Long-term tillage frequency effects on dryland soil physical and hydraulic properties

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1. Abstract

Soil tillage is considered one of most important practices in agricultural production due to its influence on physical, chemical, and biological properties of the soil environment. The effect of a long-term tillage [no-till (NT), spring till (ST), and fall and spring till (FST)] was investigated on soil penetration resistance (PR), bulk density (BD), gravimetric water content (GWC) and saturated hydraulic conductivity (K_s) under dryland conditions. Tillage effects on these physical properties were tested after 22 years on a Dooley sandy loam (fine-loamy, mixed Typic Argiborolls) derived from glacial till parent material. The statistical design used was a randomized complete block with four replications. Undisturbed soil cores were sampled at 0 to 5, 5 to 10, and 10 to 15 cm depths and were used to measure BD, GWC, and particle size distribution. Soil PR was measured by pushing a hand-held digital penetrometer into the soil at three locations across each plot. Statistical analyses indicated that soil PR was significantly greater in the NT (1.75 MPa) compared to both ST and FST treatments at $P < 0.05$. The PR generally increased with soil depth in all three treatments. Soil BD was not significantly affected by tillage. Averages BD for NT, ST, and FST were 1.59, 1.58, and 1.61 Mg m^{-3}, respectively. The NT plots had greater GWC followed by ST and then followed by FST. The data on K_s at 15 to 20 cm depth were highly variable and tillage treatments had no significant effect on soil K_s. Long-term frequency of tillage reduced compaction in the soil surface (0 to 10 cm), but increased in the subsurface soil (>10 cm) due to the traffic intensity induced by tillage system. The results generally showed that tillage intensity effectively altered soil PR, and minimally affected soil BD and GWC, but moderately affected K_s during the past 22 years.

2. Introduction

Soil tillage management influences soil as a result of altering physical, chemical and biological properties. Tillage operations generally loosens the soil, decreases soil bulk density and penetration resistance by increasing soil macroporosity. Conversely, soil compaction decreases macroporosity of soil and contributes to higher bulk density and more dense soil under no-tillage than under tilled soils.

Studies comparing no-tillage with conventional tillage systems have given different results for soil bulk density. In most of them, soil bulk density was greater in no-till in the 5 to 10 cm soil depth (Osunbitan et al., 2005). In others, no differences in bulk density were found between tillage systems (Logsdon et al., 1999).

Few studies that examined the impact of long-term tillage on saturated hydraulic conductivity. Mahboubi et al. (1993) found that no-tillage resulted in higher saturated hydraulic conductivity compared with conventional tillage after 28 years of tillage on a silt loam soil in Ohio. Whereas, Chang and Landwell (1989) did not observe any changes in saturated hydraulic conductivity after 20 years of tillage in a clay loam soil in Alberta, Heard et al. (1988) reported that saturated hydraulic conductivity of silt clay loam soil was higher when subject to 10 years of tillage than no-tillage in Indiana. They attributed the higher hydraulic conductivity of tilled soil to greater number of voids and abundance soil macropores caused by the tillage implementation.

The ambiguous nature of these research findings document the need for additional studies of the effect of long-term tillage on soil physical properties under various tillage practices in order to optimize productivity and maintain sustainability of soils. Moreover, there are few studies that have examined changes in soil physical properties in response to long term tillage and frequency management (> 20 yr) in the northern Great Plains. Therefore the main objective of this study was to examine the impact of 22-yr of tillage management and frequency on soil penetration resistance, bulk density, water content and saturated hydraulic conductivity of a sandy loam soil in dryland conditions in Northeastern Montana.

3. Material and Methods

Long term tillage and crop management practices trial was established in 1983 at the dryland site located approximately 11 km north of Culbertson (48°33′ N, 104°50′ W) in eastern Montana, USA (Aase and Pikul, 1995). The soil is mapped as a Dooley sandy loam (fine-loamy, mixed, frigid, typic Argiborolls) derived from a glacial till parent material with a slope of 0 to 2%.

Tillage treatments consisted of no-till continuous spring wheat (NT), spring tilled continuous spring wheat (ST), and fall- and spring-tilled continuous wheat (FST). In ST, plots were tilled with a sweep plow before spring wheat seeding to prepare a seedbed in the spring. While in FST, plots were tilled with standard sweeps (0.45 m wide medium-crown sweeps and about 0.1 m deep) and rods in the fall, followed by tandem disk tillage in the spring for seedbed preparation (Aase and Pikul, 1995; Pikul and Aase, 1999; Sainju et al. 2007). The experimental design was a randomized complete block with four replicates. Plot size was 12 m wide × 30 m long.

Soil physical properties, including Penetration resistance (PR) as a cone index (CI), bulk density (BD), gravimetric water content (GWC) and saturated hydraulic conductivity (K_s) were measured at the site in May 2005. Using soil core sampler, two undisturbed soil cylindrical core samples (5 cm long × 5 cm in diameter), one at each end of the plot were collected from each of the 12 plots in 5-cm increments to a depth of 15 cm. Soil cores were used to measure BD and GWC. Soil PR was measured by pushing a hand-held digital cone tipped (12.8-mm diameter) penetrometer **(**Field Scout, SC 900 Soil Compaction Meter; Spectrum Technologies, Inc., Plainfield, IL**)** into the soil at three positions on a transect across each plot, one at the middle of the plot and other two at each end of the plot to cover soil variability. The PR readings were then averaged for each plot. Soil PR readings were recorded in 2.5-cm increments to a depth of 15 cm. Particle size distribution for each core at each depth was determined by the hydrometer method. The amounts of sand, silt, and clay in the soil were 635, 184, 181 g kg^{-1}; 625, 167, 208 g kg^{-1}; and 631, 174, 195 g kg^{-1} at 0 to 5 cm, 5 to10 cm, and 10 to 15 cm depths, respectively. Soil K_s was measured using the constant head well permeameter method (Reynolds and Elrick, 1985). For each K_s measurement, a 6-cm diameter cylindrical hole was augured to a depth ranging from 15 to 20 cm, presumably the effective depth of tillage after adding 5 cm water head in the bore hole. One set of steady flow rate measurements was made at a constant pressure head of 5-cm water for each hole.

Statistical analyses were done using the analysis of variance of mixed model procedure by SAS software. The statistical analysis was used to test the differences among treatments and depths appropriately for a randomized complete block design. The variables PR and GWC were tested for linearity and a weak linear relationship was found among these two soil parameters. Therefore, the GWC was not used as a covariable in the analysis of for the data.

4. Results and Discussion

4.1. Penetration Resistance, PR

The analysis of variance for PR (Table 1) showed that tillage system, soil depth, and tillage system × soil depth interaction were significant. The PR was significantly greater in the NT (mean of 1.75 MPa when averaged over all depths) compared to the ST and FST treatments because NT treatment does not loosen or disturb the soil in the top 0 to 15 cm compared to loosely soil conditions created by both ST and FST treatments. Conventional tillage usually decreases soil resistance compared to NT plots. Differences were not significant for PR between ST and FST tillage systems (Table 1).

Table 1 Effect of tillage and depth on PR, BD, and GWC

Parameter [††]	PR (MPa)	BD ($Mg\ m^{-3}$)	GWC ($g\ g^{-1}$)
Tillage			
NT	$1.75^{a\dagger}$	1.59	0.141
ST	1.45^{b}	1.58	0.139
FST	1.54^{b}	1.61	0.135
Depth (cm)			
0 - 5	0.64^{a}	1.49^{a}	0.144
5 - 10	1.84^{b}	1.68^{b}	0.136
10 - 15	2.27^{c}	1.60^{c}	0.135
		Analysis of variance, P > F	
Tillage (T)	0.0413	0.439	0.515
Soil depth (D)	0.0001	0.0001	0.253
T × D	0.0240	0.990	0.161

[†] Different letters within the columns indicate significant difference at 0.05 probability level.
[††] NT is no-till; ST is conventional till spring only; FST is conventional tillage fall and spring; BD is soil bulk density; GWC is gravimetric water content; and PR is soil penetration resistance.

Soil depth influenced PR ($P < 0.0001$), with a mean PR of 0.64 MPa from 0 to 5 cm, 1.84 MPa from, 5 to 10 cm and 2.27 MPa from 10 to 15 cm depths. Soil PR at three depths in response to three tillage practices is given in Table 1. Results showed that soil PR generally increased with increase in depth for all three tillage treatments due to increase in shaft friction regardless of tillage type.

Soil PR in NT plots averaged 1.00, 2.11, and 2.15 MPa at the 0 to 5, 5 to 10, and 10 to 15 cm, respectively. Soil PR in NT at the 0 to 5 cm depth was significantly different and smaller compared with PR values at the 5 to 10 and 10 to 15 cm depths whereas no significant differences were found in soil PR at the two lower soil depths. In ST and FST, there were significant differences in soil PR among the three depths sampled in this study (Table 2). However, soil PR at the 10 to 15 cm depth in FST was greater than both NT and ST due to increased soil manipulation by this tillage practice. It appears that frequency of traffic after 22 years of tillage in FST plots induced a compacted layer below the depth of tillage (approximately10 cm). Furthermore, previous research demonstrated that continuous tillage at this site from 1983 to 1992 had developed a compacted layer that impeded water movement and restrict root penetration and distribution at a depth of approximately 10 cm (Pikul and Aasa, 1999; 2003).

Table 2 Effect of tillage and depth interaction on soil PR

	Penetration resistance, PR (MPa)		
	Soil depth (cm)		
Tillage	0 - 5	5 - 10	10 - 15
NT	1.00[a†]	2.11[a]	2.15[a]
ST	0.46[b]	1.75[b]	2.15[a]
FST	0.45[b]	1.65[b]	2.52[b]

† Different letters indicated significant difference within columns at 0.05 probability level.

4.2. Soil Bulk density (BD) and Gravimetric Water Content (GWC)

Mean values of soil bulk density for NT, ST, and FST tillage systems were 1.59, 1.58, and 1.61 Mg m^{-3}, respectively (Table 1). The analysis of variance showed that neither tillage system nor tillage system × soil depth interaction were significant. Soil depth had a significant influence ($P < 0.0001$), with a mean BD of 1.49, 1.68 and 1.60 Mg m^{-3} from 0 to 5, 5 to 10 and 10 to 15 cm depths, respectively (Table 1). The smallest BD values were found at the soil surface (0 to 5 cm). After 22 years, our findings showed that tillage practices apparently had not significantly influenced soil BD and only slight differences were observed in BD among tillage systems considered in this study. These findings are in agreement with those of Anken et al. (2004), and Lampurlanes and Cantero-Martinez (2006), but differ from results reported by Hill and Cruse (1985) and McVay et al. (2006).

Results in Table 1 showed that tillage, soil depth and their interaction had no significant effect on soil water content. Not surprisingly, NT plots resulted in wetter soil to a depth of 10 cm in this study. The NT plots had greater GWC (0.141 g g^{-1}) followed by ST, having 0.139 g g^{-1}, and then followed by FST with a mean of 0.135 g g^{-1}.

Soil mean GWC values averaged across three tillage systems were 0.144, 0.136, and 0.135 g g^{-1} at the 0 to 5 cm, 5 to 10 cm, and 10 to 15 cm depths, respectively (Table 1). Soil GWC generally decrease with soil depth across three tillage practices. This could be attributed to greater residues and organic matter in the soil surface than the sub surface proportions of the soil.

4.3. Saturated Hydraulic Conductivity, (K_s)

The analysis of variance showed no significant differences in soil K_s among three tillage treatments. Soil K_s was slightly influenced by tillage and varied from 3.295 mm h^{-1} for intensive tillage (FST) to 5.297 mm h^{-1} for no tillage (NT). The highest mean Ks value was recorded in NT plots with a mean of 5.297 mm h^{-1} followed by ST with a mean of 4.533 mm h^{-1} and the lowest in FST with a mean of 3.295 mm h^{-1}. The differences in K_s suggest greater porosity, less tortuous paths, and better pore continuity in NT plots at the depth greater than 10 cm compared to the two conventional tillage practices. Thus, soil K_s decreased with increased intensity of soil manipulation by tillage practices. Furthermore, previous research demonstrated that continuous tillage at this site from 1983 to 1992 had developed a compacted layer that impeded water movement at a depth of approximately 10 to15 cm (Pikul and Aase, 1999; 2003). Soil macropores and aggregations under NT formed by decayed roots can be preserved under NT whereas conventional tillage breaks up the continuity of these macropores. Macropores generally occupy a small fraction of the soil volume but their contribution to water flow in soil is high. The higher K_s in NT system may have caused by better pores continuity, aggregation, less torturous and greater in the soil.

Results generally showed that after 22 years, tillage intensity effectively altered soil PR but not soil BD, GWC, or K_s. The FST treatment showed evidence of compaction at the 10 to 15 cm depth where PR was greater than 2.5 MPa. Soil BD, GWC and K_s were only minimally influenced by tillage intensity or depth after 22 year of treatment imposition (Table 1).

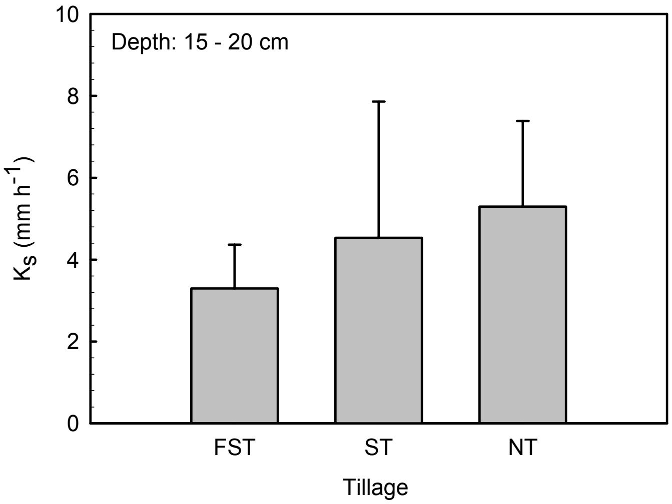

Figure 1 Soil saturated hydraulic conductivity, K_s, as affected by three tillage practices. Bars represent two standard errors around the mean

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