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 ($\rho_b$), water content ($\theta_w$), 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 $\rho_b$ and $\theta_w$. 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 $\rho_b$ and $\theta_w$ did not differ significantly between CT and ST in both years with the exception of $\rho_b$ 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 $\rho_b$, 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 ($\rho_b$), gravimetric water content ($\theta_w$), 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 \( \times \) 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 (\( \rho_b \)) as mass of oven dried soil per volume of core (Mg m\(^{-3}\)) and gravimetric water content (\( \theta_w \)) 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 \( \rho_b \) and \( \theta_w \) did not significantly differ between CT and ST in both years with the exception of \( \rho_b \) in 2007, which was significantly affected by tillage treatment at \( P \leq 0.05 \) (Table 1). Soil \( \rho_b \) 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 \( \rho_b \) compared to CT plots as the ST system includes only a single in-row soil disturbance event that decreases soil \( \rho_b \) 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 (\( \rho_b \)) and gravimetric water content (\( \theta_w \)) averaged across two depths (0–10 and 10 - 30 cm) for conventional (CT) and strip (ST) tillage practices. |
|-----------------|-----------------|-----------------|-----------------|
| **Year** | **Tillage** | **\( \rho_b \)** (Mg m\(^{-3}\)) | **\( \theta_w \)** (m\(^{3}\)m\(^{-3}\)) | Analysis of Variance, \( P \geq F \) |
|-------------|-----------------|-----------------|-----------------|
| 2007 | CT | 1.60\(^{a}\) | 0.0734\(^{a}\) | 0.038 |
| ST | 1.52\(^{b}\) | 0.0803\(^{a}\) | 0.271 |
| 2008 | CT | 1.55\(^{a}\) | 0.0922\(^{a}\) | 0.184 |
| ST | 1.52\(^{b}\) | 0.0948\(^{a}\) | 0.592 |

\(^{a}\)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 \( \rho_b \) 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 $\rho_b$, thereby reducing $K_s$ (Table 1, Figures 1 and 2). The compacted soil and higher $\rho_b$ 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 $\rho_b$ and $\theta_w$ did not significantly differ between CT and ST in both years with the exception of $\rho_b$ in 2007. Soil $\rho_b$ was numerically lower in ST plots than in CT plots while $\theta_w$ 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.
References