Tillage effects on bulk density and hydraulic properties of a sandy loam soil in the Mon-Dak Region, USA

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Abstract

We evaluated the effects of conventional (CT) and strip (ST) tillage practices on bulk density (ρ_b), water content (θ_w), infiltration rate (I_r) and hydraulic conductivity (K_s) in a Lihen sandy loam soil. Soil cores were collected during growing season from each plot at 0 to 10 and 10 to 30 cm depths under each tillage practice to measure ρ_b and θ_w. *In-situ* I_r and K_s measurements were determined using a pressure ring infiltrometer (PI) and a constant head well permeameter (CHWP) at the soil surface and 10–30 cm depths, respectively. Soil ρ_b and θ_w did not differ significantly between CT and ST in both years with the exception of ρ_b in 2007. The log-transformed I_r was significantly affected by tillage at $P \leq 0.1$ in 2007 while I_r did not differ significantly between CT and ST practices in 2008. The effects of tillage on soil K_s were significant in 2007 and 2008 at $P \leq 0.05$ and at $P \leq 0.1$, respectively. The K_s values were 68% and 56% greater for ST than for CT in 2007 and 2008, respectively. It was concluded that the CT operations increased soil compaction, which consequently altered ρ_b, thereby reducing K_s in the soil.

Key Words

Tillage, bulk density, infiltration, hydraulic conductivity, soil compaction

Introduction

Tillage is one of the most influential management practices affecting soil physical and hydraulic characteristics (Lal and Shulka 2004). Strip tillage (ST) was performed using a single operation with special equipment that provided alternating 30-cm wide strips of tilled and untilled soil while conventional tillage (CT) consisted of six to seven separate operations using different tillage implements following the harvest of one crop in preparation for the next crop.

Two of the most commonly measured soil physical properties affecting hydraulic conductivity are the soil bulk density and effective porosity as these two properties are also fundamental to soil compaction and related agricultural management issues (Strudley et al. 2008).

Saturated hydraulic conductivity is considered one of the most important parameters for water flow and chemical transport phenomena in soils (Reynolds and Elrick 2002). As little research has been reported regarding the effect of strip tillage on soil physical and hydraulic properties the objective of this study was to evaluate the effects of conventional (CT) and strip (ST) tillage practices on bulk density (ρ_b), gravimetric water content (θ_w), final infiltration rate (I_r), and saturated hydraulic conductivity (K_s) in a sandy loam soil of the Mon-Dak region (north eastern Montana and north western north Dakota), USA.

Materials and methods

The research site was located at the Nesson Valley Mon-Dak Irrigation Research and Development Project approximately 37 km east of Williston, ND (48.1640 N, 103.0986 W). The soil is mapped as Lihen sandy loam (sandy, mixed, frigid Entic Haplustoll) consisting of very deep, somewhat excessively or well drained, nearly level soil that formed in sandy alluvium, glacio-fluvial, and eolian deposits in places over till or sedimentary bedrock. Particle size distribution analysis indicated the textural class of the surface horizon (0 to 30 cm) to be consistently within the sandy loam classification. The amount of sand, silt, and clay in the soil at 0 to 30 cm depth ranged from 640 to 674, 176 to 184, and 150 to 166 g kg^{-1}, respectively.

The experimental design at the Nesson site was a randomized complete block design with six replications. Treatments consisted of two crop rotations (sugarbeet/potato [*Solanum tuberosum* L.]/malting barley [*Hordeum vulgare* L.] and sugarbeet/malting barley/potato), two tillage practices (conventional and strip) under sugarbeet using a linear-move overhead sprinkler irrigation system. The CT plots were tilled just prior to planting in the spring of 2007 and 2008, while the ST operation was completed 9/07/2006 and 9/20/2007 for the 2007 and 2008, respectively.

Soil I_r and K_s measurements were made approximately 1 m apart in the center of crop rows within CT and ST sugarbeet plots in July 17–20, 2007 and July 9–12, 2008.

Using a soil core sampler, we collected undisturbed soil cylindrical core samples (5 cm long × 5 cm in diameter) from each plot at 0–10 and 10–30 cm depths under each tillage system. Soil cores were used to measure bulk density (ρ_b) as mass of oven dried soil per volume of core (Mg m^{-3}) and gravimetric water content (θ_w) as mass of water in the soil sample per mass of the oven dried soil (kg kg^{-1}). Each measurement was replicated four and eight times at 0 to 10 and 10 to 30 cm depths, respectively.

Soil I_r measurements were determined using the single head pressure ring infiltrometer method, PI (Reynolds and Elrick 2002). The PI consists of a Mariotte-type reservoir, similar to that of the constant head well permeameter (CHWP), sealed to a stainless steel ring with a radius of 10 cm, driven to a depth of 5 cm into the soil surface (Reynolds and Elrick 2002).

In-situ K_s (L T^{-1}) using a steady state flow rate of water from a cylindrical borehole augured to a given depth below the soil surface was measured using a CHWP (Reynolds and Elrick 2002).

Soil I_r and K_s measurements were replicated four and eight times, respectively, in each year.

Results and discussion

Soil ρ_b and θ_w did not significantly differ between CT and ST in both years with the exception of ρ_b in 2007, which was significantly affected by tillage treatment at $P \leq 0.05$ (Table 1). Soil ρ_b was numerically greater in CT plots than in ST plots in both years, suggesting that the CT operations increased soil compaction due to frequent traffic passes induced by this tillage system. Nevertheless, ST is perceived as having greater porosity and wetter soil conditions compared with CT (Licht and Al-Kaisi 2005). Elimination of secondary tillage and more limited vehicular traffic in ST plots probably contributed to decreased ρ_b compared to CT plots as the ST system includes only a single in-row soil disturbance event that decreases soil ρ_b and conserves water to a greater degree than the CT system (Licht and Al-Kaisi 2005).

The log-transformed I_r and K_s under both CT and ST tillage systems in 2007 and 2008 are illustrated in Figures 1 and 2, respectively. Data indicated that I_r was significantly affected by tillage at $P < 0.1$ in 2007 while I_r did not differ significantly between CT and ST practices in 2008 (Figure 2). Although variations in I_r between CT and ST practices existed in both years, these variations were not significant at $P < 0.05$ (Figures 1 and 2). However, the similarity in I_r between CT and ST at the surface suggests that the CT and ST tillage systems are similar in terms of soil disturbance at this depth.

Table 1. Effect of tillage on soil bulk density (ρ_b) and gravimetric water content (θ_w) averaged across two depths (0–10 and 10 - 30 cm) for conventional (CT) and strip (ST) tillage practices.

Year	Tillage	ρ_b (Mg m^{-3})	θ_w (m^3 m^{-3})
2007	CT	$1.60^{a\dagger}$	0.0734^a
	ST	1.52^b	0.0803^a
		Analysis of Variance, P > F	
		0.038	0.271
2008	CT	1.55^a	0.0922^a
	ST	1.52^a	0.0948^a
		Analysis of Variance, P > F	
		0.184	0.592

†Means followed by the same letter are not different at the 0.05 probability level ($P \leq 0.05$).

The effects of tillage on soil K_s were significant in 2007 and 2008 at $P < 0.05$ and at $P < 0.1$, respectively (Figures 1 and 2). The K_s values were 68% and 56% greater for ST than for CT in 2007 and 2008, respectively. Results in Table 1 and Figures 1 and 2 showed that K_s increases as the ρ_b decreases and soil total porosity increases, indicating that soil compaction influences K_s measurements at the 10–30 cm depth. Overall, these findings agree with results reported by Jabro et al. (2009) who found that greater K_s values correspond with lower soil bulk density values at the subsurface depths.

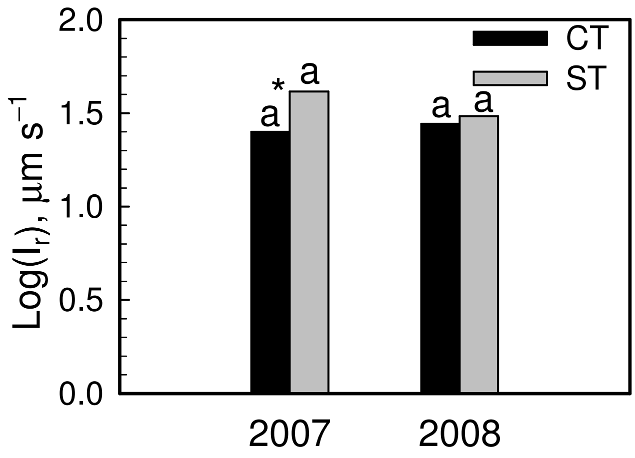

Figure 1. In-situ infiltration rate (I_r) as affected by conventional tillage (CT) and strip tillage (ST) practices in 2007 and 2008. An '*' signifies that a difference is significant at the 0.1 probability level.

The results of this study suggest that the CT operations increased soil compaction, which consequently altered soil ρ_b, thereby reducing K_s (Table 1, Figures 1 and 2).. The compacted soil and higher ρ_b in CT rows was likely responsible for the lower K_s values compared with ST plots in both years. Moreover, the ST system likely produced a greater volume of macropores (Wienhold and Tanaka 2000; Lipiec et al. 2005) resulting in more pronounced vertical pore connectivity in ST plots than in CT plots.

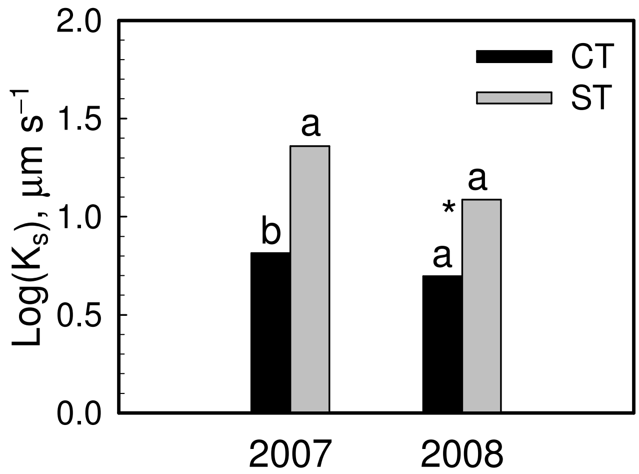

Figure 2. In situ saturated hydraulic conductivity (K_s) as affected by conventional tillage (CT) and strip tillage (ST) practices in 2007 and 2008. Different letters indicate that means are significantly different at the 0.05 probability level. An '*' signifies that a difference is significant at the 0.1 probability level.

Conclusions

It was concluded that soil ρ_b and θ_w did not significantly differ between CT and ST in both years with the exception of ρ_b in 2007. Soil ρ_b was numerically lower in ST plots than in CT plots while θ_w were greater for ST than for CT in both years. Soil I_r was significantly affected by tillage at $P < 0.1$ in 2007 while I_r did not differ significantly between CT and ST practices in 2008. The effects of tillage on soil K_s were significant in 2007 and 2008 at $P < 0.05$ and at $P < 0.1$, respectively. The I_r and K_s values were greater in ST plots than CT plots in both years. The variation in K_s values in soil was likely due to differences in soil compaction and vehicular traffic passes peculiar to the CT and ST systems. The ST plots likely had better volume of macropores than CT plots, producing greater water flow through the ST soil profile.

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