Geoderma 286 (2017) 46–53

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Soil water infiltration affected by topsoil thickness in row crop and switchgrass production systems

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ARTICLE INFO

Article history:
Received 16 August 2016
Received in revised form 13 October 2016
Accepted 16 October 2016
Available online xxxx

Keywords:
Claypan
Green-Ampt equation
Parlange equation
Saturated hydraulic conductivity
Biofuel crop
Surface runoff

ABSTRACT

Conversion of annual grain crop systems to biofuel production systems can restore soil hydrologic function; however, information on these effects is limited. Hence, the objective of this study was to evaluate the influence of topsoil thickness on water infiltration in claypan soils for grain and switchgrass (*Panicum virgatum* L.) production systems. The experiment was performed at the University of Missouri South Farm (38°54′N, 92°16′W) on a Mexico silt loam (Vertic Luvisols) soil. Since 2009, plots were planted with either switchgrass or a corn (*Zea mays* L.)-soybean (Glycine max (L.) Merr.) rotation. Infiltration rates were measured using ponded infiltrometers during two years (2014 and 2015) under switchgrass and grain crop management each with two levels of topsoil thickness (0 and 37.5 cm). Physically-based Parlange and Green-Ampt infiltration models were used to estimate saturated hydraulic conductivity (K_s) and sorptivity (S) parameters. Switchgrass planted on degraded soil (shallow topsoil treatment) resulted in greater K_s, S, q_s (quasi-steady infiltration rate) and K_{fs} (field-saturated hydraulic conductivity) values than with row crop management for both 2014 and 2015 measurement years. Results for selected 24-hour mean frequency (11.8, 14.2, and 16.2 cm) storms showed that switchgrass production systems enhanced estimated water infiltration, reduced estimated runoff, and decreased estimated time from water ponding to end of ponding compared with row crop management. Switchgrass is recommended to be planted on degraded soils especially in claypan landscapes for improved water use.

1. Introduction

Perennial grass species such as switchgrass have been widely investigated as a potential lignocellulosic biomass feedstock (McLaughlin and Adams, 2005; Monti, 2012; Parrish and Fike, 2005). The benefits of switchgrass on preserving and maintaining soil productivity have drawn attention from soil scientists as they investigate the management systems that can improve soil and water quality while providing biofuel feedstocks on degraded lands. Degraded lands refer to land that has lost part or all of its productive capacity as a result of intensive agricultural practices which can enhance soil erosion (Ruiz-Colmenero et al., 2013). The production of perennial biomass feedstock has been found to have significant effects on soil infiltration as it often changes soil physical and biological properties (Bharati et al., 2002). This land management system effects soil properties due to differences in litter quantity and quality, root biomass, root penetration, and soil architecture due to activities of soil organisms (Graaff et al., 2013; Liebig et al., 2005). Switchgrass enriches above- and belowground organic carbon through aboveground biomass returned (Blanco-Canqui, 2010) as well as decaying and decomposition of older roots (Bonin et al., 2012) which increases aggregation of soil particles (Blanco-Canqui et al., 2005) that can lead to improved water infiltration. The gradual changes in biopore shape, orientation and size distribution due to the extensive root system of switchgrass influence the infiltration rate and water flow as well as water retention in soil (Rasiah and Aylmore, 1998). The relatively compacted soil horizon such as a plowpan and hardpan can be penetrated and alleviated by perennial grass deep roots which increase water infiltration, nutrient uptake, and groundwater recharge (Blanco-Canqui, 2016, 2010).

A study conducted by Rachman et al. (2004) on a Manona silt loam soil (Typic Hapludolls) found that infiltration rate under switchgrass (grass hedge) was significantly greater compared to row crop

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Abbreviations: SPARC, Soil Productivity Assessment for Renewable Energy and Conservation; K_s, saturated hydraulic conductivity; S, sorptivity; q_s, quasi-steady infiltration rate; K_{fs}, field-saturated hydraulic conductivity; I, cumulative infiltration; I_d, estimated cumulative infiltration depth; RO, runoff depth; T_p, time to ponding; T_e, time to end of ponding.

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http://dx.doi.org/10.1016/j.geoderma.2016.10.016
0016-7061/

management. The authors also indicated that the field saturated hydraulic conductivity under switchgrass was seven times higher than under row crops. Bharati et al. (2002) reported that a perennial multi-species riparian buffer had infiltration rate five times greater than cultivated fields and pasture. Jung et al. (2007) compared annual cropping and perennial cropping management effects on water infiltration for claypan soils and concluded that perennial cropping systems greatly improved water infiltration when compared to annual cropping systems (corn-soybean). Bonin et al. (2012), who conducted an infiltration study in Ohio on a Kokomo silty clay loam (Typic Argiaquoll), reported that cumulative infiltration under switchgrass (69 cm) was higher compared to values under corn (37 cm) management. Another study by Kumar et al. (2012) comparing agroforestry buffer, grass buffer and pasture areas, also found that the infiltration rate under perennial grass buffers was significantly higher than under pasture areas. A study conducted by Zaibon et al., (2016), in a similar experimental site to the current study, indicated that switchgrass had lower bulk density, greater saturated hydraulic conductivity, and a larger proportion of soil macropores when compared to row crop management. Switchgrass can increase soil water infiltration, evapotranspiration and interception of runoff compared to row crop management by improving soil structure and building organic matter due to deep and extensive rooting systems, as well as greater water use.

Soil water infiltration is also influenced by soil texture, as finer textured soils (higher clay content) decrease the infiltration rate (Shukla, 2013). In eroded soils especially in claypan soils, the presence of an impeding subsoil layer with predominantly smectitic clay minerals greatly influences water infiltration. The restrictive subsoil layer (argillic horizon) controls the flow of water in the soil matrix (Jung et al., 2007). In a study on a Mexico silt loam in Centralia, Missouri, Jiang et al. (2007) reported that saturated hydraulic conductivity at the backslope position which had shallow topsoil thickness was lower compared to summit and footslope (thicker topsoil thickness) landscape positions. Several infiltration studies have been conducted on claypan soil landscapes (Anderson et al., 2009; Jung et al., 2007; Kumar et al., 2012; Sahin et al., 2016). Generally these studies compared the effect of soil management systems on infiltration; annual versus perennial vegetation (Jung et al., 2007), pasture management versus agroforestry buffers (Bharati et al., 2002; Kumar et al., 2012), and row crop versus agroforestry and grass buffers (Anderson et al., 2009; Sahin et al., 2016); however, studies evaluating the effects of topsoil thickness on infiltration are limited.

While switchgrass has the potential to increase infiltration of water into soil, more research is needed to understand the effects of switchgrass on soil water infiltration on degraded land, especially within eroded claypan landscapes. Hence, the objectives of this study were to assess the influence of topsoil thickness on water infiltration in claypan soils for row crop and switchgrass production systems. The hypothesis of this study was that the switchgrass treatment would have greater infiltration rates and lower surface runoff than the row crop treatment. Switchgrass can improve soil hydraulic properties of degraded land.

2. Materials and methods

2.1. Site description

The study was conducted at University of Missouri South Farm Research Center in Columbia Missouri, USA (38°54′N, 92°16′W). A research site known as the Soil Productivity Assessment for Renewable Energy and Conservation (SPARC) was established in 1982 on a Mexico silt loam (USDA soil taxonomy, fine, smectitic, mesic, Vertic Epiaqualf; FAO soil units, Vertic Luvisols) soil with 1–3% slope. The research site had two different levels of topsoil thickness treatments as main plots and two vegetative management treatments as subplots. While other topsoil thickness treatments are included at SPARC, only the main plots with shallow and deep topsoil treatments were integrated in this study. Topsoil treatments were categorized into two topsoil thickness classes: shallow [<7 cm (average = 4 cm) topsoil thickness] and deep [>27 cm (average = 36 cm) topsoil thickness]. The two vegetative management treatments were switchgrass (*Panicum virgatum* L.) or corn (*Zea mays* L.)-soybean (*Glycine* max (L.) Merr.) rotation. Each treatment was replicated four times and were in a completely randomized design.

The plots were established in 1982 with continuous corn or continuous soybean management (Gantzer and McCarty, 1987; Thompson et al., 1992, 1991). From 1993 to 2008, the plots were left unused with native grasses and weeds after the initial study at this research site. During that unused period the plots were usually mowed once each summer.

In the spring of 2009, the topsoil thickness of research plots were reassessed by using a soil apparent electrical conductivity (EC_a) device following previously established procedures (Sudduth et al., 2010). A new research study was established with two treatments: corn-soybean rotation and switchgrass production. The row crop plots were planted with soybeans in 2014 and corn in 2015 during this study. Details on research plot management practices are presented elsewhere (Boardman, 2015; Zaibon et al., 2016).

2.2. Ponded infiltration measurements

In situ water infiltration measurements were conducted using ponded infiltrometer units for the two topsoil thickness treatments [shallow (4 cm) and deep (36 cm average topsoil)] with two vegetative treatments (switchgrass and row crop). Infiltration rates were measured using single ring infiltrometer units with a Mariotte system. The dimensions of the infiltration rings were 25 cm inside diameter, 30 cm length and 0.3 cm wall thickness. The ring was inserted vertically 15 cm into the soil and crop residues or surface crusts were not removed. In the switchgrass treatment, grasses were cut off with shears at the soil surface prior to installation of infiltrometer units. Measurement positions were on non-trafficked interrow positions. A Mariotte system was used to maintain a 5 cm constant positive head inside the infiltration ring during measurement. Infiltration measurements were recorded for 120 to 150 min for selected time intervals after a constant positive head had been reached. The sodium adsorption ratio (SAR) of water used for infiltration was 0.817.

Prior to ponded infiltration measurements, antecedent water content (AWC) measurements were made. Soil samples were collected using an auger in the area surrounding the study area from soil depths of 0 to 10 and 10 to 20 cm for each treatment. Samples were weighed, oven dried at 105 °C for 24 h, then reweighed to calculate gravimetric water content. Then the gravimetric water content was converted to volumetric antecedent water content by using bulk density values reported in Zaibon et al. (2016).

Two infiltration models, the Parlange et al. (1982) and the Green and Ampt (1911), were used to fit the measured infiltration data. Philip (1957) modified the Green and Ampt model for time (t) versus cumulative infiltration (I), as follows:

$$t = \frac{I}{K_s} - \frac{\left[S^2 \ln\left(1 + \frac{2IK_s}{S^2}\right)\right]}{2K_s^2} \tag{1}$$

The physically based Parlange model for t versus I is as follows:

$$t = \frac{I}{K_s} - \frac{S^2\left[1 - exp\left(-\frac{2IK_s}{S^2}\right)\right]}{2K_s^2} \tag{2}$$

where t (T) is time (h), I (L) is the cumulative infiltration (mm), S ($LT^{-0.5}$) is the sorptivity (mm $h^{-0.5}$), and K_s (LT^{-1}) is the saturated hydraulic conductivity (mm h^{-1}). The S and K_s parameters were estimated using procedures proposed by Clothier and Scotter (2002) based on cumulative infiltration. The initial S parameter was estimated from initial