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Investigation of Plowing Depth Effect on Some Soil Physical Properties

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Abstract: Tillage or plowing quality is usually evaluated by the soil bulk density and distribution of organic matter. Soil bulk density, which is the sign of compactness and porosity in turn, depends on type of implements, soil organic carbon, tillage method and plowing depth. Plowing depth causes a lot of pulling in tractors and in order to have deep plowings, heavy-duty tractors are needed. To determine the optimum depth of moldboard plow, the bulk density and soil organic carbon of cultivated soil were investigated in this research. The experiments were conducted, using a three-bottom plow with three plowing depths and four depth of soil, in a split plot design, which lasted for three years. Main plots, consisted of three plowing methods (shallow ≈12 cm, semi-deep ≈22 cm and deep tillage ≈32 cm) and subplots, consisted of four soil depths (0-10, 10-20, 20-30 and 30-40 cm). The amounts of soil density, soil organic carbon, soil water infiltration and crop yields were measured. The results showed that, deep tillage had the greatest effects on soil densities, soil organic carbon, infiltration rates and crop yields. Mean value of soil bulk density was 1.65 g cm^{-3} in shallow tillage which decreased by increasing the plowing depth to 1.53 and 1.151 g cm^{-3} in semi-deep and deep tillage, respectively. However, soil bulk density associated with deep tillage was generally higher than that of semi-deep tillage but the differences between the semi-deep and deep tillage were not significant. The soil water infiltration increased from 1.234 cm h^{-1}, in shallow tillage to 1.405 cm h^{-1} in deep tillage. Crop yield by the deep tillage was 6571 kg ha^{-1}, while the semi-deep tillage and shallow tillage yield were 6389 and 5717 kg ha^{-1}, respectively. By increasing the plowing depth, the soil organic carbon and crop yields improved but there were no significant differences between the semi-deep and deep tillage system.

Key words: Bulk density, wheat, plowing, water infiltration, moldboard plow

INTRODUCTION

Soil bulk density, which is regarded as the sign of compactness and porosity in turn, depends on type of implements, soil organic carbon, tillage method and plowing depth. Soil compaction often measured in terms of soil density, water infiltration, or soil air porosity. Bulk density is found by determining the mass of dry soil occupied as a known volume. Most of soil physical properties and crop yield are affected by soil bulk density. Soil conditions in the seedbed zone (top 5 cm) can promote or delay seed germination and plant emergence (Kaspar *et al*., 1990; Schneider and Gupta, 1985). Therefore, quantifying the effects of tillage systems on soil Bulk Density (BD), soil water infiltration and soil organic carbon can explain some of the differences in plant growth and development in different tillage systems.

Erbach *et al.* (1992) evaluated the effect of four tillage treatments including: no tillage, chisel plow, moldboard plow and Para plow systems on three soils (poorly drained, medium and fine textured) in Iowa. The results showed that all tillage tools reduced the bulk density and penetration resistance to the depth of tillage. However, after planting, only the soil tilled with the Para plow remained less dense than before tillage. In several studies comparing tilled and no-tilled soils, smaller soil water infiltration was found under no-tilled, especially in the upper 10 cm (Hammel, 1989; Wander and Bollero, 1999; Ferreras *et al*., 2000).

In a 3-years study, Croissant *et al.* (1991) determined that compacted no-tillage reduced dry bean yields by 26% over no compacted soil. It was determined that water infiltration of chisel plow was slightly higher, compared with that of no-tillage in the top 10 cm of the soil (Erbach *et al*., 1992). Under wheat-sorghum fallow crop rotation, minimum tillage system had a greater water infiltration than a no-tillage system (Unger and Jones, 1998). Soil porosity, structure and strength are impacted by excessive soil compaction (Croissant *et al*., 1991; Voorhees, 1983). The reduction of crop growth and yield are attributed to soil bulk density and water infiltration or penetration resistance (Croissant *et al*.,

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1991). Lowery and Schuler (1991), conducted a study on two silt loam soils in Wisconsin to investigate the effect of bulk densities on corn yield. Increasing the soil bulk density reduced corn yield significantly.

Lack of good worldwide data, especially, on Soil Organic Carbon (SOC) content with depth, complicates the estimation of changes in SOC inventories following cultivation of previously untilled soils (Davidson and Ackerman, 1993). In two studies of wheat-fallow systems in western Nebraska, Doran *et al*. (1998) reported surface (0 to 7.5 cm) SOC declines of 27 and 40% for conventional tillage with a spring moldboard plow and 4 and 20% for no tillage. In addition, tillage creates a more oxidative soil environment resulting in more rapid decomposition of crop residues and soil organic matter (Doran, 1980). Kettler *et al*. (2000) showed that a single tillage event on a long-term no-till silt loam soil in Nebraska resulted in a redistribution of SOC in the top 30 cm. However, there was no significant change in SOC storage 5 year after plowing the no-till soil.

In recent years, heavier and more powerful tractors and machinery have been used on farms throughout the world (Swan *et al*., 1987). Reasons for this trend include reduced human labor and a corresponding increase in farm size with a need to increase individual operator productivity. However, problems have been noted due to increased loads on the soil surface. Some of the most serious problems resulting from increased machinery size are soil deformation, compaction and destruction of established soil structure (Hakansson *et al*., 1988; Hakansson and Petelkau, 1991; Lowery and Schuler, 1991). Therefore, currently there is a significant interest and emphasis on the shift to the minimum and no-tillage for the purpose of controlling erosion process, increasing water use efficiency of summer crops and improving crop productivity (Buschiazzo *et al*., 1998).

In recent years, cultivation is mainly done by moldboard plow with medium tractors (horsepower is lees than 70 hp) In Iran. Farmers have tendency toward deep tillage and plowing for all crops with these tractors. Deep plowing needs heavy and powerful tractors that are not available for many farmers. Deep plowing with medium tractors also cause more costs and amortization. Attentive the insufficiency of heavy tractors, having small fragment of agricultural farms and the investigation of plowing depth affect on soil physical properties and in turn on yields which are necessary for wheat and other plants whit no deep root penetration. To determine the optimum depth of moldboard plow, connected to the medium tractors, some of the soil characteristics were investigated in this research. So, the objective of this study were: evaluating the effects of plowing depth and soil dept on soil organic carbon, soil water infiltration, soil bulk density and the crop yields.

MATERIALS AND METHODS

The experiment was initiated in 2001 and lasted for three years at the farms of Karaj High Education Agriculture Center, located in Tehran province of Iran. In silty clay loam, wheat (Pishtaz variety) was planted at the site. The experimental design was a split plot, arranged in 9 plots representing three replications for three plowing depth treatments. Each plot was 25 m wide and 25 m long. Main plots, consisted of three plowing systems (shallow ≈12 cm, semi-deep ≈22 cm and deep plowing ≈32 cm) and subplots, consisted of four soil depths (0-10, 10-20, 20-30 and 30-40 cm).

The texture, density, organic carbon and infiltration of experimental plots were measured before executing the test (Table 1, 2). Tillage and planting operations were performed with a two-wheel drive Massey Ferguson tractor (MF 285), with 75 hp engine powers. All plots received primary tillage by moldboard plowing near the end of September. Plowing depth was controlled, by the gauge wheel of moldboard plow in all experiment. Secondary tillage operations consist of disking and land leveling performed for all plots at the same way before planting wheat in October. All treatments were planted with a fifteen-row seed drill (Machine Barzegar seed drill), with double disc openers at a 5 cm planting depth and 17.5 cm row spacing. During the experiment, the soil bulk densities, soil organic carbon and water infiltration rates, were measured soon after harvesting the experimental plots at the end of June.

Crop yields over the subsequent three growing seasons were measured. For this purpose a 1-m square steel frame was randomly placed in two locations of each plot and the wheat inside the frame was harvested by hand. The yield for each plot was calculated as the average of the yield at each location within the plot. Harvested yield was then calculated to kg ha^{-1} for each plot.

Table 1: Textural analysis of soil, before plowing the plots of the study

Soil depth (cm)	Clay	Silt (%)	Sand
0-10	37	54	9
10-20	39	48	13
20-30	39	49	12
30-40	37	48	15

Table 2: Amounts of bulk density, particle density, organic carbon and infiltration rate of the soil, before plowing the plots of the study

Soil depth (cm)	Bulk density (g cm^{-3})	Particle density (g cm^{-3})	Organic carbon (%)	Infiltration (cm h^{-1})
0-10	1.47	2.51	1.50	
10-20	1.68	2.63	0.80	
20-30	1.71	2.65	0.30	0.98
30-40	1.73	2.65	0.08	

Soil bulk density was measured using samples obtained by cores method. These cores were 5 cm in diameter and 100 cm^3 in volume (Blake and Hartge, 1986). The soil samples were taken randomly in each plot. The data for each treatment was compiled and individual values were averaged for each 10-cm depth. Dry bulk density was calculated by using the Hillel (1982) equations.

Water infiltration rates were measured in the field; one week after wheat was harvested. Three locations were chosen in each plot, ≈8 m apart. A 30-cm diameter (inner) and 60-cm diameter (outer) double-ring infiltrometer was installed to a depth of approximately 15 cm at each location and infiltration times were recorded. Soil organic carbon was determined with the wet combustion technique (chemical oxidation) as described by (Robert *et al*., 1995).

The statistical analysis for these measurements was performed using SPSS for the analysis of variance and Duncan tests for means separation.

RESULTS AND DISCUSSION

The main and interactive effects of tillage method and soil depth were significant on BD and SOC (Table 3). Effect of tillage methods was significant on SOC ($p<0.028$), infiltration, BD and crop yield ($p<0.0001$), as resulted from the ANOVA procedure. Effects of soil depth and tow-way interaction of method × depth were also significant on BD and SOC ($p<0.0001$). The tow-way interaction of year × depth on soil bulk density was significant ($p<0.01$), but the tow-way interaction of year × depth on SOC and three-way interaction of method × depth × year, on BD and SOC were not significant. Therefore, for means separation of depended variable, Duncan tests were accomplished (Table 4, 5).

Table 3: Results of ANOVA for soil bulk density, organic carbon, infiltration and crop yield

		Mean square (MS)			
SOV	df	Yield	Infiltration	Organic carbon	Bulk density
Year	2	0.191*	0.006**	0.056**	0.013**
Error	6	0.059	0.001	0.006	0.002
Method	2	1.760**	0.067**	0.015*	0.090**
Year* Method	4	0.006^{ns}	0.001*	0.004^{ns}	0.001^{ns}
Error	12	0.048	0.000	0.002	0.003
Depth	3	-	-	4.539**	1.510**
Year* Depth	6	-	-	0.017**	0.001^{ns}
Method* Depth	6	-	-	0.158**	0.087**
Year* method* depth	12	-	-	0.014^{ns}	0.001^{ns}
Error	54	-	-	0.004	0.001

ns = not significant; * = significant at $p\leq0.05$; ** = significant at $p\leq0.01$

Table 4: Interaction of plowing methods and soil depths on soil bulk density and soil organic carbon

Plowing methods	Soil depths (cm)	Bulk density (g cm^{-3})	Organic carbon (%)
Shallow tillage	0-10	1.220^{h}	1.178^{a}
	10-20	1.640^{d}	0.411^{d}
	20-30	1.740^{b}	0.098^{fg}
	30-40	1.820^{a}	0.040^{g}
Semi deep tillage	0-10	1.273^{g}	1.013^{b}
	10-20	1.370^{f}	0.367^{d}
	20-30	1.693^{c}	0.147^{f}
	30-40	1.763^{b}	0.050^{g}
Deep tillage	0-10	1.293^{g}	0.767^{c}
	10-20	1.390^{f}	0.433^{d}
	20-30	1.523^{e}	0.278^{e}
	30-40	1.874^{a}	0.114^{fg}

Values followed by different letters within a column (a-h), are significantly different at the 5% level of probability

Table 5: The effects of plowing methods and soil depths on soil bulk density, organic carbon, infiltration and yield

Main effects	Bulk density (g cm^{-3})	Organic carbon (%)	Yield (kg ha^{-1})	Infiltration (cm h^{-1})
Plowing (tillage) methods				
Shallow	1.605^{a}	0.432^{a}	1.234^{c}	5717^{b}
Semi deep	1.525^{b}	0.398^{b}	1.303^{b}	6389^{a}
Deep	1.513^{b}	0.394^{b}	1.405^{a}	6571^{a}
Soil depths (cm)				
0-10	1.262^{d}	0.986^{a}	-	-
10-20	1.467^{c}	0.404^{b}	-	-
20-30	1.652^{b}	0.174^{c}	-	-
30-40	1.810^{a}	0.068^{d}	-	-

Values followed by different letters within a column (a-c), are significantly different at the 5% level of probability

Soil bulk density: The Effects of the soil depth and tillage methods (plowing depth), on bulk density are shown in Table 4 and 5. The bulk density changed significantly after tillage and responded similarly in all methods. The linear relationship between soil depth and bulk density was positive and it increased by depth. On the basis of Table 4, the highest decrease in soil bulk density was observed in shallow tillage at the 0 to 10 cm depth. The greatest decrease in bulk density at the 0 to 10 cm depth in the shallow tillage plots can be attributed to the increase in organic carbon that had been accumulated at the soil surface after 3 year of shallow tillage treatment. The soil bulk density was decreased by a greater percentage with the deep tillage compared with the shallow and semi deep tillage in the 0 to 30 cm depth range. In addition, the bulk densities measured in the semi-deep and deep tillage treatments were similar in from to 20 cm soil depths (Table 4). The bulk densities below the 30 cm depth were not more different between the three methods of plowing. The greatest value of bulk density from 30 to 40 cm depth on deep tillage may have been due to plow pan of moldboard plow. It could be concluded that in all cases of studies a plow pan was detected just below the depth of operation.

There was a negative linear relationship between plowing depth and soil bulk density. The bulk density decreased by increasing the plowing depth (Table 5). Mean bulk density was similar for semi-deep and deep tillage (1.525 and 1.513 g cm^{-3}) and greater for shallow tillage (1.605 g cm^{-3}). However, the values of soil bulk density associated with deep tillage were generally higher than that of semi-deep tillage, but the difference was not significant (Table 5). Semi-deep and deep tillage appears to have redistributed the organic carbon, which had become concentrated at the soil surface. The distribution of organic carbon may be a factor in decreasing the soil bulk density in semi-deep and deep tillage systems. The trend for lower soil bulk density is found in deep tillage rather than in other tillage treatments, as seen in this study, agrees with the findings by others, who measured greater bulk density values in shallow tillage and reduced bulk density with conventional tillage, after plowing (Erbach *et al*., 1992; Hakansson *et al*., 1988; Lowery and Schuler, 1991).

Soil organic carbon: Soil organic carbon was significantly affected by tillage methods. The soil organic carbon decreased as tillage intensity increased and the greatest decreases were observed in deep tillage. Organic carbon content at the 0 to 10 cm depth of shallow tillage was higher than semi-deep and deep tillage by 16 and 54%, respectively. Semi-deep and deep Plowing appear to have distributed OC, concentrated at the soil surface and creating a more uniform OC distribution (Table 4).

Total OC content of deep tillage was lower than the other methods (Table 5). This reflects the increasing level of crop residue returned to the soil with increasing tillage intensity. As tillage intensity increases, crop residue-soil contact is increased and incorporated residues are placed into moister conditions than those left on the soil surface. In addition, tillage creates a more oxidative soil environment resulting in more rapid decomposition of crop residues and soil organic matter (Doran, 1980). However by increasing the plowing depth, the soil organic carbon content improved, but there were no significant differences between the semi-deep and deep tillage systems, 3 year after tillage (Table 5). Concentration of soil organic carbon in the top layer by shallow tillage and better distribution by increasing the tillage depth, agrees with others who measured lower DB in the surface soil layers as tillage intensity increased (Doran *et al*., 1998; Davidson and Ackerman, 1993).

Infiltration: The effect of tillage on soil infiltration was significant in the three tillage methods (Table 5). Infiltration rate was greater for deep tillage (mean of 1.405 cm h^{-1}), medium for semi-deep (1.303 cm h^{-1}) and lower for shallow tillage systems (1.234 cm h^{-1}). The increase in infiltration rate with semi-deep and deep tillage probably reflects the decrease in soil BD shown in Table 4. Higher infiltration rate in deep tillage due to increasing plowing depth, agrees with the findings by others, who measured greater infiltration values in deep tillage (Erbach *et al*., 1992; Croissant *et al*., 1991).

Crop yields: As shown in Table 5, the yield increased with increasing plowing depth. Crop yield by the deep tillage were 6571 kg ha^{-1}, while the semi-deep tillage and shallow tillage yield were 6389 and 5717 kg ha^{-1}, respectively. Comparing the shallow tillage, semi-deep and deep tillage increased wheat yield by 12 and 15%, respectively. Crop yield in semi-deep and deep tillage show no significant differences. However, the yields associated with deep tillage were higher than that of semi-deep tillage (Table 5). The distribution of organic carbon may be a factor in the yield increases seen in the semi-deep and deep tillage treatments and may be due to the placement of plant nutrients at a greater soil depth was more accessible to where plant roots growing.

CONCLUSION

Increasing the plowing depth improved soil bulk density, distribution of soil organic carbon and crop yields, but there was no significant difference between the semi deep and deep tillage systems. So for wheat and other plants with no deep root penetration, semi-deep tillage could be used for farmers who lack easy access to powerful tractors.

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