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Short communication

Long-term tillage impact on soil hydraulic properties

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ABSTRACT

An improved understanding of the impact of tillage systems on soil hydraulic properties is necessary to conserve and manage soil water under a changing climate. The objective of this study was to specifically measure soil hydraulic properties (total porosity, water infiltration, saturated hydraulic conductivity, and water retention characteristics) in no-till, chisel plow, disk, and moldboard plow systems under rainfed continuous corn (*Zea mays* L.) after 35 yr on silty clay loam soils in eastern Nebraska. We measured ponded water infiltration (positive soil water pressure) and tension (−1 kPa matric potential) infiltration to exclude macropore (>125 μm diameter) flow. Tillage treatments affected ponded infiltration only. Moldboard plow significantly increased ponded infiltration rate by 21.6 cm h^{-1} at 5 min and by 8.8 cm h^{-1} at 60 min compared with no-till. However, when compared with disk and chisel, moldboard plow increased ponded infiltration rates at all measurements times, which lasted 3 h. Regarding cumulative infiltration, moldboard plow increased cumulative infiltration by 26.9 cm to 39.0 cm after 3 h compared with other tillage systems. Similarities in tension infiltration suggest that the higher ponded infiltration for moldboard plow was most likely due to the presence of voids or fractures (>125 μm) created by full inversion tillage. Total porosity, saturated hydraulic conductivity, and water retention among the treatments did not differ. Overall, soil hydraulic properties did not differ among tillage systems except water infiltration in these silty clay loam soils after 35 yr of management.

1. Introduction

An improved understanding of the impacts of tillage systems on soil hydraulic properties is necessary to conserve and manage soil water under different soil types, management scenarios, and climates. This knowledge is particularly important in water-limited or rainfed regions such as the western Corn Belt. Soil hydraulic properties such as water infiltration, hydraulic conductivity, and water retention determine the ability of the soil to capture and store precipitation or irrigation water. Soils that drain rapidly when wet and retain water under drought conditions are important for agricultural production under increasing climate fluctuations that is expected to include more intense and frequent rainstorms or droughts in the future (Pryor et al., 2014).

Different tillage practices could affect the ability of the soil to adsorb and retain water, depending on the level of soil disturbance. Previously published studies comparing soil hydraulic properties among tillage systems have reported some inconsistent results. For example, no-till management, which is a leading conservation tillage system for reducing both soil erosion and production costs may increase (Stone and Schlegel, 2010), reduce (Unger, 1992; Baumhardt et al., 1993) or not affect (Unger, 1992; Pikul and Aase, 1995) water infiltration compared with other tillage systems. Similarly, no-till management may also increase (Lyon et al., 1998) or have no effect (McVay et al., 2006) on soil water retention. Effects on saturated hydraulic conductivity can be even more inconsistent (Blanco-Canqui et al., 2004). On one hand, tillage could increase water infiltration by disrupting compacted layers and loosening the soil relative to no-till management. On the other hand, tillage can reduce infiltration by reducing soil aggregate stability and macroporosity, increasing surface crusting, and causing soil consolidation after tillage in the absence of crop residues on the soil surface (Unger, 1992). The contrasting tillage effects and mixed findings warrant the need for additional research to better understand how tillage systems affect water flow and retention characteristics in the soil.

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Duration of tillage management can be a major factor in revealing tillage impact on soil hydraulic properties because these properties are often measurable in the long term (>10 yr). Thus, existing long-term tillage experiments could be ideal laboratories. The scant data on soil hydraulic properties from long-term experiments limit our understanding of the implications of different tillage management scenarios on soil water management. Thus, the objective of this study was to evaluate soil hydraulic properties such as total porosity, water infiltration, saturated hydraulic conductivity, and water retention characteristics under no-till, chisel plow, disk, and moldboard plow systems in rainfed continuous corn in eastern Nebraska.

2. Materials and methods

2.1. Site description

A long-term tillage experiment established in 1980 at the University of Nebraska's Rogers Memorial Farm (latitude 40.843, longitude 96.465; 368 m above sea level) about 19 km east of Lincoln, NE, under natural rainfall conditions was used for this study. The mean annual precipitation from 2004 to 2013 for the study site was 693 mm. The soil is classified as Aksarben silty clay loam (fine, smectitic, mesic Typic Argiudolls) and Wymore silty clay loam (fine, smectitic, mesic Aquertic Argiudolls). These upland soils are deep, moderately well-drained, and formed in loess parent material.

The experiment was originally designed as a randomized complete block (six replications) with six tillage treatments in continuous corn as main plots. The tillage treatments were chisel plow, tandem disk, moldboard plow, no-till, ridge-till, and subsoil tillage. Whole tillage plots were modified in the fall of 2014 by converting all tilled treatments to no-till to answer other research questions. Tillage operations were done in the fall after corn harvest each year from 1980 to 2014. After grain harvest each year, corn was chopped and tillage treatments were applied. Tillage depth was 25 cm for the chisel and moldboard plow treatments. Chisel shanks with straight points at 25 cm spacing were used. The depth of tillage for the disk treatment was approximately 10 cm. Residue was chopped in spring for the disk and no-till treatments. All tilled treatments except ridge-till were disked to <10 cm depth in spring before planting. No primary or secondary pre-plant tillage operations were done on no-till treatment.

The original design was then modified in 1986 to a randomized complete block design with a split-plot arrangement of cropping systems. Subplot treatments were continuous corn, continuous soybean (*Glycine max* L.), and a 2-yr soybean-corn rotation, with both phases present each year. Whole tillage plots were 18.3 m (24 rows, 0.76-m between rows) by 22.9 m. Subplots were 4.6 (six rows, 0.76-m between rows) by 22.9 m. The present study considers four tillage systems (no-till, tandem disk, chisel plow, and moldboard plow) under continuous corn.

Corn was planted usually in the first two weeks of May at 76-cm row spacing. Corn hybrids planted each year were chosen from commercially available selections adapted to the area. However, glyphosate-resistant corn hybrids have been planted since 1999. Other cultural practices were similar to those used by local producers. Nitrogen fertilizer was applied at the V3 growth stage on the corn at 113 kg N ha^{-1} as ammonium nitrate from 1986 to 2003 and at 168 kg N ha^{-1} from 2004 to 2014 as urea (Sindelar et al., 2015). Other plant nutrients were within acceptable levels for corn and soybean production (Sindelar et al., 2015). Further details on the experiment establishment and management are described by Varvel and Wilhelm (2011) and Sindelar et al. (2015).

2.2. In situ field measurements and soil sampling

Field measurements and soil sampling were conducted in June 2015, which was about one year after the last tillage operations. We measured water infiltration, bulk density to compute porosity, saturated hydraulic conductivity, and water retention characteristics. These properties were selected because data on the above hydraulic properties from long-term (>35 yr) experiments are limited and the few published data reported some mixed findings, which warrant further investigation.

Water infiltration was measured under: i) −1 kPa matric potential using tension infiltrometer (Perroux and White, 1988) and ii) ponded conditions using double ring infiltrometers (Reynolds et al., 2002a). Water infiltration under the negative pressure (−1 kPa matric potential) was determined using a tension infiltrometer with a wetting area of 0.03 m^2 (Perroux and White, 1988). The negative pressure was used to exclude macropore (>125 μm diameter) contribution to the total water flow in the soil, allowing the measurement of water infiltration through the soil matrix. Surface residues were removed and 4 mm layer of fine silica sand was placed on the soil surface to provide good contact between the soil and the tension infiltrometer (Perroux and White, 1988). The water infiltration under tension was measured for 30 min, with reservoir level readings taken every minute.

For the ponded water infiltration measurement, an inner ring with 20 cm diameter was nested within an outer ring with 40 cm diameter. The rings were carefully inserted to 10–15 cm depth of the soil with surface free of cracks and plant residues. Tap water was added to both rings and the water levels in both the outer and inner rings were at the same height during the measurement. The tap water had an electrical conductivity of 0.75 dS m^{-1} and a pH of 7.1. The infiltration rate was measured for 3 h by recording the change in water level height in the inner ring at specific time intervals. Water level in the rings was maintained between 5 cm and 10 cm height. Water infiltration rate (cm h^{-1}) and cumulative water infiltration (cm) were computed after 3 h.

Intact soil cores were collected from non-trafficked rows for the measurement of soil bulk density, saturated hydraulic conductivity, and water retention characteristics. Two intact soil cores (7.5 cm diam. and 7.5 cm long) per plot were collected using a hammer-driven core sampler for depths of: 0–7.5, 7.5–15, 15–22.5, and 22.5–30 cm. Soil cores were sealed in plastic bags, transported to the laboratory, trimmed, and stored at 4 °C prior to laboratory measurements.

2.3. Laboratory measurements and data analysis

Saturated hydraulic conductivity was measured using the constant head method (Reynolds et al., 2002b). Soil cores were slowly saturated for 24 h from the bottom with de-aired tap water delivered using a Mariotte bottle at a constant flow rate of 5 mm h^{-1}. The tap water had an electrical conductivity of 0.60 dS m^{-1} and a pH of 7.4. Saturated soil cores were transferred to the permeameter to measure saturated hydraulic conductivity under constant head for 30 min. Immediately after saturated hydraulic conductivity determination, water retention at 0, −1, and −3 kPa matric potentials was determined on the intact soil cores using a tension table Soil cores were slowly resaturated, weighed, and placed on the tension table. The cores were drained on the tension table and weighed at each pressure level. Next, water retention at −10, −33, −100, −400 and −1500 kPa was determined by using pressure plate apparatus (Dane and Hopmans, 2002). For water retention determination at matric potentials between −10, and −400 kPa, the intact soil cores were transferred from the tension table to the pressure extractors, drained at each pressure head, and weighed after drainage stopped. At the end of the determination at