at 20-35 cm depth was identified by cone penetration measurements. The non-inverting tillage system succeeded in breaking up the plough pan, which reduced the cone index from approximately 1.8 MPa in the CT and RCT treatments to 0.6 MPa in the NIT treatment.

A detailed soil profile description of the top 30 cm of the soil indicated that root growth was restricted for especially CT and RCT treatments in the form of thickened and horizontally deflected roots at the interface between the topsoil and the plough pan at approximately 22 cm depth. For RCT a new plough pan was under development just below the present ploughing depth at 10 cm. This also resulted in root growth restriction, but to a lesser extent than the deeper plough pan.

A soil drop test was performed to characterise soil fragmentation. Undisturbed cubic soil samples were taken from the 5-15 cm layer and dropped from 75 cm height in to a metal box. The resulting aggregate size distribution differed between the treatments with geometrical mean weight diameter (GMD) of 5.7 mm 7.4 mm and 8.9 mm for CT, RCT and NIT treatments, respectively. The higher degree of fragmentation for the mouldboard ploughed soil may be explained by higher energy input per soil volume by mouldboard ploughing than by non-inverting deep loosening. The results indicate for the 5-15 cm layer, that plant growth conditions were best for CT treated soil, due to a combination of low cone index and small aggregates. For the 20-35 cm layer, the results indicates best plant growth conditions for NIT treated soil due to a low cone index and less restricted root growth.

The spring barley/pea mix with grass/clover undersown yielded on average 47.6 hkg/ha. There were no significant differences between treatments.

1. INTRODUCTION

Danish agriculture is presently characterised by a shift towards farming systems with a lower input of pesticides and plant nutrients. The reasons for this are an increased interest in organic farming practice and lower inputs of nitrogen and pesticides in conventional farming due to general legislation. The planned further cut in EU grain prices makes it necessary for the farmer to save costs, which may lead to an increased interest in less labour-intensive soil tillage systems that are successful in a situation with a lower input of nitrogen and low or no inputs of pesticides.

Conventional tillage with annual ploughing to about 20 cm depth is still by far the most common tillage practice in Danish conventional and organic farming, despite the known disadvantages (e.g. plough pans and high inputs of energy and labour). Work by Schjønning[1,2] confirms that plough pans are common in Danish agricultural soils.

Reduced tillage systems have been tested in all the Scandinavian countries during the last about 25 years as reviewed by Rasmussen[3]. The success of reduced soil tillage depends especially on soil type, crop and crop rotation. Rasmussen concludes that reduced tillage is successful especially on loamy soils, whereas it has been less successful on sandy Danish soils. Most success has been obtained by growing winter wheat, winter oil seed rape and late potatoes, whereas reduced tillage has been less successful in spring cereals. The major problems concerning reduced tillage may be increased problems with especially root weeds, unsatisfactory incorporation of crop residues and amended farmyard manure, and an increased compaction in the central and lower part of the former plough layer.

One of the main objectives of soil tillage is to optimise soil tilth. Soil tilth is a term, which has been used by scientists as well as farmers to describe the physical state of the soil in relation to plant growth. The concept of soil tilth has been reviewed recently in a number of papers. Karlen *et al.*[4] defined soil tilth as "*the physical condition of soil as related to ease of tillage, fitness as a seedbed, and its impedance to seedling emergence and root penetration*". Hadas[5] has more strongly emphasised the direct influence of tillage on soil tilth in his proposed rather broad definition: *Soil tilth: "tillage affected, quantifiable soil structural-state-dependent attributes governing and controlling a soil environment, favourable to crop production"*.

In low input farming systems a poor soil tilth is more likely to have a stronger negative impact on plant growth than under high input conditions, because poor soil tilth cannot be compensated by an increased addition of plant nutrients or chemical weed control (Hampl *et al.*[6]). Hansen[7] has shown that soil compaction has a more negative effect on crop growth and yield when organically farmed than when conventionally farmed.

In a tillage experiment initiated in 1997 we try to integrate the advantages of reduced soil tillage systems with the advantages of annual ploughing. We are testing an alternative tillage system based on the principle of shallow intensive tillage and non-inverting deep loosening as suggested by e.g. Hampl *et al.* (6).

The system is less labour-intensive but at least as energy consuming as conventional tillage, when deep loosening is carried out to maximum depth of 40 cm.

2. MATERIALS AND METHODS

The site

The experimental site is located at the Rugballegård Experimental Station, Research Centre Bygholm, Horsens, Jutland. Rugballegård is a newly established experimental station with research focusing solely on organic farming. The soil is a sandy loam developed on diluvial clay, sand and gravel. On the experimental site there is 11-14% clay and about 3% organic matter. Annual precipitation is about 650 mm.

Experimental design and tillage treatments

The experiment was established in 1997 in a field converted to organic farming practices in 1995. There is a five-course rotation on the field consisting of 1. barley/pea with grass/clover undersown, 2. and 3. grass/clover, 4. oats and 5. winter wheat. Four tillage treatments were applied to plots in a randomised block design with four replicates (Table 1). Sampling and measurements took place in the spring barley/pea mix with clover grass undersown. No animal manure was added in 1997.

Table 1. Tillage treatments

	Conv. Tillage (CT)	Reduced conv. Tillage (RCT)	Non-inverting tillage (NIT)	Reduced non-inverting tillage (RNIT)
Primary tillage	20 cm Mouldb. pl.	10 cm Mouldb. pl.	35 cm Loosening	35 cm Loosening
Secondary tillage	S-tine harrowing	S-tine harrowing	Rotovating	S-tine harrowing

An implement composed of subsoiler tines combined with a rotovator (NIT) or an S-tine harrow (RNIT) and a drill was used for the non-inverting tillage. The depth of subsoil loosening is flexible, but was set at approximately maximum depth (35 cm) in 1997. The ploughing systems included mouldboard ploughing followed by secondary tillage and drilling in one pass by a combined implement.

Measurements

Cone index data were collected in May at field capacity with a cone penetrometer (8). The measurements were carried out in CT, RCT and NIT treatments with 20 replicates per plot. Cone index was automatically recorded for each cm increment to a maximum depth of 50 cm.

A soil drop test was performed in the middle of July in the field in CT, RCT and NIT treated plots. The test is performed as follows: an undisturbed cubic soil sample (644 cm^3) is collected from 5-15 cm layer, dropped from 75 cm height into a metal box and passed through a nest of sieves to determine the aggregate size distribution. Six replicates were carried out per plot in three of the four blocks.

A detailed profile description was carried out in the middle of July in the 0-30 cm layer in three replicates per treatment (CT, RCT and NIT). Soil structure was assessed according to conventional methods for profile description (9). Root growth characteristics, earthworm activity and turnover of organic matter were described according to our own guidelines based on (9), (10) and (11).

3. RESULTS AND DISCUSSION

Cone index

A plough pan was found in the 20 to 35 cm depth for CT and RCT with cone index values up to 2.0 MPa (figure 1). The response of root growth to dense and compacted soil depends on plant specie, variety, water content, etc. Dexter[12] has found an exponential decrease in root elongation with increased cone index of the soil. He also found that root elongation rate was reduced to half the unaffected value at cone indices of 0.7 MPa and 2.0 MPa for cotton and pea, respectively. The deep loosening in NIT had broken up the plough pan and the cone index was reduced up to 1.0 MPa in comparison with CT and RCT.

For RCT, the cone index increased markedly just below the present ploughing depth indicating the development of a new plough pan. This finding is in agreement with the general results from Scandinavian experiments with reduced tillage, where increases in density and cone index have been found just below tillage depth (5).

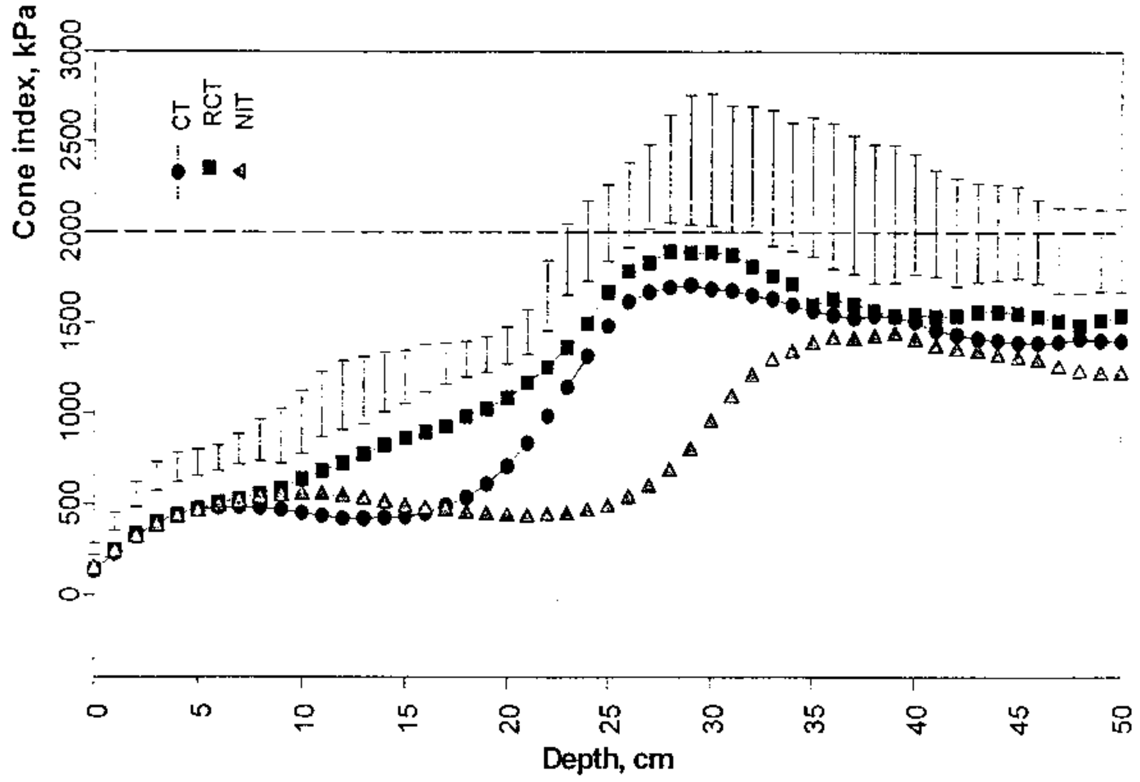

Figure 1. Cone penetration results. Vertical bars denote LSD_{95} range.

Soil drop test

The resulting aggregate size distribution of the soil drop test is a result of fragmentation due to primary tillage and to the drop itself. The mean weight diameter (MWD) was 13.0 mm, 16.3 mm and 17.8 for CT, RCT and NIT, respectively. The geometrical mean weight diameter (GMD) was 5.7 mm. 7.4 mm and 8.9 mm respectively for CT, RCT and NIT. The higher fragmentation of the CT compared with the NIT treated soil (Figure 2) may be due to the difference in primary tillage method rather than the drop itself. The energy input per soil volume in the tested soil layer is higher for mouldboard ploughing than for deep loosening. The soil from the RCT-treatment fragmented to some extent in the same manner as CT, but with more large fragments or clods (>32 mm). This may be ascribed to the occurrence of compacted clods at the bottom of the layer sampled as a consequence of the development of a new tillage pan below 10 cm as indicated by the cone index results.

Hewitt and Dexter[13] conclude in their work on modelling root growth in structured soils, that the smaller the aggregate size, the greater the nutrient availability and that the influence of aggregate size decreases with decreasing aggregate strength. This implies for the studied 5-15 cm layer, that plant growth conditions are best with CT treatments (low cone index and smallest aggregates) followed by NIT (low cone index, bigger aggregates) and RCT (highest cone index, relative high proportion of largest size of aggregates (clods)).

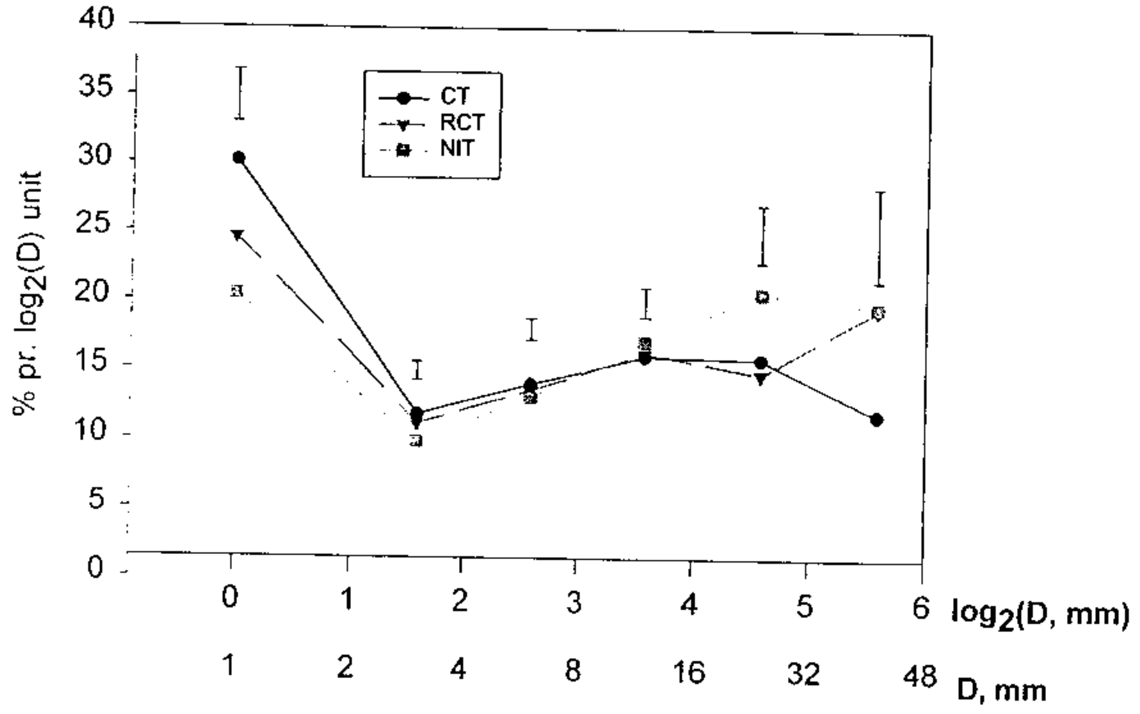

Figure 2. Aggregate size distribution after soil drop. Bars denote LSD_{95} range.

Soil profile description
The upper 30 cm of the soil profile could be divided into three zones (Table 2): 1. an upper harrowed or rotovated porous layer; 2. the lower part of the traditionally ploughed layer, which was divided into two for RCT; 3. the plough pan below the traditionally ploughed layer, which was broken up in the NIT treatment.

Table 2. Soil structure

	CT	RCT	NIT
Layers	*1.* 0-9 cm harrowed layer *2.* 9-22 cm plough layer *3.* 22-30 cm plough pan	*1.* 0-6 cm harrowed layer *2.1.* 6-12 cm plough layer *2.2.* 12-23 cm old pl. layer *3.* 23-30 plough pan	*1.* 0-8 cm loose cult. l. *2.* 8-23 cm old plough l. *3.* 23-30 cm loosened pl. pan
Structure	*1.* Crumbly *2.* Subang. bl.+crumbly *3.* Comp. massive	*1.* Ccrumbly *2.1.* Sub. blocky+crumbly *2.2.* Subang. blocky *3.* Subang. blocky+ comp. massive	*1.* Crumbly *2.* Crumbly +subang. bl. *3.* Subang. blocky

Below the upper intensively cultivated layer, soil structure differed markedly between the treatments. For the RCT treatment the compaction below the present tillage depth at 10 cm resulted in a more blocky structure. The deep loosening in NIT had broken up the compact massive plough pan resulting in a blocky structure.

Root growth was strongly affected by the physical conditions (Table 3). Thickened and horizontally deflected roots were observed at the interface between the loose cultivated layer and the plough pan below and also at the interface between the ploughed 10 cm layer in the RCT treatment and the soil below. These observations of horizontally deflected roots are in accordance with model observations by Dexter[14,15]. Usually the plant roots grew horizontally above the plough pan until they reached a vertical crack or biopore. This was especially the case for the CT and RCT treatments.

Nodulation on pea roots was also negatively affected in the compacted soil layer. Nodules were not observed in the plough pan layer for CT and RCT, whereas some were observed in that layer for the NIT treatment. A poor nodulation on pea roots may indicate low aeration in the plough pan layer.

Crop yield
The yield level was an average of 47.6 hkg/ha, which is quite high when considering the rates of applied plant nutrients. There was no significant difference between the tillage treatments. We might have expected that the better root growth conditions observed for the deep loosened treatments would have resulted in an increased yield. However, 1997 was a year with normal precipitation that was also well distributed in time. This may explain why reduced root growth conditions for CT and RCT did not result in a decreased yield.

Table 3. Root growth characteristics

	CT	RCT	NIT
No. >2 mm roots pr. dm^2	*1.*[1] 1-5 *2.* <1 *3.* <1	*1.* 1-5 *2.1.* <1 *2.2.* <1 *3.* <1	*1.* 1-5 *2.* <1 *3.* <1
No. 0,5-2 mm roots pr. cm^2	*1.* >5 *2.* 1-5 *3.* <1	*1.* >5 *2.1.* 1-5 *2.2.* 1-5 *3.* <1 – 1-5	*1.* >5 *2.* 1-5 - >5 *3.* 1-5
Branching	*1.* Good *2.* Moderate *3.* Poor	*1.* Good *2.1.* Moderate *2.2.* Moderate *3.* Poor	*1.* Good *2.* Moderate-Good *3.* Moderate
Obstacles	Compacted layer in 3	Weakly comp. layer in 2 Compacted layer in 3	Compacted layer in 3
Thickened roots	Interface 2-3: Some	Interface 1-2: Few Interface 2-3: Some	Interface 2-3: Some
Extent of horizontally deflected roots	Interface 2-3: Large	Interface 1-2: Some Interface 2-3: Large	Interface 2-3: Large
Nodulation on pea roots	*1.* Many *2.* Some *3.* None	*1.* Some *2.1.* Some *2.2.* Some *3.* None	*1.* Some-Many *2.* Some *3.* Some
Distribution of nodules on pea roots	*1.* Good *2.* Good *3.* -	*1.* Moderate *2.1.* Moderate *2.2.* Poor-Moderate *3.*-	*1.* Good *2.* Good *3.* Good

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[1] Numbers indicate layers defined in Table 2

4. CONCLUSIONS

Most of the presented results indicate an improved soil tilth when NIT tillage practice was applied compared to CT or RCT. The subsoiler in the NIT treatment broke up a plough pan in the 20-35 cm layer. This resulted in diminished mechanical impedance in the plough pan layer and improved root growth characteristics. For the 5-15 cm layer the results indicate that soil tilth was best for CT treated soil, due to a combination of a rather low cone index and small aggregates. NIT treated soil had a similar cone index but larger aggregates, whereas RCT had both a larger cone index and a relatively high amount of large aggregates or clods.

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