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Soil hydraulic properties as influenced by prairie restoration

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ABSTRACT

Prairie restoration has received increased public attention in recent years for its ecosystem services. The objective of this study was to evaluate effects of prairie restoration on soil hydraulic properties as compared to native prairie (NP), grass and row-crop management. Soil cores (76 mm diam. × 76 mm long) from six replicate locations were sampled to a 60-cm depth at 10-cm intervals from two prairie treatments, a continuous no-till treatment (NT), a long-term timothy grass (*Phleum pratense* L.) treatment (TM) and a row-crop (RC) treatment. The NP has never been tilled and the restored prairie (RP) was established in 1993. All treatments have Mexico silt loam (fine, smectitic, mesic, Vertic Epiaqualfs) soil. Bulk density, saturated hydraulic conductivity (K_{sat}), soil water retention and pore size distribution were determined. *In-situ* K_{sat} was measured using a constant head permeameter with five replications. Bulk density was significantly lower for NP than all treatments. Bulk density was significantly lower for the 0 to 10 cm depth for all treatments, and the 10 to 30 cm depth recorded the highest values. The *in-situ* K_{sat} of RP was lower than other treatments. The first horizon had the highest value for this parameter for all treatments. NP had significantly higher laboratory measured K_{sat}, and it was almost four times higher than RP. The 0 to 10 cm depth of all treatments had significantly higher values for laboratory K_{sat} than other depths and the 50 to 60 cm showed the lowest K_{sat}. NP had the highest macroporosity and fine-mesoporosity, while RP had the highest microporosity. NP had significantly higher water retention at saturation while RP had the highest water retention for soil water pressures of −33 kPa, −100 kPa and −1500 kPa. Soil water retention was significantly higher in NP for −0.4 kPa to −10 kPa soil water pressures; at −20 kPa NP, RP and RC had significantly higher water retention. The NP treatment had higher soil water content than the other treatments for the 0 to 10 cm, 10 to 20 cm, 20 to 30 cm and 50 to 60 cm depths at soil water pressure of −20 kPa. The 30 to 40 cm and 40 to 50 cm depths of RP had higher soil water content at all soil water pressures. Results imply that prairie restoration influences some hydraulic properties in claypan soils; however, it is unlikely to achieve the original prairie soil characteristics due to the prior erosion of the top soil.

1. Introduction

Prairie ecosystems are dominated by grasses and non-woody broadleaf plants (forbs) with <10% tree cover where trees and other woody plants are either absent or widely scattered (Missouri Prairie Foundation, 2014). The importance of prairies has long been recognized and as a result many conservation attempts are being made to restore land to prairies. Goals of these conservation practices are to preserve biological diversity, aesthetic value and to reduce the negative impact of land practices on the environment. Recent interest in prairie restoration and its environmental benefits has encouraged the appraisal of restored prairies compared to native prairies and intensively cultivated areas in several regions of the USA (Mazurak et al., 1960; Udawatta et al., 2008). However restoration success can be affected by previous land use, initial soil conditions, topography, establishment and subsequent management procedures (Brye et al., 2008), degree of future management persistence (Kucharik, 2007) and time (Brye et al., 2002).

Prairies provide habitat for thousands of species of plants and animals (Brye et al., 2008). Studies have also shown that prairie soils have significantly greater quantities of soil organic carbon (C), total C, and nitrogen (N); with low pH, electrical conductivity, calcium (Ca) and phosphorous (Kucharik et al., 2006). A remnant prairie showed 37% higher below-ground C than a 65-year-old restored prairie (Kucharik et al., 2006). McCulley et al. (2005) showed that prairies play a significant role in global flux of carbon dioxide (CO_2). Tallgrass

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prairies are well documented for their ability to accumulate higher amounts of organic matter particularly C, due to deep extensive rooting (Follet et al., 2001). Furthermore, studies have shown that replacing annual crops with perennials have been known to change the quantity and quality of residue added to the soil (Wienhold and Tanaka, 2001). Prairies are also known for their improved soil hydraulic properties compared with conventional management systems.

Soil hydraulic properties are dynamic and influenced by many factors; those can be either physical, chemical or biological. Soil structure (Fuentes et al., 2004), shrink-swell cracks in clay soils (Baer and Anderson, 1997), and agricultural activities such as tillage and traffic compaction (Fuentes et al., 2004; Udawatta et al., 2008) are some physical factors that affect soil hydraulic properties. Plants and organisms that grow and decay also can alter soil hydraulic properties (Beven and Germann, 1982; Meek et al., 1992).

Soil physical properties can be degraded due to erosion (Lal and Moldenhauer, 1987; Arriaga and Lowery, 2003). Erosion removes the coarse-textured topsoil and exposes the fine-textured subsoil with higher bulk density and lower hydraulic conductivity (Seobi et al., 2005; Jagadamma et al., 2009). Perennial vegetation reduces the amount of surface runoff and the rate of erosion (van Rompaey et al., 2001) and thus perennial vegetation may cause differences in soil hydraulic properties. Schwartz et al. (2003) showed that land use practices also have a significant effect on water movement in soils compared to native prairie.

Saturated hydraulic conductivity is an essential parameter for understanding soil water movement. It is an important input for modeling runoff, drainage, and movement of solutes in soils (Mallants et al., 1997), and it is an important soil parameter which is highly influenced by soil management (Rachman et al., 2005; Udawatta et al., 2008). Natural prairies have been shown to increase hydraulic conductivity, organic matter content and lower soil bulk density values (Brye and Pirani, 2005; Brye and Moreno, 2006). Mazurak et al. (1960) reported that infiltration rates under perennial grasses in Nebraska approached those of a native grassland on a silt loam soil within 16 years of establishment. Studies conducted by Udawatta et al. (2008) using computed tomography reported that measured total number of pores, number of macropores (>1000 μm diam.), macroporosity, mesoporosity (200 to 1000 μm diam.), and fractal dimension of macroporosity were significantly higher and pore circularity was lower for native and restored prairies compared to continuous no-till management. Furthermore, soils under native prairie, restored prairie and no-till corn had 83, 43, and 26 pores on a 2500 mm^2 area, respectively, for the 0 to 40 cm depth (Udawatta et al., 2008). Computed tomography measured soil pore parameters showed improvement in restored prairie compared to a no-till corn system (Udawatta et al., 2008).

In Missouri, Kremer and Anderson (2005) observed lower soil bulk densities for prairie soils as compared to a row-crop soil for the 0 to 10 cm soil depth. The difference was attributed to greater organic matter content in prairie soils.

Few studies have been conducted to evaluate soil physical and hydraulic properties to quantify beneficial effects of conservation efforts related to prairie restoration. A better knowledge of the soil water status and the movement of soil water could help develop better prairie restoration plans to improve overall environmental quality. We hypothesized that prairie restoration and long-term management practices can have a significant effect on soil hydraulic properties. The objective of this study was to quantify benefits of prairie restoration compared to a native prairie and long-term cultivated systems on soil water retention, pore-size distributions, bulk density, and saturated hydraulic conductivity. To test our hypothesis, soil physical and hydraulic properties were compared among a native prairie (NP) that has never been cultivated, a 21-year-old restored prairie (RP), a long-term timothy grass (TM) treatment, a continuous corn (*Zea mays L.*) under no-till cultivation (NT) treatment for 45 years and a treatment under row-crop (RC) cultivation for approximately 100 years.

2. Materials and methods

2.1. Experimental sites

All sites were located in central Missouri within the Central Claypan Area which occupies about 33,150 km^2 in Missouri and Illinois (USDA, 2006). The native prairie (Tucker Prairie) is an untilled natural prairie (Dahlman and Kucera, 1965). The native vegetation consists of big blue stem (*Andropogon genardi* Vitman.), little blue stem (*Schizachyrium scoparium* Nash.), prairie dropseed (*Sporobolus heterolepis* [A. Gray]), and Indian grass (*Sorghastrum nutans* [L. J. Nash]) (Udawatta et al., 2008). The burning process of the prairie was rotation burning and for the past decade the prairie was split into five sections and each section was burned twice every five years with one burning in the spring (March) and one in the fall (September or October) as weather permits. The only source of soil disturbance in the prairie was due to small rodents, insects and microbial processes other than fire (Kucera et al., 1967).

The restored prairie (Prairie Fork) is a conservation area. This area was under row-crop management for nearly 150 years and was restored in 1993 with native grass and legumes (Udawatta et al., 2008). The restored prairie vegetation consisted of Indian grass (*Sorghastrum nutans* [L. J. Nash]), little blue stem (*Schizachyrium scoparium* Nash.) and side-oats gamma (*Bouteloua curtipendula* var. *curtipendula*) (Udawatta et al., 2008). There are now about 260 native local ecotypes in the restored prairie. The burning of the restored prairie is rotation burning and the area is divided into three sections and each section is burned every three years.

The corn/soybean crop rotation, no-till continuous corn, continuous timothy, and cover crop treatments were under row-crop cultivation for approximately 150 years prior to present. The corn/soybean crop rotation treatment has been under conservation tillage for the past 30 years. During the earlier half of the 20th century, this site was under plow and disk tillage and crops were wheat (*Triticum aestivum* L.) and corn. Corn, soybean (*Glycine* max *L.*) and grain sorghum (*Sorghum bicolor L.*) were cultivated during the latter part of the 20th century with plow and disk tillage. The detailed historical management records of this site were documented by Lerch et al. (2005).

The no-till continuous corn treatment was managed under no-till management since 1970. The continuous timothy treatment was established over 125 years prior to sampling. The cover crop (CS) treatment was under cover crop management for the past 15 years. The management was cereal rye (*Secale cereal*) during the time of measurements. The cover crop treatment was only used to measure *in-situ* saturated hydraulic conductivity. No soil cores were obtained from this treatment for laboratory analysis.

Mexico silt loam (fine, smectitic, mesic, Vertic Epiaqualfs) is the major soil series for all study treatments. The parent material for soils in the selected study areas was loess over loamy sediments which developed from pre-Illinoisan till. Mexico soils are mostly located on ridges or hillsides with 0% to 4% slopes (Ghidey and Alberts, 1999). The presence of an argillic claypan (Fig. 1) horizon located between 10 and 30 cm below the surface is characteristic for these soils; they are therefore poorly drained (Ghidey and Alberts, 1999). Mean annual temperature ranges from 10 to 18 °C and mean annual precipitation ranges from 890 to 1020 mm (Missouri Climate Center, 2014). During winter and spring seasons, the water table is very shallow, and during summer the soil becomes very dry.

2.2. Sample collection and analysis

The treatments were located near each other. Due to land management constraints, the study used a pseudo-replication approach as has been used in other research with similar challenges. Soil sampling protocol was similar to method described by Brye and Riley (2009). There are number of studies which had the similar challenge when sampling