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Physical and hydraulic properties of a sandy loam soil under zero, shallow and deep tillage practices☆

Jay D. Jabro[a,*], William M. Iversen[a], William B. Stevens[a], Robert G. Evans[a], Maysoon M. Mikha[b], Brett L. Allen[a]

[a] Northern Plains Agricultural Research Laboratory, USDA-ARS, 1500 N. Central Avenue, Sidney, MT 59270, United States
[b] Central Plains Resources Management Research, 40335 County Road GG, Akron, CO 80720, United States

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ABSTRACT

The effect of tillage depth on physical properties in sandy soils under sugarbeet (*Beta vulgaris* L.) is not well understood and documented. A 4-yr study was conducted to investigate the effect of zero tillage (ZT), shallow tillage (ST), and deep tillage (DT) practices on soil bulk density (BD), saturated hydraulic conductivity (Ks), and moisture content (MC) in a sandy loam. Undisturbed soil cores were collected at 0- to 10, 10- to 20, 20- to 30, and 30- to 40 cm depths to measure BD and MC under each tillage practice. Soil Ks for the surface and subsurface layers were measured using a single head pressure ring infiltrometer and a constant head well permeameter, respectively. Soil BD was not significantly influenced by tillage in the 0- to 10, 10- to 20, 20- to 30, and 30- to 40 cm layers when averaged for four years. When averaged across the 0- to 40 cm depth, soil BD did not differ significantly among three tillages in 2008, 2009 and 2010; however, BD was significantly lower in DT (1.50 $Mg\,m^{-3}$) than in ZT (1.61 $Mg\,m^{-3}$) and ST (1.59 $Mg\,m^{-3}$) in 2011. Soil BD averaged over all years and layers resulted in nonsignificant differences among three tillage practices. Soil Ks did not differ significantly among three tillage practices in 2008, 2009, and 2011 for the 0- to 40 cm depth. Similarly, soil Ks averaged across four years and four layers was not affected by tillage. In 2010, Ks was significantly greater in ST (27.60 $mm\,h^{-1}$) than in ZT (17.21 $mm\,h^{-1}$) and DT (12.46 $mm\,h^{-1}$). Soil MC was not significantly influenced by tillage in any of the four depths when averaged across four years and when also averaged across four depths for each year. Across four years and four depths, averaged MC was not influenced by tillage. Large variations in Ks among ZT, ST and DT were likely caused by soil variability among replications within each tillage treatment. We concluded that tillage did not significantly affect BD, Ks and soil MC most likely due to the unchanging total porosity in sandy loam soil regardless of tillage type.

1. Introduction

Since the first early great civilizations, tillage has been an integral component of agricultural and food production. Tillage has been considered one of the most important agronomic practices that can alter soil properties and create a complex soil ecosystem (Strudley et al., 2008; Jabro et al., 2015). It is performed to control weeds, to incorporate amendments and plant residues and to provide a favorable soil environment for seed germination, plant emergence, growth, and development.

The effect of tillage on soils leads to soil loosening, disturbance and manipulation. The degree of soil loosening and overturn by tillage depends on soil texture, soil moisture, organic matter, and type of tillage operation. Further, soil loosening and manipulation by deep tillage improves water movement and aeration in the soil, increases rooting depth and development as well as allows for deeper chemical movement than in untilled soil (Diaz-Zorita, 2000; Strudley et al., 2008). Tillage practices induce changes in soil physical properties such as soil bulk density, aggregate stability, water movement and storage in soil (Lal and Shukla, 2004; Jabro et al., 2009, 2011, 2015).

Soil bulk density and water infiltration rate vary with type of implement, depth and method of tillage (Hamza and Anderson,

Abbreviations: BD, bulk density; Ks, saturated hydraulic conductivity; MC, moisture content; ZT, zero tillage; ST, shallow tillage; DT, deep tillage.

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* Corresponding author.
E-mail address: jay.jabro@ars.usda.gov (J.D. Jabro).

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2005). Therefore, assessing the influence of tillage depth and method on these soil properties can help explain some of the differences in crop growth, development, yield and quality. Soil bulk density often increases with the number of traffic passes and intensity while water infiltration rate decreases with number of passes. Generally speaking, all tillage methods reduced soil bulk density to the depth of tillage (Erbach et al., 1992; Osunbitan et al., 2005). In other studies, water infiltration was higher in tilled soil than no-tilled soil (Erbach et al., 1992; Ferreras et al., 2000). However, Alamouti and Navabzadeh (2007) reported that deep tillage had the greatest effects on soil bulk density, organic carbon, water infiltration rate, and crop yield compared with semi-deep and shallow tillage systems. They concluded that soil bulk density, infiltration rate, and crop yield increased with increased plow depth. Another recent study by Afzalinia and Zabihi (2014) revealed that reduced tillage and no-tillage increased soil bulk density compared to conventional tillage practices. However, other studies showed contradictory results that various tillage practices had no significant impact on soil bulk density (Alvarez and Steinbach, 2009; Jabro et al., 2011; Karuma et al., 2014).

Numerous studies evaluated the effects of various tillage practices on hydraulic properties of the soil. Topaloglu (1999) found that tillage practices had no significant effect on infiltration rates in sandy loam and clay loam soils. Ankeny et al. (1990) noted no considerable differences in infiltration rates between tilled and untilled soils, while Heard et al. (1988) observed higher infiltration rates in tilled soils and attributed the difference to soil surface sealing and crusting in untilled soils. Allmaras et al. (1977) determined, on the other hand, that soil hydraulic conductivity was greater in chisel-plowed plots than untilled soil due to greater soil aggregation resulting from the chiseling practice. Chan and Mead (1989) noticed that untilled soils exhibited greater hydraulic conductivities than tilled soils and attributed the difference to decreased soil bulk density and improved porosity than in soils without tillage. Recently, Miriti et al. (2013) and Karuma et al. (2014) concluded that various tillage practices did not significantly affect soil saturated hydraulic conductivity in rotational cropping systems.

Previous studies have revealed that zero and conservation tillage practices are important for reducing evaporation and improving soil water storage. Lal (1975) reported that zero tillage plots had higher soil moisture contents than plowed plots throughout the growing seasons under continuous maize (*Zea mays* L.), particularly at the 0- to 10 cm depth. Martinez et al. (2011) found that soil water content was greater in conservation tillage than in conventional tillage in a compacted sandy loam soil. On the other hand, Kovac et al. (2005) concluded that soil moisture content was significantly greater under conventional tillage than under reduced and zero tillage systems in a loamy soil.

There is insufficient information available about the influence of different tillage depths on soil physical properties in sandy soils under sugarbeet production. Previous contradictory research results and the uncertain nature of the aforementioned findings necessitate further research on effects of various tillage practices on soil physical and hydraulic properties. We hypothesized that the depth of tillage would considerably affect soil physical and hydraulic properties. Knowing these properties under various tillage practices can help us explain some of the differences in crop yield and quality. Thus, the objective of this study was to evaluate the short-term impact of zero tillage (ZT), shallow tillage (ST), and deep tillage (DT) practices on soil bulk density (BD), saturated hydraulic conductivity (Ks), and moisture content (MC) in sandy loam plots under irrigated sugarbeet.

2. Materials and methods

2.1. Site selection, soil type and experimental design

A 4-yr field experiment was established in spring of 2008 at the North Dakota State University Williston Research Extension Center irrigated research farm located approximately 37 km east of Williston, ND, USA. The soil at the experimental site is Lihen sandy loam (sandy, mixed, frigid Entic Haplustoll). The respective sand, silt, and clay contents were 738, 172, and 90 g $kg^{-1}$for the 0- to 10-cm layer; 679, 228 and 93 g kg^{-1} for the 10- to 20-cm layer; 738, 172 and 90 g kg^{-1} for the 20- to 30-cm layer; and 746, 163 and 91 for the 30- to 40-cm layer.

The experimental design is a randomized complete block with five replications.

2.2. Field operations and management practices

Tillage treatments comprised zero tillage (ZT); shallow tillage, 10-cm depth (ST); and deep tillage, 30-cm depth (DT). The ST consisted of a pass with field cultivator to a 10 cm depth. The DT was performed with a ripper with seven shanks spaced 60 cm apart. The ripper was set to a 30 cm tillage depth that was verified with a laser level. The tillage was performed on 30 April 2008, 05 May 2009, 28 April 2010, and 13–14 May 2011. Tillage treatments were rotated among plots to imitate the conditions a grower would experience when a change in tillage practices is newly initiated and was not intended to study the long term effects of tillage practices. Plot area was variable due to the width of the equipment and limited field space (6–8 m wide × 30 m long). Plots were not in the same location every year due to the 2-yr rotation and randomization process. The preceding crop was barley (*Hordeum vulgare* L.) in all four study years. Details regarding tillage and farming operations are given in Jabro et al. (2015).

Dry fertilizer was broadcast in the spring immediately prior to tillage. Fertilizer applied to ZT plots was incorporated by subsequent precipitation and irrigation events. The amounts of N, P_2O_5, and K_2O applied were respectively, 129, 168 and 187 kg ha^{-1} in 2008; 106, 168 and 187 kg ha^{-1} in 2009; 156, 56 and 56 kg ha^{-1} in 2010 and 123, 56, and 56 kg ha^{-1}in 2011. Sugarbeet (variety BTS 47 RR 31, Betaseed Inc., Shakopee, MN) was planted on 01 May 2008, 07 May 2009, 29 April 2010, and 14 May 2011.

Irrigation amounts were applied as required using a self-propelled overhead linear move sprinkler irrigation system (model 8000, Valmont Irrigation, Valley, NE). Further information regarding tillage operations, management practices, irrigation system, and amounts was provided in detail by Evans et al. (2010) and Jabro et al. (2015).

2.3. Soil bulk density (BD) and moisture content (MC) measurements

For soil BD determination, cylindrical soil samples were collected using a stainless steel sampler with an internal diameter of 50 mm and 50 mm length from each plot at 0- to 10, 10- to 20, 20- to 30, and 30–40 cm depths under ZT, ST and DT practices each year throughout the course of study (2008–2011). Sampling dates were 16 May 2008, 19 May 2009, 13 May 2010, and 19 May 2011. Soil cores were used to measure bulk density as mass of oven dried soil per volume of core and gravimetric moisture content as mass of water in the soil sample per mass of the oven dried soil (g g^{-1}). Soil cores were extracted from within the crop row for each tillage treatment. Soil BD and MC measurements were replicated five times.