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Switchgrass impact on selected soil parameters, including soil organic carbon, within six years of establishment

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ABSTRACT

Switchgrass (*Panicum virgatum* L.) cultivation for bioenergy has the potential to improve soil properties. However, little is known about the changes in soil properties for first few years of switchgrass establishment. The objectives of this study were to evaluate the impacts of nitrogen fertilization rate (N rate) and landscape position on soil properties that include pH, soil organic carbon (SOC), total nitrogen (TN), soil bulk density (ρ_b), SOC stock, and phosphorus (P) for consecutive years (2009 through 2013) under switchgrass field in South Dakota. The experiment was a split-plot design with 4 replications of 3 N rates (low, 0 kg N ha^{-1}; medium, 56 kg N ha^{-1}; and high, 112 kg N ha^{-1}) and 3 landscape positions (shoulder, backslope, and footslope). Data from this study showed that N rate did not impact the selected parameters at all five (0–5, 5–15, 15–30, 30–60, and 60–100 cm) depths from 2009 to 2013. The landscape position significantly influenced these properties for all five depths in 2009–2013. These properties showed some pattern among the three N rates and positions. The year significantly impacted these properties at some sampling depths. The SOC and TN at the 0- to 5-cm depth had an increasing trend over the observed years. These findings indicate that N rate cannot impact the soil properties, and footslope position can be beneficial for improving these soil properties. This study concludes that switchgrass can be a sustainable energy crop to improve or stabilize the soil properties over the years.

1. Introduction

Switchgrass (*Panicum virgatum* L.) is a native perennial warm-season (C_4) grass with a deep root system in North America (Lewandowski et al., 2003). It was first identified as a renewable energy source by the United States Department of Energy in 1985 (Lee et al., 2012), and was selected as a "model" potential bioenergy crop in 1991 (Wright and Turhollow, 2010). To successfully implement switchgrass cultivation for bioenergy in the United States, the potential ecological impacts should be assessed in concert with economic impacts (Hartman et al., 2011). Some studies on the ecological impacts including the impact of switchgrass on soils have been reported. Results from a review study by Lemus and Lal (2005) showed that switchgrass production could restore soil organic carbon (SOC) in surface soils. Switchgrass also has the potential for storing a significant quantity of soil carbon (C) in the Northern Great Plains (Frank et al., 2004). Moreover, the deep root system of switchgrass has the potential to lower soil erosion rate (McLaughlin et al., 2002; Williams et al., 2009). The magnitude of the benefits, however, depends on soil type, topography, harvest frequency, fertilizers, pesticides, and climate. So far, studies to address the impacts of switchgrass production on soils are very limited in South Dakota.

Soil pH, SOC, total nitrogen (TN), soil bulk density (ρ_b), SOC stock, and phosphorus (P) were selected for evaluating the impacts of switchgrass production on soils in this study. Soil properties can be used as indicators for evaluating soil quality (Gong et al., 2015; Smith et al., 1993). Soil pH affects the chemical reactions in soils (Zhao et al., 2011), influencing the availability of some plant nutrients (Jensen, 2010). The SOC, pH, and nutrient availability, electrical conductivity, and infiltration are strongly interdependent in soils, and ρ_b is one of the primary indicators for evaluating soil quality in a given agricultural ecosystem (Arshad and Martin, 2002). Similarly, SOC and TN are the most critical indices of soil fertility (Li, 1992; Ming et al., 2011). Moreover, soil nutrients [e.g., nitrogen (N) and P] have favorable effects on physical, chemical, and biological properties of soils (Cao et al., 2011). The increase of SOC stock in soils can reduce carbon dioxide (CO_2) emissions from soils through C sequestration, and improve soil properties

Abbreviations: SOC, soil organic carbon; SOM, soil organic matter; C, carbon; N, nitrogen; TN, total nitrogen; ρ_b, soil bulk density; P, phosphorus; N rate, nitrogen fertilization rate; CO_2, carbon dioxide; TC, total carbon; SIC, soil inorganic carbon; *d*, soil depth; ANOVA, analysis of variance

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(Blanco-Canqui, 2010; Robertson et al., 2008).

Nitrogen is a limiting nutrient for switchgrass (Hong et al., 2014; Owens et al., 2013), and thereby N fertilization becomes a key factor in switchgrass land management. However, the amount of N fertilization depends on different soil conditions (Kering et al., 2012). An adequate amount of N fertilization can enhance SOC accumulation and soil fertility (Bowman and Halvorson, 1998). Conversely, a long-term excessive amount of N fertilization can cause severe degradation of soils, characterized by high acidity, low nutrients, and a disturbed and unbalanced ecosystem (Dong et al., 2012; Zhang et al., 2009). However, specific information about the effect of N fertilization rate (N rate) on soils under switchgrass production in South Dakota is still lacking.

Landscape position is also a key factor influencing soil properties under a hillslope scale (Jackson-Gilbert et al., 2015). Previous studies have shown that soil properties are related to topographic positions in different landscapes (e.g., Bronson et al., 2003; Guzman and Al-Kaisi, 2011). Only a few studies, however, are related to the position/spatial effects on soil properties in switchgrass fields. For instance, the field-scale soil properties such as ρ_b, pH, P, and SOC under switchgrass managed in Nebraska, South Dakota, and North Dakota are quite variable depending on different sites (Schmer et al., 2011). The overall potential environmental benefits of switchgrass production and the realized improvements to ecosystem functioning are likely dependent on the locations (Dale et al., 2011). However, little is known about the landscape position effects on soil properties under switchgrass fields in South Dakota.

The specific objectives of this study, therefore, were to (i) evaluate the impacts of N rate and landscape position on soil pH, SOC, TN, ρ_b, SOC stock, and P and (ii) assess the impacts of switchgrass production on these soil properties.

2. Materials and methods

2.1. Study site and experimental design

The study site is located 45°16′24.55” N, 97°50′13.34” W (altitude: 524.3 m above sea level), near Bristol, South Dakota, USA. The experiment was a split-plot design with 4 replications. The treatments included the three N rates (low, 0 kg N ha^{-1}; medium, 56 kg N ha^{-1}; and high, 112 kg N ha^{-1}) and landscape positions (shoulder, backslope, and footslope). Plot size was 21.3 m by 365.8 m with 2–20% slope. Switchgrass [cultivar: Sunburst; planting rate: 10 kg pure live seed (PLS) ha^{-1}] was planted on May 17, 2008. The previous crop grown at this location was soybean (*Glycine* max. L.). Switchgrass was harvested once annually around a killing frost from 2009 to 2013. The soils at the site are dominated by loamy soils (Mbonimpa et al., 2015). The mean annual precipitation and the mean daily maximum and minimum temperature from 2008 to 2013 were 633.24 mm and 11.43 and 0.72 °C, respectively.

2.2. Data measurements and analysis

Soil samples were collected from each plot during summer (June) of 2009, 2010, 2011, 2012, and 2013 for measuring the selected soil properties that included soil pH, SOC, TN, ρ_b, SOC stock, and P at the 0- to 5-, 5- to 15-, 15- to 30-, 30- to 60-, and 60- to 100-cm depths. The soil samples for each year were collected before application of N fertilizer. The switchgrass was planted in 2008 (no fertilizer was applied this year) and was not harvested in the year because it had very poor stand during the year. Therefore, the initial sampling was in 2009. The soil samples were bulked together and air dried, and then ground to pass a 2-mm screen. To analyze TN and total carbon (TC), the samples were further ground to pass through a 0.5 mm sieve. All visible residues were removed prior to grinding. The TC and TN were determined by combustion using a TruSpec CHN analyzer (LECO Corporation, St. Joseph, MI). Soil pH (1:1 soil/water) was determined using the procedure given by McLean (1982). The soil samples were tested for soil inorganic carbon (SIC) using the method described by Wagner et al. (1998). The SOC was calculated by subtracting SIC from TC. The P concentrations were measured using the Olsen P test (Olson et al., 1954). Soil ρ_b was determined by the core method (Grossman and Reinsch, 2002). The SOC stock (Mg ha^{-1}) was computed by multiplying the SOC concentration by the ρ_b (Mg m^{-3}) and the equivalent soil depth d (cm):

$$SOC\ stock = \rho b \times SOC \times \frac{d}{10} \tag{1}$$

where d is soil depth (cm), ρ_b is soil bulk density (Mg m^{-3}), *SOC* is SOC concentration (g kg^{-1}).

2.3. Statistical analysis

The statistical analysis of N rate and landscape position effects on soil pH, SOC, TN, ρ_b, SOC stock, and P for each depth from 2009 to 2013 were obtained using pairwise differences method to compare least-squares means estimated by a mixed model using the GLIMMIX procedure in SAS9.3 (SAS, 2012), where the N rate, position, and N rate × position were considered as fixed effects and replication and replication × N rate as random effects. The analysis of variance (ANOVA) was used to test the fixed effects of the N rate and position on the soil properties based on the mixed model. Similarly, the year effects on these properties for each depth were tested using another mixed model, where year, N rate, position, N rate × position, year × N rate, year × position, year × N rate × position comprised the fixed effects, while replicate, replicate × N rate, replicate × position constituted the random effects. Data were transformed when necessary, and the transformation was determined using the Box−Cox method (Box and Cox, 1981; Box and Cox, 1964). Significance was determined at $\alpha = 0.05$ level for all statistical analysis in this study.

3. Results

3.1. Soil pH

The soil pH data for all five soil depths from 2009 to 2013 are presented in Table S1 and S2. The N rate did not significantly influence soil pH at five depths from 2009 to 2013. However, the mean pH values showed a pattern among the three N rates, namely that the mean pH values under the medium N rate, generally, were higher than those of the high and low N rates at the 0- to 5-, 5- to 15-, 15- to 30-, and 30- to 60-cm depths from 2009 to 2013. The landscape position significantly impacted pH at all the depths in the observed years except for the 0- to 5-cm depth in 2010. The mean pH values for all five depths in the years increased in the order of footslope position < backslope position < shoulder position. The mean pH values for the three positions and all five depths varied in the range of 7.63 to 8.52, 7.44 to 8.49, 7.76 to 8.89, 7.31 to 8.46, and 7.34 to 8.53 in 2009, 2010, 2011, 2012, and 2013, respectively. Most of the mean pH values increased with the increase in soil depth. The pH was influenced by the year under the three N rates and positions at all depths from 2009 to 2013. Most of the mean pH values in 2011 were significantly higher than that for 2009, 2010, 2012, and 2013, and the trends of mean pH values for each N rate and position over the 5 years were downward curves (Table S1).

3.2. Soil organic carbon (SOC)

Data for SOC contents (g kg^{-1}) under different treatments at five depths from 2009 to 2013 are presented in Tables 1a and 1b and S3. The N rate did not significantly influence the SOC contents at all five depths from 2009 to 2013. However, the mean SOC contents at the 0- to 5-cm depth showed a pattern among the three N rates, namely that the mean SOC contents were in the order of medium N rate < high N rate < low N rate from 2009 to 2012. In 2013, the order of the mean