Evaluating the impacts of landscape positions and nitrogen rates on dissolved organic carbon under 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 N fertilizer rates on DOC leaching in switchgrass (*Panicum virgatum* L.). This experimental design included three nitrogen (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.

Keywords: Dissolved organic carbon (DOC), landscape positions, nitrogen management, switchgrass

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 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 C₄ 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. 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 land can be beneficial for soils, the economy, and the environment as well. 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 CO₂ 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 (*Fine-loamy, 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 hours of sample collection. The samples were collected 2 to 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 described 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 kilometers). Precipitation (2003-2010 and 2014)

was measured at the nearest weather station in Bristol, SD (10 kilometers). Switchgrass yields were measured and the method was described 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 correlation analysis was conducted using the CORR procedure in SAS (SAS, 2012) and Pearson correlation coefficients.

3. **Results**

3.1. *Climate data and biomass yields*

The annual average values of maximum temperature for 2009, 2010, 2011, 2012, 2013, and 2014 were 10.1, 11.6, 11.7, 14.3, 10.4, and 10.3°C, respectively. The annual average values of minimum temperature for these years were 0.15, 1.81, 0.74, 2.47, -0.57, and -0.46°C, respectively. The cumulative annual precipitation values from 2009 to 2014 were 717, 647, 538,

585, 617, and 432 mm, respectively. The long-term (30 years, 1985-2014) average daily maximum and minimum temperature and annual precipitation values were 11.7°C, 0.97°C, and 621 mm, respectively. 2011, 2012, and 2014 were drought years because precipitation in the years were lower than the long-term annual average precipitation. The annual average maximum and minimum temperature in 2012 were substantially higher compared to the average of other 5 study years, and the long-term annual average of temperature. The monthly average of maximum and minimum temperature and cumulative monthly precipitation are shown in Fig. 1A and Table S3.

The total average switchgrass yields monitored from 2010, 2011, 2012, 2013, and 2014 were 4.85 ± 1.15 , 4.46 ± 0.78 , 5.04 ± 1.14 , 4.7 ± 1.16 , and 4.50 ± 1.19 Mg ha⁻¹. Data show that switchgrass yield was maximum in 2012 and minimum in 2011. The average switchgrass yields with high N rate from 2010 to 2014 were 5.24 ± 1.03 , 4.99 ± 0.45 , 5.88 ± 0.99 , 5.86 ± 0.44 , and 5.36 ± 0.70 Mg ha⁻¹, respectively. The average switchgrass yields with medium N rate from 2010 to 2014 were 5.42 ± 0.59 , 4.81 ± 0.33 , 5.45 ± 0.55 , 4.97 ± 0.41 , 5.07 ± 0.60 Mg ha⁻¹. The average switchgrass yields with low N rate from 2010 to 2014 were 3.90 ± 1.26 , 3.58 ± 0.59 , 3.78 ± 0.44 , 3.31 ± 0.27 , 3.06 ± 0.38 Mg ha⁻¹. Data indicate that the switchgrass biomass yield followed a trend similar to that of the annual average temperature and annual precipitation. The yield with medium or high N rate was higher than that with the low N rates (Fig. 2B).

3.2. *Daily average DOC contents*

A total of 313 values of DOC contents were measured for the 2009 through 2014 period. The mean and standard deviation of DOC contents were 8.29 ± 8.03 mg L⁻¹ with the maximum value of 70.9 and minimum value of 0.25 mg L⁻¹. The daily average DOC contents at the

backslope position were lower than that at footslope and shoulder. The DOC contents from plots that received medium N rate were also lower than those of high and low N rates (the average DOC at low N rates was higher than that of high N rate) (Table 1). The first three largest differences in daily DOC contents values among landscape positions occurred on 16 October, 2014, 14 August, 2013, and 19 September, 2014. The three smallest differences occurred on 16 April, 2014, 10 August, 2010, and 11 July, 2014. The trends of DOC contents at three landscape positions were similar from 2009 to 2011 but more different in 2012 and 2014 (Fig. 1C).

The N rate influenced the DOC contents, however, differences were not always significant. The DOC contents under medium N rate were significantly different from that under low N rate. The DOC contents at backslope position were significantly different between medium and low N rates (Table 1). However, there were no significant differences of DOC contents among three N rates at shoulder or footslope positions (Table 1). The daily average DOC contents were influenced by landscape positions. The DOC contents at shoulder and footslope were significantly different from that at backslope. Specifically, within plots under high or low N rate, the DOC contents between backslope and footslope were significantly different. However, under medium N rate plots, no significant differences of DOC contents were observed within the three landscape positions (Table 1).

The DOC contents under high and low N rate were similar on all collection dates except for 31 August, 2012. Because of missing values of DOC under medium N rate, their pattern from 2009 to 2012 could not be displayed. In 2013 and 2014, the DOC pattern under medium N rate is different from that under high and low N rates (Fig. 1D). The impacts of landscape positions and N rates on DOC contents were different from 2009 to 2014 (Table S4). The DOC contents at backslope were significantly different from those at footslope in 2010 and 2011. The DOC

contents at backslope were significantly different from that at shoulder and footslope in 2012. There were also significant differences in DOC between shoulder and backslope in 2014. However, no significant differences in DOC contents under landscape positions were observed in 2009 and 2013. When compared among different N rates, the DOC contents were not significantly impacted by three N rates in 2013 and 2014 (Table S4). The DOC contents between high and low N rates were not significant in 2009, 2010, and 2011. However, there was significant difference between high and low N rates in 2012 (Table S4). In 2009-2012, it is unknown whether there were significant differences of DOC between medium N rate and high or low N rates because of missing data under medium N rate. The daily average DOC contents at footslope and high N rate followed a negative trend ($p < 0.1$) over time because of their slopes of -0.0343 and -0.0106, respectively (Table 2 and Fig. 1C and D).

3.3. *Annual average DOC contents*

The annual average DOC contents were calculated to explore the relationships between DOC contents and switchgrass biomass yields, and annual average temperature and cumulative precipitation. Under low N rate, the DOC contents were higher than that under high N rate (Fig. 2C). The maximum difference in DOC contents between low and high N rates was 2.69 mg L^{-1} in 2012, and the minimum difference was 0.77 mg L^{-1} in 2010. The DOC contents at footslope position were higher than that at shoulder position. The DOC contents at backslope had more changes from 2009 to 2014 than that at shoulder and footslope (Fig. 2D). The maximum range of DOC content among three positions was 5.70 mg L^{-1} in 2012, and the minimum was 1.34 mg L^{-1} in 2009. The annual average DOC contents at different levels of treatments had a similar pattern with cumulative annual precipitation (Fig. 2A, C, and D). The DOC contents at all N levels

followed no specific trend over the sampling years (2009 to 2014; *data not shown*). The Pearson correlation coefficients (r) showed that there was no relationship between maximum and minimum annual average temperature and the DOC contents under all treatments ($r < 0.30$) except for shoulder position ($r = 0.51$ with minimum temperature) (Table 3). The scatter plots of this analysis are shown in Fig. S1 and Fig. S2. For the annual average maximum temperature, the DOC contents at shoulder followed a quadratic relationship. The quadratic function was analyzed as: $y = 0.9933x^2 - 25.289x + 165.47$ with R^2 of 0.70 (Fig. S3B).

The annual average DOC contents at high and low N rate and footslope had a strong and moderate positive relationship with annual cumulative precipitation ($r = 0.72$ and 0.58 , respectively) (Table 3). The DOC content at shoulder had a quadratic relationship with precipitation. The function is given by the equation: $y = 0.0205x^2 - 2.1966x + 64.813$ with $R^2 = 0.70$ (Fig. S3A). There was a moderate positive relationship between the DOC contents at backslope and annual cumulative precipitation ($r = 0.56$). The relationship between DOC contents at footslope and the precipitation was positive ($r = 0.79$) (Table 3). In general, there was a moderate positive relationship between the total average DOC contents and the precipitation ($r = 0.65$). The scatter plots of these analyses are shown in Fig. S4. For the switchgrass yields, the DOC contents at high N rates had a strong positive relationship with yields at high N rates ($r = 0.82$). The r value of 0.07 between DOC contents and yields at low N rates indicated that there was no relationship between these two parameters. However, there was a moderate positive relationship between the total average DOC contents and the total average yield ($r = 0.52$) (Table 3 and Fig. S5).

4. Discussion

4.1. *Landscape position impacts on DOC contents*

The findings from this study suggest that the landscape position has statistically significant impacts on DOC contents under switchgrass land, and these impacts vary temporally. It is important to understand that the mechanism of DOC contents changes with various parameters in the natural environment. So far, no study was found to report in the literature that showed the impacts of landscape position on DOC contents. However, some studies have demonstrated that certain environmental and soil factors impact the DOC contents. The DOC, for example, originates from accumulated plant matter, soil humus, microbial biomass or root exudates (Kalbitz et al., 2000; Chibnall, 2013). The DOC content is the net result of processes that release and remove DOC from the soil. DOC is removed from soil through adsorption or decomposition by microbes (Chibnall, 2013), and it can be broken down by microbes in the soil into CO₂ and released to the atmosphere before it is leached to the lower horizons or the ground water. Thus, the fate of DOC leached from the soil follows three pathways: leaching to the groundwater, mineralization to CO₂, or sorption and storage in the soil. These processes are in turn dependent on internal soil conditions and environmental controls, in which temperature, moisture and soil (chemical, physical and biological) properties have the largest influence (Chibnall, 2013). For example, Sodium and calcium can preferentially adsorb to soil microsites and cause the displacement of absorbed organic ions including carbon (Reemtsma et al., 1999). The high clay content of the mineral horizons promotes DOC adsorption and thus DOC retention (Don and Schulze, 2008). Therefore, the higher soil organic carbon (SOC), total carbon (TC), water content (WC) and lower bulk density (BD) at footslope (Table S1) (clay contents in the soils at footslope position were higher than those at shoulder and backslope positions) could result in DOC retention. There are different DOC contents at three positions primarily because of

the differences in soil properties (e.g. pH, soil texture, soil moisture and temperature) associated with these positions. Moreover, differences in these soil parameters are greater between backslope and footslope than that between backslope and shoulder (Table S1), therefore, this could result in significant differences in DOC contents between backslope and footslope. Further, the difference in soil properties within these landscape positions is mainly due to the effects of past erosion including tillage and water erosion and long-term soil development (Mbonimpa et al., 2015). Specifically, erosion can affect soil organic matter in different ways through the removal of surface soil material, the incorporation of subsoil into surface horizons and the deposition of soil (Pennock, 1997). All three processes work together to change the properties of an eroded soil, including its bulk density, porosity, moisture retention, cation exchange capacity, organic matter, and nutrient concentrations (Gregorich et al., 1998). Furthermore, the erosion can directly impact DOC leaching content through reducing the amount of soil C in two ways. *First*, the reduction causes soil degradation which in turn results in reduced crop productivity. *Second*, the erosion removes nutrients, surface soil and C from higher slopes (especially shoulder and backslope) and deposits eroded material including C at the downslopes (footslopes) (Gregorich et al., 1998).

4.2. *N rate impacts on DOC contents*

The results from this study also confirm that N application significantly affects the DOC contents. As previously mentioned, there are many factors that impact DOC leaching contents from soils. However, the N fertilizer is a part of land management used for the plant growth and productivity. It impacts on DOC or other parameters in soil and environment that are closely related to sustainability of soil-plant ecosystem. Some studies have shown the variations in DOC

contents with different N rates. McTiernan et al. (2001) reported that the increased N inputs increased concentration of DOC leachate, which was explained by the increased dry matter production that contributes to a greater production of soluble C. This result is not consistent with the present findings where DOC contents at low N rate are higher than that at medium and high N rates (Table 1). However, another study conducted by Parfitt et al. (2009) reported that DOC leaching was found to be higher in the low N system and lower in the higher N input system, which is consistent with results from our study. This could be explained by measuring the composition of the DOC, with higher ratios of C/N at low N rate indicating the presence of the more hydrophobic fraction of DOC which is known to readily adsorb to soil mineral surfaces, and thus would contribute to an increased DOC concentration (Marschner and Kalbitz, 2003). Another possible biological mechanism is that the increased N inputs in the soil could be taken up by switchgrass and the extra N could be converted into other material (for example, organic N in soil organic matter may be converted to inorganic N through the process of mineralization), which could result in different variation in soil properties. For example, the differences of the SOC and WC in soil between medium and low N rates are higher than those between medium and high N rates (Table S1). This could lead to significant differences in DOC contents between medium and low N rates.

Indeed, the physical controls may also play an important role in dominating DOC transformations in soils (Neff and Asner, 2001). It has been stated that the increase of soil solution pH (or acid neutralizing capacity) would lead to net positive changes in DOC concentration by increasing DOC solubility in soil, and N treatments significantly decreased soil solution pH below the dominant rooting zone (Lu et al., 2013). Therefore, the N fertilizer increased the DOC contents. However, in this study, in the dominant rooting zone of switchgrass,

there were higher pH with increase of N rates (data not shown), the DOC contents were higher at low N rates (Table 1). Thereby, we could not explain the results only based on pH changes. Furthermore, the effect of pH on DOC dynamics may be confounded with other factors. On the one hand, the confounding effect could result in different effect of pH change on DOC contents. For example, there was a decrease in the sorption capacity of soils when the solution added had a high pH (Schneider et al., 2010), which could result in increase of DOC contents. On the other hand, the Fe and Al could have more impact on the sorption capacity of soils than pH on that in switchgrass field. Soils containing high concentrations of extractable Fe or/and Al exhibit the capacity to adsorb DOC as water percolates down through the soil profiles, thereby decreasing DOC concentrations (Boudot et al., 1989; Sleutel et al., 2009). The sorption by hydrous Al oxides could be an important reason for N-induced decreases of soil solution DOC (Corre et al., 2010). The N addition significantly increased extractable Fe (Lu et al., 2013). Switchgrass has a deep perennial rooting system with an abundant and dense network of hairs (Clark et al., 1998; Blanco-Canqui, 2010). Therefore, switchgrass has more arbuscular mycorrhizal (AM), which improve the ability to reduce nutrient loss from soils by enlarging the nutrient interception zone and preventing nutrient loss after rain-induced leaching events (Augé, 2004; Cavagnaro et al., 2006). Thus, the switchgrass could maintain Fe and Al in soil in long-term. When N fertilizer is applied to the field in this study, it could induce the more extractable Fe and Al in soil, which could reduce the DOC contents.

4.3. *Relationship of DOC contents to year, climate, and yield*

The different treatment effects (landscape positions and N rates) on DOC contents from 2009 and 2014 could be linked to annual changes in temperature and precipitation because other

conditions such as perennial switchgrass, positions, N rates, no-till, and harvest are relatively stable. The findings from this study show that the DOC contents are not significantly related with annual average temperature changes (only there are significant relationships between DOC contents at shoulder and annual average temperature), but are related to annual precipitation (Table 3). Some studies have reported higher concentrations of DOC in summer, which is assumed to be evidence for a greater production of DOC by microbes (McDowell and Likens, 1988). Harrison et al. (2008) showed that the effect of temperature on DOC leaching is not strong and that the leaching is more dependent on the volume of water being leached through the soil, which are similar to this study. Therefore, higher precipitation in 2009 and 2013 in this study site resulted in higher DOC contents than the sampling years with lower precipitation. Further, the DOC contents in 2009 and 2013 were less variable than in dry years, primarily due to a lack of a dilution effect on DOC concentrations (Peichl et al., 2007). In the dry years, the DOC contents could have higher variation because a wet dry process can produce large amounts of DOC (Lundquist et al., 1999). This is primarily because drying is known to produce large amounts of water soluble neutral organic matter through the lysis of microbial cells (Christ and David, 1996). This material is highly soluble and can be readily leached when wet (Kaiser and Zech, 1999). On the other hand, these variations in soil properties under different landscape positions and N rates could indirectly complicate the relationships between climate and DOC content. The findings from this study confirm that there are different relationships between precipitation and DOC contents at three positions and N rates. The relationships observed in this study will aid in further understanding the variations of DOC contents under switchgrass land.

Further, results from this study showed no significant time trends of DOC at different N rates and positions except for at footslope (p value = 0.0095) and high N rate (p value = 0.074).

However, the slopes of time trend were very small (-0.0343 and -0.0106) (Table 2), therefore, in general, DOC contents were not significantly influenced by time from 2009 through 2014. This may be linked to switchgrass production directly since all factors have changed over time except for the switchgrass, which was seeded in the field as a perennial crop in 2008. This indicates that the switchgrass field could keep DOC contents constant over time, which is helpful to sequester C and retain soil and environment sustainability. One possible explanation is that switchgrass has a deep root system that can enhance translocation of SOC to deeper layers, thereby reducing decomposition of SOC and promoting long-term SOC sequestration (Frank et al., 2004). The fraction of SOC stored in deeper (>30 cm) soil profiles is critical for long-term SOC sequestration because this fraction has longer residence times and slower turnover due to reduced microbial processes and fluctuations in soil water content and temperature (Liebig et al., 2005; Blanco-Canqui, 2010). In the long-term, the time trends of DOC contents need to be further investigated.

Relationships between yield and DOC contents were not found from previous studies. However, based on findings from this study, there was a positive relationship between switchgrass yields and DOC contents (Fig. S5). This is partly because increases in SOC and SOM resulting from increases in switchgrass yields could result in more DOC contents. Switchgrass yield increases may be realized in the future as a result of technological innovation of breeding, improvements in field management, and possibly if there is a greater demand for switchgrass for bioenergy. Therefore, the DOC contents in leachate from switchgrass land might increase in the long-term, which could result in an increase of sorption and storage in the soil, thereby increasing C sequestration.

5. Conclusions

This study indicates that DOC leaching contents in the switchgrass field were influenced by landscape positions and N rates. Especially, the N fertilization reduced DOC leaching contents in switchgrass field. Annual precipitation was positively correlated with the DOC contents of leachate. Furthermore switchgrass yields had a positive relationship with DOC contents to some extent. The DOC contents had insignificantly time trends from 2009-2014 periods. This indicates that switchgrass retain soil and environment sustainability to some extent. These findings will assist in understanding the mechanisms of DOC content changes with landscape positions and N fertilizer rates, and evaluation of carbon budget on switchgrass land. However, for the six year period of this study, data on DOC contents were not large enough because of some missing values. Therefore, continuous interval (weekly, bi-weekly or monthly) monitoring of DOC for longer duration is required to deeply understand the impacts of above mentioned factors on DOC leaching contents from switchgrass fields.

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Appendix A. Supplementary data

Supplementary data related to this article have been attached to better understand the information included in this manuscript.

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Table 1

Least-square means and standard error (within parenthesis) of dissolved organic carbon (DOC) contents (mg L^{-1}) from land seeded with switchgrass managed with different landscape (shoulder, backslope and footslope) positions and nitrogen rates (high, medium and low).

Treatments	DOC contents (mg L^{-1})			
	Average	High	Medium	Low
Position				
Shoulder	8.38(1.72) ^a	8.72(1.22) ^{a,b}	7.5(1.46) ^a	8.6(2.94) ^{a,b}
Backslope	6.45(1.72) ^b	6.41(1.19) ^b	5.33(1.46) ^a	6.83(2.95) ^b
Footslope	8.95(1.70) ^a	9.03(1.14) ^a	6.51(1.82) ^a	9.14(2.92) ^a
N rate		Shoulder	Backslope	Footslope
High	7.77(1.70) ^{b,a}	8.69(1.79) ^a	6.38(1.40) ^{a,b}	7.96(2.67) ^a
Medium	6.00(1.97) ^b	7.53(2.77) ^a	4.18(1.94) ^b	8.97(2.94) ^a
Low	8.54(1.66) ^a	8.48(1.54) ^a	7.70(1.33) ^a	9.18(2.65) ^a

Note: LS-Means with the same letter are not significantly different.

Table 2

Trends test for daily average DOC contents (mg L^{-1}) from field seeded with switchgrass managed with different landscape positions and nitrogen rates over months.

Treatments	Slope ^a	p-value ^b
Position		
Shoulder	-0.0132	0.26
Backslope	-0.0201	0.134
Footslope	-0.0343	0.0095
N rate		
High	-0.0106	0.074
Medium	-0.234	0.29
Low	0.02196	0.68
Total	0.0289	0.999

a. Slopes were estimated by Sen Estimator.

b. p-values were from Mann–Kendall test.

Table 3

Pearson correlation coefficients (r) between levels of positions and N rates and year, temperature, precipitation, and yields.

DOC contents	Tmax ^a	Tmin ^b	Prpc ^c	Yield
Low_DOC	-0.02	-0.16	0.58	0.07 (L_yield)
High_DOC	-0.27	-0.25	0.72	0.82 (H_yield)
Shoulder_DOC	-	-0.51	-	-
Backslope_DOC	0.23	0.08	0.56	-
Footslope_DOC	0.09	0.08	0.79	-
Total_DOC	-0.07	-0.13	0.65	0.52 (Total_yield)

a. Tmax, maximum temperature.

b. Tmin, minimum temperature.

c. Prpc, precipitation.

Fig. 1. (A) Monthly cumulative precipitation (cm) and monthly average temperature (°C), (B) daily precipitation and daily temperature for the sampling day, (C) daily DOC content (mg L⁻¹) from leachate in switchgrass at three landscape positions (shoulder, backslope, and footslope), and (D) three nitrogen fertilizer rates (high, medium, and low). Note Tmax, maximum temperature; Tmin, minimum temperature; Prcp, precipitation.

Fig. 2. (A) Annual average temperature (°C) and cumulative precipitation (cm) from 2009 to 2014; (B) switchgrass yields (Mg ha⁻¹) in the 2010-2014 period under different N-fertilizer rates; (C) DOC leaching contents (mg L⁻¹) in switchgrass land in the 2009-2014 period under three N-fertilizer rates and (D) landscape positions. Note Tmax, maximum temperature; Tmin, minimum temperature; Prcp, precipitation.