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Research article

Evaluating the impacts of landscape positions and nitrogen fertilizer rates on dissolved organic carbon on switchgrass land seeded on marginally yielding cropland

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ABSTRACT

Dissolved organic carbon (DOC) through leaching into the soils is another mechanism of net C loss. It plays an important role in impacting the environment and impacted by soil and crop management practices. However, little is known about the impacts of landscape positions and nitrogen (N) fertilizer rates on DOC leaching in switchgrass (*Panicum virgatum* L.). This experimental design included three N fertilizer rates [0 (low); 56 (medium); 112 (high) kg N ha^{-1}] and three landscape positions (shoulder, backslope and footslope). Daily average DOC contents at backslope were significantly lower than that at shoulder and footslope. The DOC contents from the plots that received medium N rate were also significantly lower than the plots that received low N rates. The interactions of landscape and N rates on DOC contents were different in every year from 2009 to 2014, however, no significant consistent trend of DOC contents was observed over time. Annual average DOC contents from the plots managed with low N rate were higher than those with high N rate. These contents at the footslope were higher than that at the shoulder position. Data show that there is a moderate positive relationship between the total average DOC contents and the total average switchgrass biomass yields. Overall, the DOC contents from leachate in the switchgrass land were significantly influenced by landscape positions and N rates. The N fertilization reduced DOC leaching contents in switchgrass field. The switchgrass could retain soil and environment sustainability to some extent. These findings will assist in understanding the mechanism of changes in DOC contents with various parameters in the natural environment and crop management systems. However, use of long-term data might help to better assess the effects of above factors on DOC leaching contents and loss in the switchgrass field in the future.

1. Introduction

The processes of respiration and photosynthesis to explain the loss or gain of net carbon (C) from soil-plant ecosystems have been reported by many studies across the globe. However, there are other mechanisms of net C loss such as dissolved organic carbon (DOC) through leaching into the soils that need to be quantified. Leaching of DOC is an important process that affects the C stabilization in soils (McDowell and Likens, 1988). The DOC is a complex mixture of organic compounds which plays an important role in the terrestrial ecosystems. The major roles of DOC include substrate for biological activity, acidifying and weathering agent, availability and mobility of nutrients and metals, and source of C in aquatic ecosystems (Moore et al., 2008). The DOC leaching in soil is an important source of C in rivers and lakes (Aitkenhead and McDowell, 2000; Chibnall, 2013). On the other hand, the process of DOC leaching from the surface soil to lower in the profile provides a way to transfer C where it can be absorbed and stored in the vadose zone (Chibnall, 2013). Therefore, it is potentially an

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important way to sequester C (Sanderman and Amundson, 2009).

A number of studies have reported the leaching of DOC contents from various systems, for example, forest soils (Peichl et al., 2007; Sanderman and Amundson, 2009), unmanaged grasslands (Don and Schulze, 2008), grazed pasture systems (McTiernan et al., 2001; Harrison et al., 2008), and different croplands (Royer et al., 2007; Ruark et al., 2009; Xu et al., 2013). The agricultural management systems impact the timing and magnitude of DOC export from soils to rivers or ditches (Hernes et al., 2008; Wilson and Xenopoulos, 2009; Wang et al., 2010). Various studies have investigated the role of manure, and/or organic residues on chemical, biological, and physical properties of soils including the dynamics of DOC or water-extractable organic C (Royer et al., 2007). Some researchers studied the effects of irrigation (Xu et al., 2013), tile-drained (Ruark et al., 2009), biochar (Novak et al., 2010), soil types (Jones et al., 2014) and depths (Siemens and Kaupenjohann, 2003; Chibnall, 2013) on DOC contents. Temperature and hydrological controls (McDowell and Likens, 1988; Davidson and Janssens, 2006; Mertens et al., 2007; Don and Schulze, 2008; Harrison et al., 2008) and Nitrogen fertilizer controls (McTiernan et al., 2001) were examined based on different regimes. However, limited research has been conducted to investigate the impacts on DOC contents under switchgrass land which was recently converted from marginally yielding cropland.

Switchgrass is a perennial C_4 grass which is native to North America and successfully adapted to diverse environmental conditions over large geographic regions (Lewandowski et al., 2003). It is adapted to marginally productive cropland, and tolerates soil water deficits and low soil nutrient concentrations. After establishment, the stand can be productive for 10 years or more (Sokhansanj et al., 2009). In the U.S., switchgrass was first identified as a renewable energy source by the U.S. Department of Energy in 1985, and has been extensively evaluated for further development over the last two decades (Parrish and Fike, 2005; Wright, 2007). However, switchgrass can be beneficial for soil and environment (Blanco-Canqui, 2010). However, very little information in the literature is available on DOC content in leachate from switchgrass land at landscape positions and N fertilizer rates. Novak et al. (2010) conducted the short-term CO_2 mineralization study after additions of biochar in a switchgrass field to monitor the DOC contents for two days. Another study was conducted by Nichols et al. (2012) to evaluate the impact of in the intercropping of loblolly pine and switchgrass and focused on exploring characteristics of only forest and not switchgrass. Therefore, the present study was based on the hypotheses that (1) N fertilization in switchgrass land enhances crop growth and roots productivity which may impact the DOC leaching contents, (2) switchgrass growth impacted by landscape positions which ultimately may impacts DOC leaching contents. The specific objectives of the study are to: (i) assess the impacts of switchgrass land managed under different landscape positions and N rates on DOC contents, and (ii) evaluate the relationship between DOC leaching contents, and switchgrass biomass yield and climatic parameters.

2. Materials and methods

2.1. Study area and experimental design

The study area is located at 45°16′24.55″N, 97°50′13.34″W, near Bristol, South Dakota, USA. This study was arranged into 12 plots (each plot is 21.3 m wide and approximately 365.8 m long), and each plot was comprised of three landscape positions: shoulder, backslope, and footslope with 2–20% slope. The switchgrass was planted on May 17, 2008. The previous crop grown on these plots was soybean (*Glycine max*. L.). The plots were laid out in a split plot factorial design comprised of three N fertilizer rates treatments (low, 0 kg N ha^{-1}; medium, 56 kg N ha^{-1}; and high, 112 kg N ha^{-1}) and three landscape positions (shoulder, backslope, and footslope). In this manuscript, hereafter, 0 kg N ha^{-1} will be referred to as low, 56 kg N ha^{-1} as medium, and 112 kg N ha^{-1} as high N rate levels. The soils at the site are dominated by loamy soils; Forman (*Fine-loamy, mixed, frigid Udic Argiborolls)*, Buse (*Fine-loamy, mixed, frigid Udic Calciborolls)*, Aastad (*Fine-loamy, mixed, frigid Pachic Udic Haploborolls)*, and Barnes (*Fineloamy, mixed, frigid Udic Haploborolls)*. There are also minor occurrences of Netley (*Fine, montmorillonitic, frigid Chromic Hapluderts)* and Sinai (*Fine, montmorillonitic, frigid Typic Hapluderts)* silty clays. Buse soils are mostly encountered at shoulder landscapes, and Aastad at footslopes (Mbonimpa et al., 2015). The selected soil properties for the 2009–2011 are shown in Table S1.

2.2. Data measurements

To measure the DOC contents, water samples (leachates) from the unsaturated soil was collected using porous stainless steel suction lysimeters installed at 100 cm depth and 36 positions in this study site. After installation below ground level, vacuum was applied to the lysimeter through a sealed tubing system from the lysimeter to the soil surface using a pump. The pore water collected in the lysimeters was sampled using a tube and transferred to collection bottles. The lysimeters were then emptied using a pump. The leachates were filtered through 0.45 μm paper and concentration of DOC was measured by Shimadzu TOC-Vcsh analyzer using the standard method 5310C (i.e., the persulfate-ultraviolet or heated-persulfate oxidation method) within 48 h of sample collection. The samples were collected 2–6 times per year from April to November. There are some missing samples because of no leachate at some positions resulting from dry weather or others unknown reasons. Table S2 shows the number of water samples at each of 19 collection times in the 2009 to 2014 period. A total of 313 samples were collected at this study site during this period.

Soil sample collection and soil property measurements were descripted in a previous publication (Mbonimpa et al., 2015). Daily minimum and maximum temperature from 2011 to 2013 were measured using temperature sensor connected to the LI-8100 instrumentation at this study site. The precipitation for 2011–2013 was monitored at this study site. The daily maximum and minimum air temperature and precipitation from 1985 to 2010 and 2014 were retrieved from the nearest weather station in Webster, SD (25 km). Precipitation (2003–2010 and 2014) was retrieved from the nearest weather station in Bristol, SD (10 km). Switchgrass yields were measured and the method was descripted in previous publications (Hong et al., 2012) and averaged across three N rates and each year from 2010 to 2014 for this study.

2.3. Data analysis methods

Statistical comparisons of differences of parameters between three landscape positions and three N rates were obtained using all pairwise differences method to compare least squares means (LS-means) estimated by the mixed model using the GLIMMIX procedure in SAS (SAS, 2012) where the landscape position, N rate, and time were considered as fixed effects and replication considered as random effect. The data trend analysis was conducted by the Mann–Kendall test (Mann, 1945; Kendall, 1975) with slopes estimated by the Sen Estimator (Sen, 1968) using the package "mblm" in R (Komsta, 2013; R Core Team, 2014). Significance was determined at the $\alpha = 0.10$ level for all statistical analysis because of limited degrees of freedom (replications per treatment are not enough because of missing values) (Royer et al., 2007). The