Swedish University of Agricultural Sciences
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Influence of mouldboard ploughing and shallow tillage on soil physical properties and crop performance

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Master's Thesis in Soil Science
Soil and Water Management – Master's Programme

Institutionen för mark och miljö, SLU
Examensarbeten 2012:01

Uppsala 2012

SLU, Swedish University of Agricultural Sciences
Faculty of Natural Resources and Agricultural Sciences
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EX0430, Independent Project in Soil Science - Master´s thesis, 30 credits, A2E
Soil and Water Management – Master's Programme 120 credits

Institutionen för mark och miljö, SLU, Examensarbeten 2012:01
Uppsala 2012

Keywords: mouldboard ploughing, shallow tillage, soil physical properties, crop performance

Online publication: http://stud.epsilon.slu.se

Cover: Spring barley at Ultuna, 2011. Photo by author.

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Nargish Parvin, 2012. Uppsala: SLU, Dep. Soil and Environment

Abstract

This study was conducted in spring 2011 in a long-term field experiment with the objective of assessing the effect of shallow tillage and mouldboard ploughing on some soil physical properties and crop performance. In this field, different tillage experiments established in 1974. Five treatments were included in the experiment but this investigation considered only two treatments, shallow tillage and mouldboard ploughing. In these two treatments, undisturbed soil samples were taken before sowing the seeds at the depth of 15-20, 25-30 and 35-40 cm for the determination of saturated hydraulic conductivity (Ks), bulk density (Bd), and water retention in laboratory condition. Penetrometer resistance (PR) were measured in the field one month after sowing. Plant density of barley was also counted one month after sowing. Significantly higher Ks value was found for shallow tillage at the depth of 15-20 and 25-30 cm. Bd was significantly lower for mouldboard ploughing for the first two investigating depth and it was higher at 35-40 cm but the difference was not statistically significant. Moreover, Bd was high in both treatments. Significant higher PR value was found for shallow tillage especially at the depth of 5-35 cm but the result was not so high to reduce the root growth. Water content determined parallel with PR measurement was similar for the two treatments. Plant density and crop yield were significantly higher in shallow tilled treatment than in moulboard ploughing. Field water content at 15-20 and 25-30 cm was significantly higher for moulboard ploughing. Water retention at 1 meter suction was also significantly higher in the treatment with mouldboard ploughing. However, the differences of the physical parameters due to tillage treatments was sufficient to markedly influence crop performanc and yield.

Contents

1. Introduction

The prime necessity of tillage is to prepare the land or the seedbed where the plants can easily grow. Using different types of equipments driven manually or by powered machines make the soil suitable to place the seeds into the desirable depth. Tilling the fields hinders or slowdown the growth of weeds and improve crops' competition against weeds. Moreover, tillage loosens the compacted layers. The history of tillage goes back to 3000 BC in Mesopotamia (Hillel, 1998). People started cultivation in the fertile land close to the river valleys of Nile, Tigris, Euphrates, Yangste and Indus (Hillel, 1991). In the early age it was not possible to till vast area of land to desirable depth by hand tools. Following the industrial revolution in the nineteenth century, agricultural machinery and tractors became avaiable for tillage operations.

Different types of tillage systems have different tillage depths and capacity to change soil physical and chemical properties that affect the crop yield and quality (Strudley *et al.,* 2008). Time and frequency of tillage also has significant effect on crop production (Stenberg *et al.*, 1997). Important soil physical properties such as bulk density, penetration resistance, water infiltration, hydraulic conductivity and soil compaction are affected by tillage (Hamza and Anderson, 2005).

Tillage disturbs the natural condition of soil. Ploughing may damage the pore continuity and aggregate stability resulting in sediment mobilization, erosion and surface hardening. Ploughing is also high energy consuming. Shallow tillage has the positive effects on soil health such as aggregate stability (Vakali *et al.*, 2011; Riley *et al.,* 2008) as well as infiltration capacity, hydraulic conductivity and aeration. Also, the importance of reduced or shallow tillage for soil conservation and low cost have been well documented (Carter, 1994; Sijtsma *et al.,* 1998; Tebrugge and During, 1999; Arvidsson *et al.,* 2004).

Objective

The objective of this study is to evaluate the influence of long-term shallow tillage (ST) and mouldboard ploughing (MP) on some important soil physical properties (hydraulic conductivity, bulk density, penetration resistance and water retention) and crop performance.

2. Literature review

2.1 History and purpose of mouldboard ploughing (MP) and shallow tillage (ST)

It has been documented that mouldboard plough was invented about 2000 years ago and since 11th century it has been used in a larger scale (Carter, 1994). The main purpose of MP is to cut and turn the furrows. Ploughing cuts and burries weeds and incorporates crop residues. However, ploughpan formation and sub-soil compaction may occur (Carter, 1994).

During early 1970s, the cost of mouldboard ploughing became very expensive due to high cost of fuel. This forced the investigation and implementation of different types of reduced or minimum tillage (Bullen, 1977). In addition, invention of effective herbicide during 1960s increased the successfulness of reduced tillage. Shallow tillage is one of the several reduced or minimum tillage types and it's usual tillage depth is about 10 cm (Carter, 1994). Unlike MP, ST does not invert soil and it can decrease the cost of tillage by 25-48% without having considerable negative effects on crop production (Carter, 1991).

2.2 Effects of ST and MP on bulk density and penetration resistance

Bulk density (Bd) is one of the natural soil characteristics (Cassel, 1982; Chen *et al.,* 1998; Franzen *et al.,* 1994). During the year Bd can vary because of the natural processes such as freezing-thawing and drying-wetting cycles (Blevins *et al.,* 1983; Unger, 1991), and rainfall effect (Cassel, 1982). Also, anthropogenic effects like tillage activity and animal grazing may change soil Bd. Generally, most of the soils have Bd between 1 to 2 g cm^{-3} and optimum Bd for better crop yield varies according to soil types and crop species. Ideal Bd for clay soil is <1.1 gcm^{-3} and Bd greater than 1.47 gcm^{-3} can hinder the root growth (USDA, 2008). According to Campbell and Henshall (1991), Bd that can reduce root growth is between 1.46 to 1.90 gcm^{-3} (Pabin et al., 1998). In a sandy soil, optimum Bb found to be 1.43 Mgm^{-3} for barley root growth and crop yield (Czyz et al, 2001).

Generally all tillage practices reduce Bd and penetration resistance (PR) to the depth of loosening (Erbach *et al*., 1992). However, several experiments were investigated to compare no-tillage (direct drilling) or Shallow tillage with other conventional tillage (mouldboard ploughing). In most cases, no tillage systems had higher Bd in the upper top soil layer (Ehlers *et al.,* 1983; Pelegrin *et al.,* 1988; Radcliffe *et al.,*1988; Hammel, 1989; Hill, 1990; Campbell and Henshall,1991; Grant and Lafond, 1993; Rhoton *et al.,* 1993; Franzen *et al.,* 1994; Hubbard *et al.,* 1994; Franzluebbers *et al.,* 1995; Unger and Jones, 1998; Tebrugge and During,1999; Wander and Bollero, 1999). On the other hand, some experiments found no differences in Bd for different tillage systems (McCalla and Army, 1961; Cassel, 1982; Blevins *et al.,* 1983; Burch *et al.,* 1986; Blevins and Frye, 1993; Taboada *et al.,* 1998; Arshad *et al.,* 1999; Logsdon *et al.,* 1999; Ferreras *et al.,* 2000; Logsdon and Cambardella, 2000).

Since highest positive effect on the soil physical properties (bulk density, infiltration rate, and organic carbon content) has been found for deep tillage than shallow tillage the crop yield increase with increasing the depth of tillage (Alamouti and Navabzadeh, 2007). On the other hand, ploughing depth in the range of 12-25 cm had no significant difference in crop yield as several Northern European research results revealed. However, weed infestation in shallow tillage may significantly decrease yields (Håkansson *et al.,* 1998). In an experiment in central Sweden in a weakly-structured silty clay loam soil, mouldboard ploughing with and without liming was compared and aggregate stability was improved in shallow tillage compared to conventional ploughing (Stenberg *et al.,* 2000).

Penetration resistance is a good tool to evaluate soil strength related to root growth but it is strongly influenced by the water content of the profile (Paul and Ordie, 1998; Carlos *et al.,* 2001; Daniel *et al.,* 1994) and in most cases soil structure has no significant effect on PR

(Koolen and Kuipers, 1983). In one experiment with barley crop in a sandy clay loam soil PR was found to vary proportionately with Bd and inversely with moisture content. (Khan *et al.*, 2001). Depending on particle size, surface roughness and organic matter content, penetrometer reading can vary within same soil (Cassel, 1982).

Generally, penetrometer gives 2 to 8 times greater value than the root actually faces while penetrating the soil (Bengough, 1991; Atwell, 1993; Gregory, 1994). During elongation roots of different crop species can exert pressure between 7-2.5 MPa (Gregory, 1994). Higher penetration resistance reduces root growth (Taylor, 1983; Atwell, 1993; Gregory, 1994) and the values greater than 2 MPa can significantly reduce the root growth (Atwell, 1993). In another experiment they found root growth cease at penetrometer resistance of 8 to 5 MPa, but the result can vary depending on soil types and crop species (Greacen et al., 1969)

2.3 Effects of MP and ST on hydraulic conductivity and water retention

Hydraulic conductivity is the ability of soil to transmit water and it depends on soil and fluid characteristics together. It mainly depends on the total porosity and the pore size distribution in soil and the density of water. Hydraulic conductivity is generally low in clay soil. Saturated hydraulic conductivity between 1-15 cmh^{-1} is suitable for most of the agricultural practices (Brady and Weil, 2002)

The influence of tillage on hydraulic conductivity depends on the time of sampling, location and historical background of the field and the results are sometimes conflicting because of generic and qualitative information (Onstad and Voorhees, 1987). Shallow tillage increases the organic matter content on the surface soil which can increase the moisture holding capacity of soil (FAO, 2005; Kay, 1990; Soane, 1990).

Several investigations showed that saturated hydraulic conductivity (Ks) was higher under no-till or shallow tillage systems than under mouldboard ploughing (Allmaras *et al.,* 1977; Rizvi *et al.,* 1987; Coote and Malcolm-McGovern, 1989). Some researchers also reported where the ploughed and no-tillage had similar Ks (Obi and Nnabude, 1988) and in some other cases ploughed soil had higher Ks than no-tilled soil (Heard *et al.,* 1988). Most researchers explained the presence of macropores as the reason behind the higher Ks under shallow or no-till systems (Allmaras *et al.,* 1977; Rizvi *et al.* 1987; Coote and Malcolm-McGovern, 1989). Conservation or shallow tillage system favors the formation of vertical channels created by earthworms or dying roots (Channel, 1985).

2.4 Effects of MP and ST on seed emergence and plant density

Maximum number of seed emergence satisfies the appropriate plant density in field that is important for maximum crop yield. Seedbed preparation and quality of seed determined the seedling emergence that is very important stage for crop establishment. Several soil factors affect plant emergence. Some important factors are soil temperature, water content and residual fertility (Forbes and Watson, 1992), surface layer hardening and quality of seeds (Ahmed, 2001), organic matter content (Önemli, 2004), proper contact of the seeds to soil (Stewart *et al.* 1999) and compaction effect (Nasr and Selles, 1995). According to Western Australian Department of agriculture and food, plant density of barley less than 80 m^{-2} can significantly reduce crop yield and weight of seeds can be reduced with plant density greater than 150 m^{-2}.

Compaction of seedbed after sowing affects the emergence but high amount of organic matter content in the soil can minimize this problem (Fawusi, 1978). Organic matter maintains the soil moisture content that is an important factor for the emergence of plants and this effect is clear for soils with less than 2% organic matter. At least 2% organic matter is essential to keep the soil productive (Önemli, 2004). Long-term adoption of any tillage systems may affect the distribution of soil organic carbon throughout the profile specially 0-20 cm but total organic carbon content remain same, shallow tillage only stratified the carbon content with increasing concentration close to soil surface while mouldboard ploughing uniformly distributed the organic carbon (Hermle *et al.*, 2008, Yang *et al.*, 2008).

3. Materials and methods

3.1 Site description and sample collection

Soil sampling was carried out in the spring 2011 at Ultuna near Uppsala, Sweden and the location of the area is marked in figure 1. The soil at the site is classified as clay soil with 42-50% clay content and the soil type is Eutric Cambisol. This field is under long-term field experiment since 1974.

There are five different tillage treatments (A, B, C, D and E) in a randomized block design with four replicates (I, II, III and IV):

A= Mouldboard ploughed (MP) to 22-24 cm

B= Shallow tillage (ST) has been done in B up to 10-12 cm and treated as A in every fourth year

C= Chisel ploughed to 22-24 cm with non-inverting implements and also treated as A in every fourth year

D= only shallow tillage (ST) to 10-12 cm

E= Chisel ploughed to 22-24 cm with non-inverting implements annually

Soil organic carbon content in MP at 0-20 cm is 19 g kg^{-1}, in ST at 0-10 cm is 26 g kg^{-1} and in ST at 12-17 cm is 19 g kg^{-1} (Etana *et al.*, 2009).

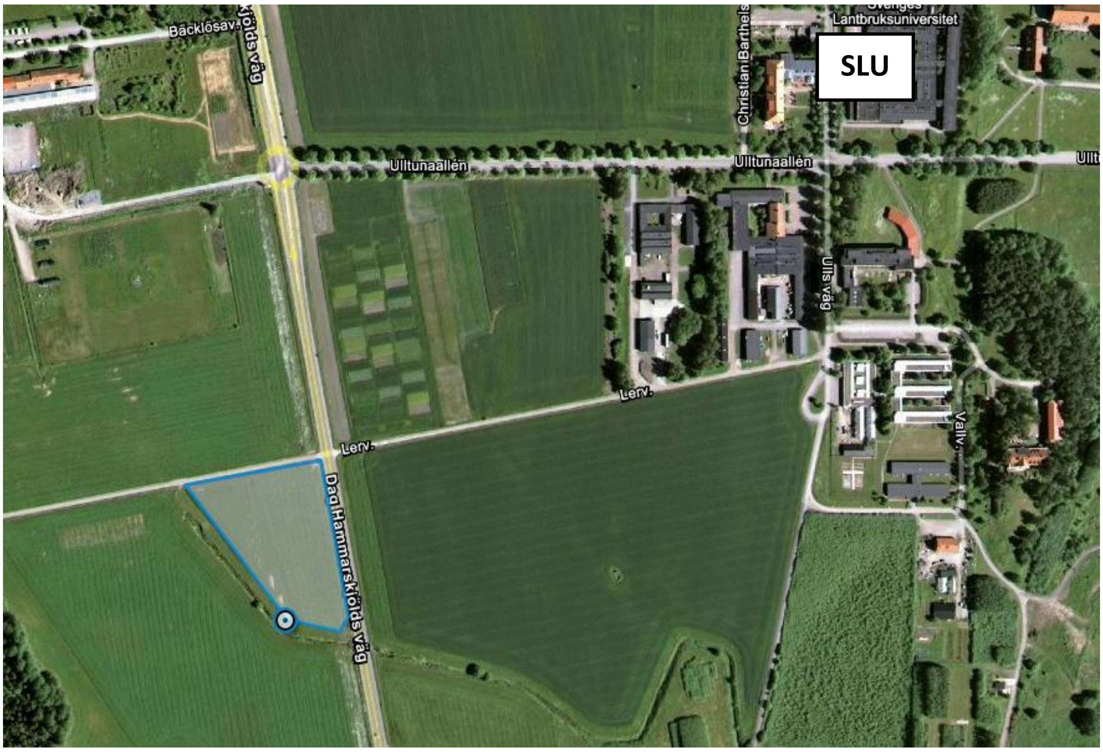

Figure 1. Experimental site (bordered area) (59°48’N/17°39’E) (Eniro, 2011).

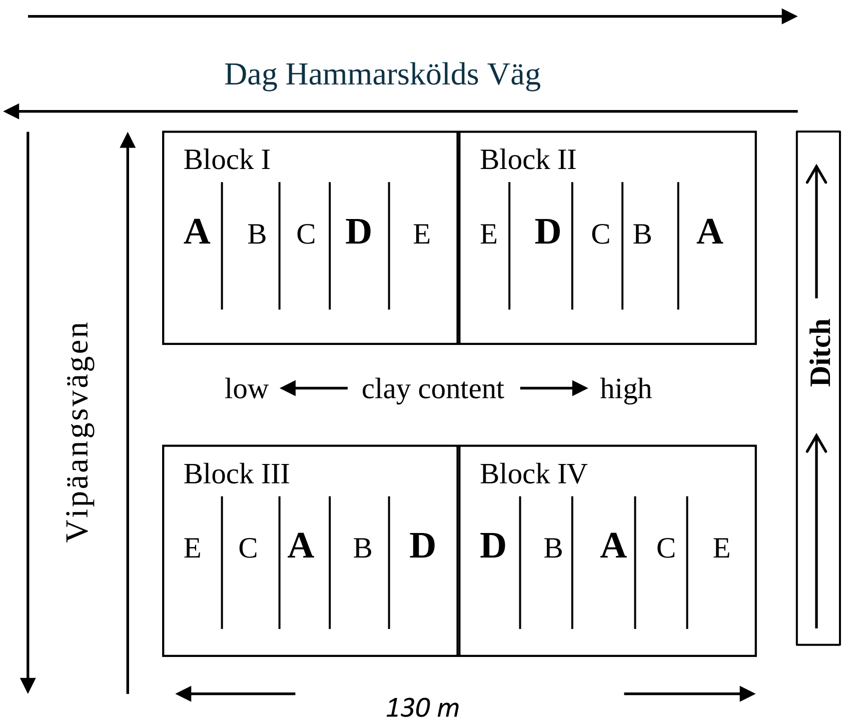

Figure 2. Experimental design. The investigated treatments (A and D) are shown with **bold.**

Soil samples were collected in three layers (15-20, 25-30, 35-40 cm) of MP and ST. Three soil cores were taken in each plot and depth. The sampling cores were 5 cm in height with cross sectional area of 40.715 cm^2. The field was tilled in autumn and barley seeds were sown in spring. Samples were collected before sowing of seeds.

3.2 Saturated hydraulic conductivity (Ks)

Ks was measured on the core samples by the constant head method (Andersson, 1955). Before the measurement core samples were saturated with water for three days. Measurements were done two times with 8 hours difference at a constant head of 10 cm. K_s was calculated using Darcy's equation for saturated flow. Core samples were weighed before saturation in water in order to determine the soil water content at sampling.

3.4 Water content at 1m suction and bulk density

Water retention at 1 m water column was determined in Eijkelkamp sandbox which is equipped with suction levelling stand; filter cloth (140-150 micron) over the sand bed. The saturated soil samples used for measuring hydraulic conductivity were placed on the filter cloth surface and the equilibrium was attained in week. After one week samples were weighed and water content and dry bulk density were determined after drying the samples at 105^{o}C for three days.

3.3 Penetration resistance

Penetration resistance (PR) was measured one month after sowing using an Eijkelkamp hand-held electronic cone penetrometer. The penetrometer was pushed vertically into the soil profile at a steady speed of 2 cm/sec. The cone type was 60^o angle with 1 cm^2 base area. The penetrometer is connected to a software that registers the data of cone index along with depth. Ten measurements were done in each plot, giving 80 measurements for 8 replications (40 per treatment). PR data were recorded to a depth of 48 cm. On the same day soil augur samples were collected at 0-50 cm depths from two representative blocks to determine the gravimetric water content.

3.5 Plant density

Plants were counted one month after sowing within 50 cm by 50 cm steel frame. Counts were done randomly at four points in each replication of MP and ST and plant density was calculated per square meter.

3.6 Statistical analysis

The computer software Minitab 16 was used for statistical analysis. Paired t-test with 95% confidence interval was done between the treatments for all the parameters. The variables involved in this test were two tillage methods (MP and ST) and different depths (15-20, 20-35 and 35-40 cm).

4. Results

4.1 Soil water content

Soil water content (%) at sampling is given in Figure 3 and MP had significantly (P=0.00) higher water content than ST at 15-20 and 25-30 cm. Figure 3 shows that the water content increased with depth, and block II and IV were wetter than block I and II.

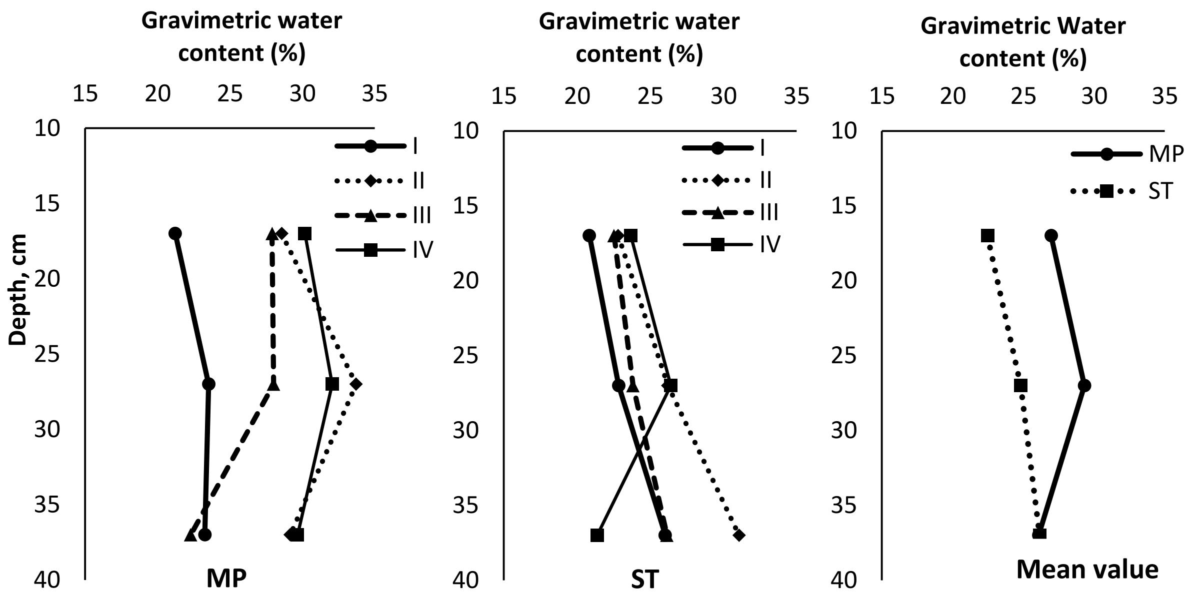

Figure 3. Gravimetric soil water content (%) at sampling (MP= water content in each replication (I, II, III and IV) of mouldboard ploughing, ST= water content in each replication (I, II, III and IV) of shallow tillage and Mean value= average result of four replication in MP and ST).

4.2 Water content at 1m suction

Figure 4 shows that higher water content at 1 meter suction was found in the samples taken in MP than in ST and significance was found (P=0.03) for the depth of 25-30 cm. In all the replications, MP plots had the highest water content at 25-30 cm (Fig. 4) at 1 m suction. All the replications of ST except in block IV had the highest water content at the depth of 35-40 cm (Fig. 4).

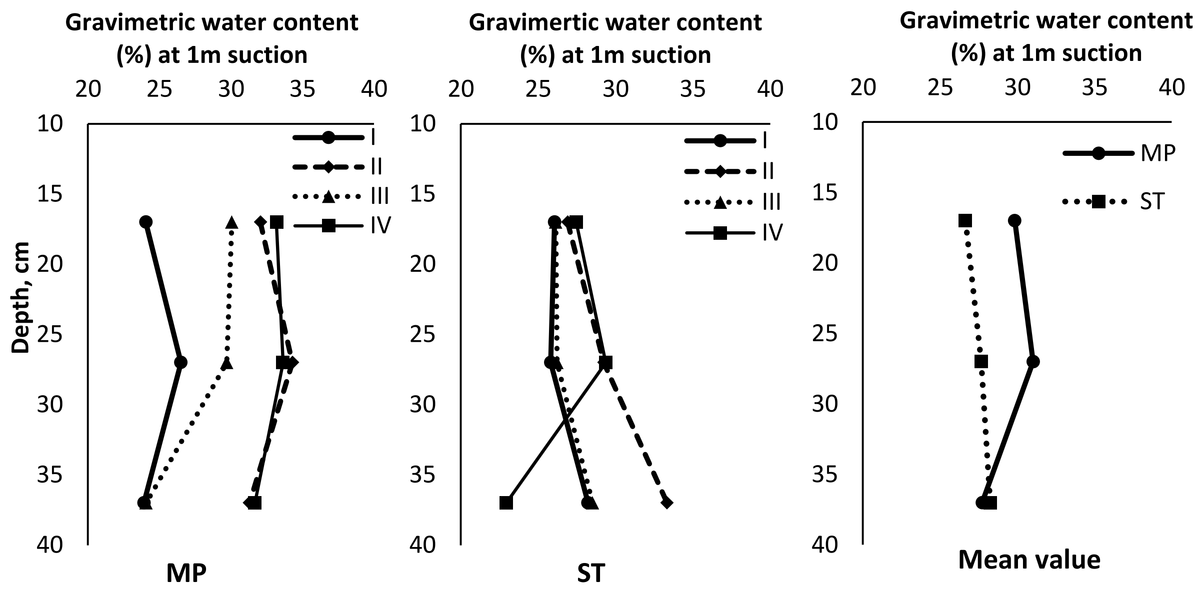

Figure 4. Gravimetric water content (%) at 1 m suction (MP= water content in each replication (I, II, III and IV) of mouldboard ploughing, ST= water content in each replication (I, II, III and IV) of shallow tillage and Mean value= average result of four replications in MP and ST)

4.3 Bulk density

Figure 5 shows that the bulk density was significantly (P<0.00) higher in ST than for MP for the depth of 15-20 and 25-30 cm, but at 35-40 cm Bd was higher for MP than ST. All the replications of ST except in block IV had lower Bd than MP at the depth of 35-40 cm (Tab. 1 in appendix).

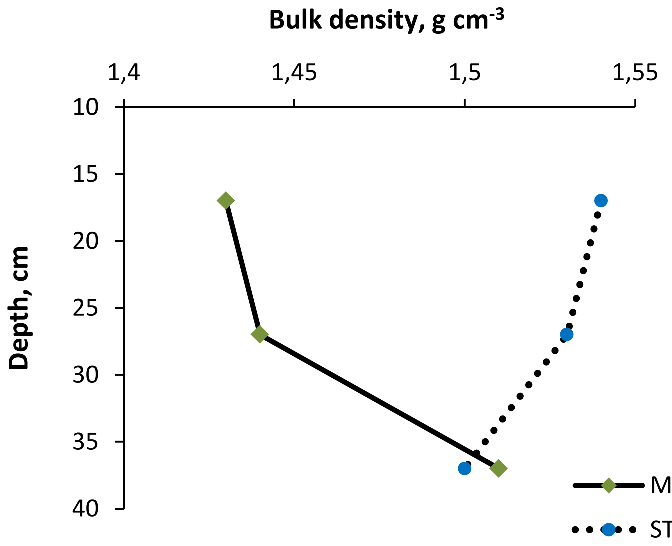

Figure 5. Bulk density in Mouldboard ploughing (MP) and Shallow tillage (ST) in three different layers.

4.4 Hydraulic conductivity

In the measured depths, Ks decreased with depth and it was significantly higher (P=0.01) for ST than MP at 15-20 and 25-30 cm (Fig. 7). However, there was high variation among the replications of same treatment. Ks measured after 1hr (Ks1) and after 8 hrs. (Ks2) are shown by the Figure 6.

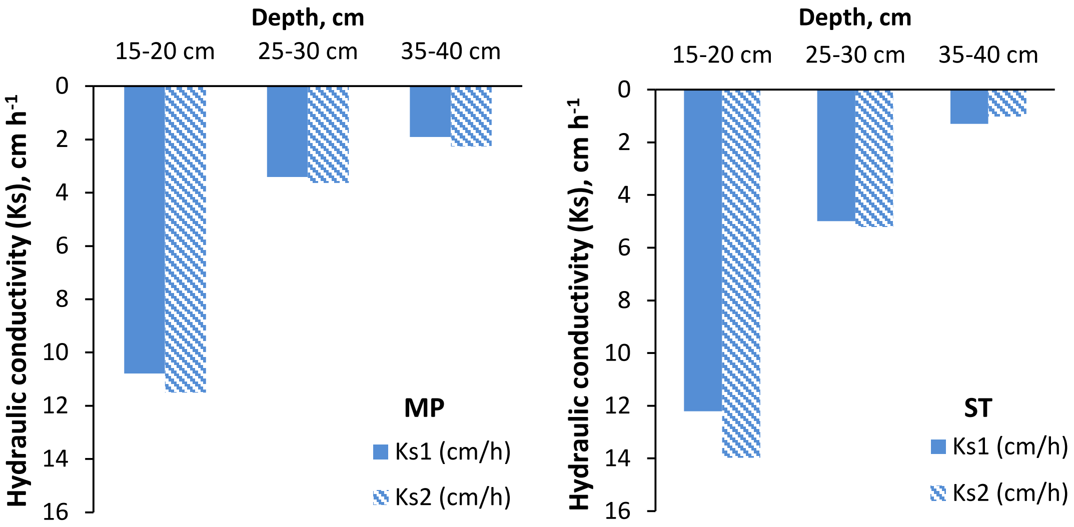

Figure 6. Saturated hydraulic conductivity (Ks) for two measurements (Ks1 and Ks2) with 8 hours difference in Mouldboard ploughing (MP) and Shallow tillage (ST).

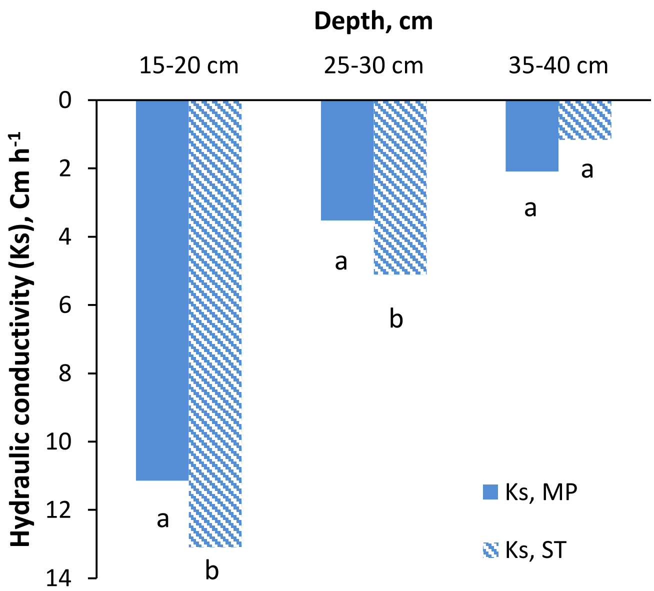

Figure 7. Saturated hydraulic conductivity in Mouldboard ploughing (MP) and Shallow tillage (ST) in three layers (Ks= average of Ks1 and Ks2). Mean values that do not share common letters are significantly different.

4.5 Penetration resistance

Figure 8 shows penetration resistance (mean for 10 measurements) in MP and ST plots. Mean value (Fig. 9) shows the penetration resistance was significantly (P=0.00) lower in MP than ST in 5-35 cm depth. Soil samples taken on the same day as penetration measurement did not give significant difference in soil water content (Fig.10b) but significant difference was found between replicates (Fig. 10a). All the replicates of ST except in block IV had higher penetration resistance than MP. The deviation in block IV was due to the high water content.

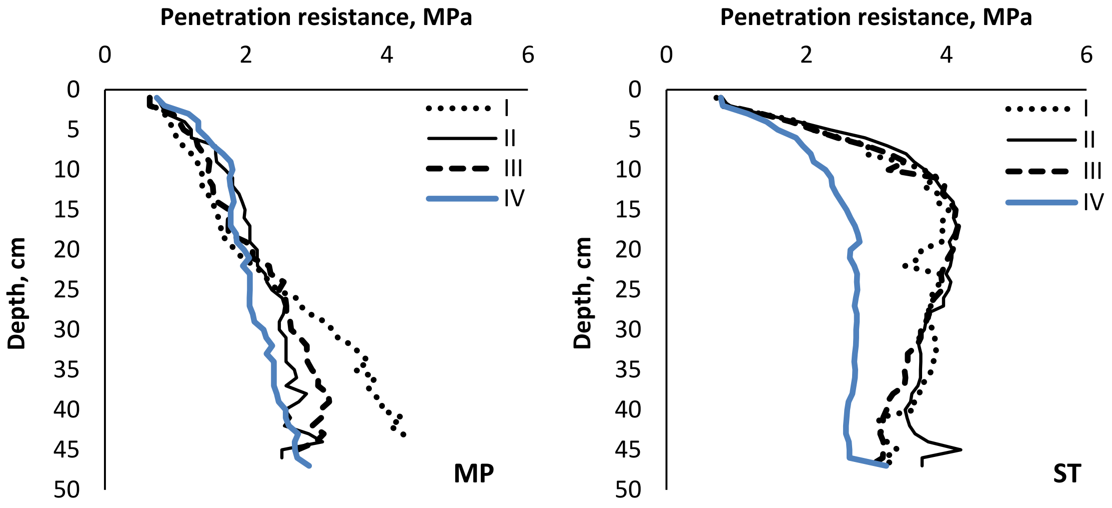

Figure 8. Penetration resistance in four replication (I, II, III and IV) of Mouldboard ploughing (MP) and Shallow tillage (ST) as a function of depth.

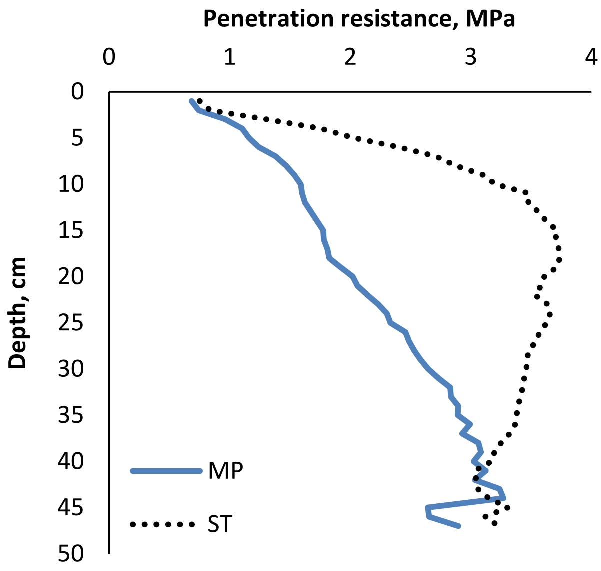

Figure 9. Penetration resistance in Mouldboard ploughing (MP) and Shallow tillage (ST) as a function of depth.

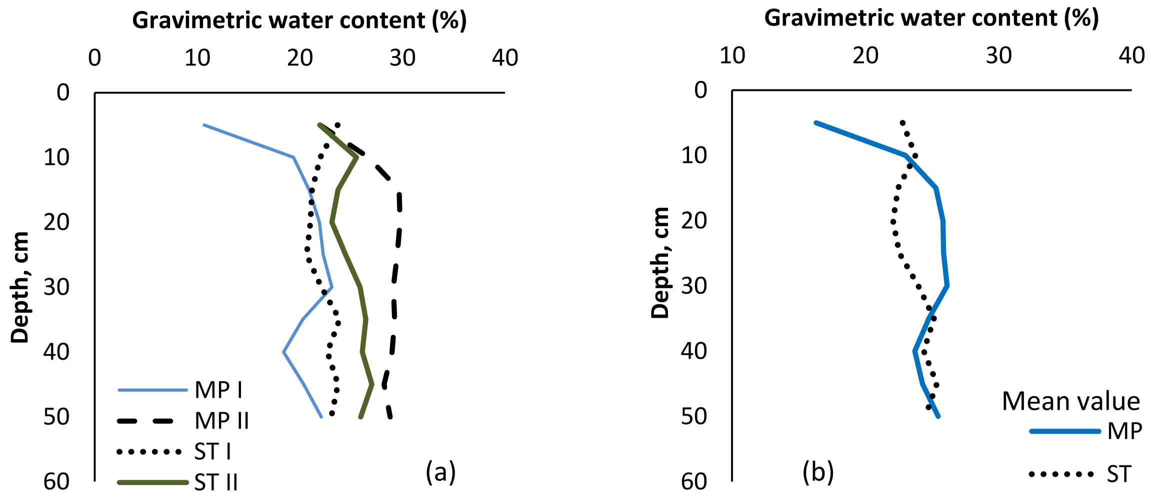

Figure 10. Gravimetric water content (%) in samples taken at the time of penetration resistance measurement (a= water content of block I and II in Mouldboard ploughing (MP) and Shallow tillage (ST) and b= average water content of block I and II in MP and ST).

4.6 Plant density and crop yield

Generally, plant density was low for the whole experiment. All the replications of ST had higher amount of plants than MP (Tab. 2 in Appendix) and this was in agreement with visual observation. ST in block III had the highest amount of plants and MP in block III had the lowest (Fig. 11). The difference in plant density between the treatments was highly significant ($P<0.001$). Consequently, ST had higher crop yield (3840 kg/ha) than MP (2490 kg/ha) (Tab. 1). On average (1975-2011), the relative crop yield was higher in shallow tillage by 4% than in mouldboard ploughing (Tab. 1).

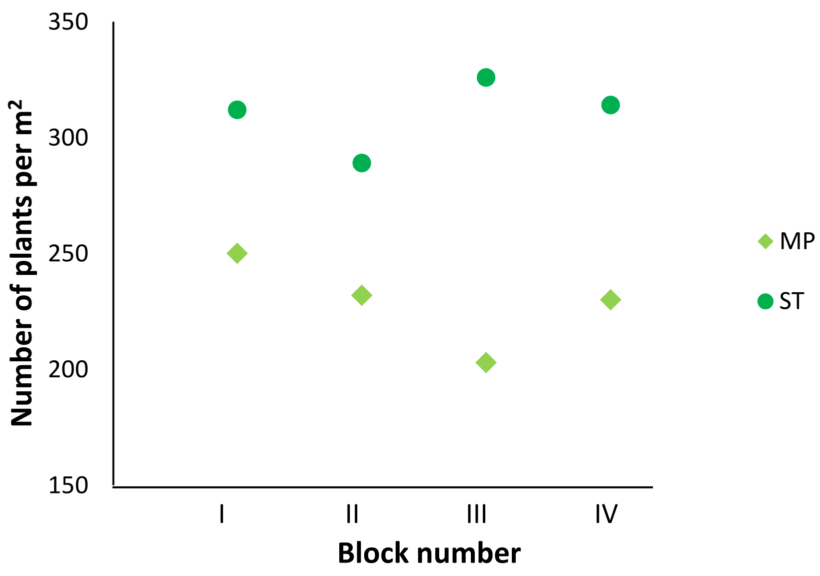

Figure 11: Average number of plants per m^2 in treatment Mouldboard ploughing (MP) and Shallow tillage (ST).

Table 1: Crop yield data and relative value from 1995-2011 (Faltförsk, SLU, 2011)

Year	*Crop*	*Yield, Kg/ha*		*ST in % of MP*
		MP	*ST*	
1995	Barley	3970	4920	124
1996	Spring wheat	5170	5370	104
1997	Barley	4840	5020	104
1998	Barley	2360	3250	138
1999	Barley	2340	1920	82
2000	Winter wheat	7500	7660	102
2001	Winter wheat	3850	4130	107
2002	Spring oil seed rape	1520	1540	102
2003	Winter wheat	6290	6490	103
2004	Winter wheat	5320	4410	83
2005	Oats	6280	6260	100
2006	Barley	3670	4250	116
2007	Winter wheat	6430	6320	98
2008	Oats	3620	2780	77
2009	Oil seed rape	2450	2340	95
2010	Winter wheat	6070	5130	84
2011	**Barley**	**2490**	**3840**	**154**
1975-2011	-	-	-	104

5. Discussion

Higher hydraulic conductivity under shallow tillage than under mouldboard ploughing is due to stable macropores (Allmaras *et al.*, 1977; Rizvi *et al.* 1987; Coote and Malcolm-McGovern, 1989). In shallow tillage biopores and cracks in the lower topsoil are not destroyed by tillage action. Several researchers also found higher Ks in shallow tillage than mouldboard ploughing where they explained presence of earthworm channels, and root channels as the responsible factors (Allmaras *et al.*, 1977; Rizvi *et al.*, 1987; Coote and Malcolm-McGovern, 1989). In addition, in shallow tillage crop residues are left close to the surface or mixed within only 10-12 cm which could be another reason for higher Ks (Lampurlanes and Cantero-Martínez, 2006). Furthermore, inversive tillage (ploughing) makes the aggregates unstable during wetting (Vakali *et al.*, 2011 and Riley *et al.*, 2008) that could cause lower Ks. However, Ks is extremely variable even between samples taken adjacent to each other (Russo and Bresler, 1981; Lauren et al., 1988; Mohanty et al., 1994). Thus, although there was a tendency for greater Ks in ST than in MP, the values were not always statistically different from each other. This is due to the variation in size and number of macropores.

Almost all kind of inversive tillage reduces bulk density (Erbach *et al.*, 1992). In this study I found lower Bd in MP in 15-20 and 20-35 cm depth. On the other hand, at the depth of 35-40 cm the average Bd was higher for the MP. This may due to wheeling in the furrow during ploughing. Additional reason may be due to the traffic for secondary tillage and for other operations. In case of ST, the undisturbed topsoil, which had relatively greater bulk density and penetration resistance, could protect the upper subsoil from compaction. However, ST cannot protect the soil from excessive compaction. The greater bulk density in ST in block IV can be an example: the relatively high bulk density in this replicate might be due to some heavy machinery passing by this block. Moreover, both treatments had high bulk density value that might have negative effect on root growth. In contrast, shallow tillage with stable structure and macropores could minimize the negative effect of higher bulk density on root growth. Depending on method of measuring, Bd can vary because during the drying of soil cores in oven wide cracks formed by swelling to shrinking that are usually avoided during calculation (Hakansson and Lipiec, 2000). However, this may have significant importance.

As the MP causes lower bulk density, the system results also in lower PR than shallow tillage (Khan *et al.,* 2001). Statistical analysis showed significant difference between MP and ST for the PR at the depth of 5-35 cm whereas there was no significant difference in soil water content between treatments at measuring PR. In ST, the PR was high enough at 10-20 cm depth to reduce root growth. However, roots can grow at a speed greater than penetrometer reading because they can elongate through the biopores and interaggregate spaces (Campbell and Henshall, 1991). Furthermore, values given by penetrometer are usually 2 to 8 times greater than the resistance value that roots actually get while penetrating the soil (Bengough, 1991; Atwell, 1993; Gregory, 1994).

Soil water content in field was affected by the position of the replicates in the field and clay content. Block II and IV were located on a relatively lower part of the field. The clay content was also greater in block II and IV than in block I and III. Due to the combination of these two factors, higher water content was measured in block II and IV than in block I and III respectively.

The continuity of pores usually not regular in MP because the soils are disturbed by ploughing that might be one of the reasons for higher water content in MP after one meter suction. On the other hand, ST had better continuity of pores under the tillage depth that cause higher drainage and lower water content than MP after I meter suction. However, water content (%) at 1 meter suction was higher in MP than ST. This shows better drainage possibilities in soils under shallow tillage.

In this study, ST had higher plant density than MP that caused also the higher yield (D=3840 A=2490 kg/ha) this year. Several physical factors especially air, water, soil-seed contact and temperature are responsible for proper plant establishment. Snow cover in winter 2010-2011 was very much thick resulting into less freezing-thawing cycles which could facilitates soil structure regeneration and this might affect the seedbed quality especially in the MP plots, which were ploughed in autumn 2010. In MP plots especially in more moist part of the field (block II and IV) large clods might be produced during seedbed preparation. Unfortunately, the seedbed characteristics were not evaluated due to rainfall after sowing. So, extreme winter following long dry season might be an important reason for lower plant density as well as lower crop yield in MP. Several experiments in Nordic countries also reported higher yield of spring cereals under ST than MP, especially when the early summer is dry (Rydberg, 1987; Børresen, 1993; Pitkänen, 1994). Clay soil under ST is better to retain water during long dry season and soil moisture content just after sowing is important. Presence of higher organic carbon (26 g kg^{-1}) in ST than MP (19 g kg^{-1}) near to the soil surface (Etana *et al.*, 2009) is one of the main reason to reduce evaporation in ST during drought. Higher proportion of biopores in ST than MP below the harrowing depth (at 20 cm) also favored the root growth (Aura, 1999). However, plant density in both treatments was not less than optimum value (80 plants per m^2).

If we consider previous 10 years yield data, ST did not have constantly higher yield than MP but on average relative yield of ST in % of MP was higher for the long-term experiment. Generally, most of the years ST had higher yield for barley than MP. In some years ST had also lower crop yield than MP. Weed problem due to mix of crop residues close to the upper part of soil or disease infestation might be the reason for the lower yield in ST.

6. Conclusion

Shallow tillage had positive effect on hydraulic conductivity which may be due stable biopores. Water retention at 1 m water column also revealed better drainage possibilities in the shallow tillage. Bulk density and penetration resistance in the topsoil was higher in shallow tillage than in the treatment with mouldboard ploughing The undisturbed layer in shallow tillage protect subsoil compaction, but this tillage system may not help in case of excessive compaction. In general, plant density was very low, especially in the treatment with mouldboard ploughing. Severe conditions were in the wettest blocks. Large clods produced during seedbed preparation might be the cause of low emergence. Shallow tillage can minimize the negative effect of long dry early season on crop establishment. However, shallow tillage had higher plant density and crop yield in this investigation as well as in the long-term experiment.

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8. Appendix

Table 1. Dry bulk density in three different layers in four blocks of Mouldboard ploughing (MP) and Shallow tillage (ST)

Block	***MP (15-20) cm***	***ST (15-20) cm***	***MP(25-30) cm***	***ST(25-30) cm***	***MP (35-40) cm***	***ST (35-40) cm***
	1.4	1.5	1.5	1.6	1.6	1.5
I	1.6	1.5	1.5	1.6	1.6	1.5
	1.6	1.5	1.5	1.5	1.6	1.5
	1.5	1.5	1.4	1.5	1.5	1.4
II	1.4	1.5	1.5	1.5	1.5	1.4
	1.4	1.4	1.4	1.5	1.5	1.5
	1.4	1.6	1.5	1.6	1.5	1.5
III	1.5	1.6	1.3	1.5	1.6	1.5
	1.4	1.5	1.4	1.6	1.5	1.5
	1.4	1.6	1.4	1.5	1.4	1.6
IV	1.4	1.6	1.4	1.5	1.4	1.6
	1.4	1.6	1.4	1.5	1.4	1.6

Table 2. No. of plants per m^2 in different plots of Mouldboard ploughing (MP) and Shallow tillage (ST)

No. of counts	**MP I**	**ST I**	**MP II**	**ST II**	**MP III**	**ST III**	**MP IV**	**ST IV**
1	264	324	228	312	280	344	260	344
2	212	332	208	292	268	452	256	308
3	272	292	232	244	112	296	164	324
4	252	300	260	308	152	212	240	280