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Soil Carbon Accumulation under Switchgrass Barriers

Humberto Blanco-Canqui,* John E. Gilley, Dean E. Eisenhauer, Paul J. Jasa, and Alan Boldt

ABSTRACT

The benefits of grass barriers or hedges for reducing offsite transport of non-point-source water pollutants from croplands are well recognized, but their ancillary benefits on soil properties have received less attention. We studied the 15-yr cumulative effects of narrow and perennial switchgrass (*Panicum virgatum* L.) barriers on soil organic C (SOC), total N, particulate organic matter (POM), and associated soil structural properties as compared with the cropped area on an Aksarben silty clay loam (fine, smectitic, mesic Typic Argiudoll) with 5.4% slope in eastern Nebraska. Five switchgrass barriers were established in 1998 at ~38-m intervals parallel to the crop rows in a field under a conventional tillage and no-till grain sorghum [*Sorghum bicolor* (L.) Moench]–soybean [*Glycine max* (L.) Merr.]–corn [*Zea mays* L.] rotation. Compared with the cropped area, switchgrass barriers accumulated about 0.85 Mg ha⁻¹ yr⁻¹ of SOC and 80 kg ha⁻¹ yr⁻¹ of total soil N at the 0 to 15 cm soil depth. Switchgrass barriers also increased coarse POM by 60%. Mean weight diameter of water-stable aggregates increased by 70% at 0 to 15 cm and by 40% at 15 to 60 cm, indicating that switchgrass barriers improved soil aggregation at deeper depths. Large (4.75–8 mm) macroaggregates under switchgrass barriers contained 30% more SOC than those under the cropped area. Switchgrass-induced changes in SOC concentration were positively associated with aggregate stability ($r = 0.89^{***}$) and porosity ($r = 0.47^*$). Overall, switchgrass barriers integrated with intensively managed agroecosystems can increase the SOC pool and improve soil structural properties.

Grass barriers, also called grass hedges, are narrow (<1.5 m) and permanent strips of dense, tall, and stiff-stemmed perennial grasses established on the contour within croplands to control soil erosion (Kemper et al., 1992; NRCS, 2003). Grass barriers differ from other grass strips (e.g., vegetative filter strips, riparian buffers) because they are established within croplands at short intervals (<20 m) in parallel rows and are commonly planted to native perennial warm grass species such as switchgrass. Unlike vegetative filter strips, which are relatively wide strips (5–15 m) normally planted to short-growing and cool-season grasses at the bottom perimeter of croplands, switchgrass barriers are integrated along the slope profile with crops in parallel rows.

The benefits of switchgrass barriers for reducing water erosion are well documented (Kemper et al., 1992; Gilley et al., 2000, 2011; Blanco-Canqui et al., 2004; Rachman et al., 2004; Dabney et al., 2012). Switchgrass barriers intercept, retard, and pond runoff (Dabney et al., 1999); increase runoff water infiltration opportunity time (Rachman et al., 2004); promote sediment deposition; filter sediment and nutrients; and reduce

losses of pesticides and other pollutants in surface runoff (Gilley et al. 2000, 2011). Switchgrass barriers may also decrease the field slope length by forming mini-terraces upslope of the barriers with time as result of sediment deposition (Dabney et al., 1999). Grass barriers can therefore serve as an important ecological and biological practice for managing agricultural soils.

Switchgrass barriers are multifunctional systems and can provide numerous ancillary benefits, including improvements in wildlife habitat, as well as providing forage for livestock. An additional ancillary benefit associated with switchgrass barriers could be the accumulation of SOC with time and an improvement in associated soil structural properties within the barriers. Such improvements in soil properties could explain the mechanisms by which switchgrass barriers increase water infiltration within barriers and reduce runoff from croplands. However, switchgrass barrier-induced changes in SOC concentration and soil structural properties have not been widely documented. Previous research on grass barriers has often focused on assessing their effectiveness in reducing water erosion and improving associated water quality parameters (Dabney et al., 1999; Gilley et al., 2000; Blanco-Canqui et al., 2004; Gilley et al., 2011; Dabney et al., 2012). Because switchgrass barriers are under perennial vegetation and are not subject to cultivation or tillage operations relative to the cropped area, they may significantly favor accumulation of SOC and improve soil structural processes compared with row crops.

Switchgrass barriers could increase SOC concentration in sloping lands by trapping sediment-associated C and by

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Abbreviation: POM; particulate organic matter; SOC, soil organic carbon.

increasing belowground biomass. On a Monona silt loam in Iowa (fine-silty, mixed, superactive, mesic Typic Hapludolls), Rachman et al. (2004) reported that switchgrass barriers increased soil organic matter content compared with row crops at the 0- to 30-cm soil depth after 10 yr of establishment. More information is needed for different soil types and management systems to better understand the extent to which switchgrass barriers accumulate SOC in croplands. When integrated with row crops, switchgrass barriers may also restore some of the SOC lost with intensive tillage. This information is needed to better manage soil and water resources and to restore the SOC lost with intensive tillage.

Data on SOC from switchgrass barriers are few but some information is available from sites where switchgrass has been grown as a bioenergy crop. In eastern Nebraska, switchgrass grown for biofuel adjacent to corn plots for 9 yr sequestered about 2 Mg ha⁻¹ yr⁻¹ at the 0- to 150-cm soil depth and ~50% of the increase in SOC was below the 30-cm depth (Follett et al., 2012). Across 10 on-farm fields in North Dakota, South Dakota, and Nebraska, increases in SOC after switchgrass establishment varied among locations (Schmer et al., 2011). In eastern Kansas, SOC concentrations between switchgrass and row crop plots did not differ after 5 yr of management (Evers et al., 2013). These studies suggest that switchgrass managed for cellulosic ethanol feedstock production have variable effects on SOC storage, possibly depending on the soil and length of management. For example, in some soils, switchgrass barriers may increase SOC concentration and improve soil properties in the subsoil because of their extensive root systems relative to row crops (Follett et al., 2012).

An improved understanding of the impacts of switchgrass buffers on SOC accumulation and the associated soil properties is necessary to manage and address emerging land use changes in agriculture. Switchgrass barriers, as an innovative soil conservation practice, can contribute to SOC accumulation in agricultural lands, which could subsequently and positively influence soil processes (e.g., aggregation and water transmission characteristics) within the barriers. Identifying the effects of upland grass barriers on SOC pools can also be important in understanding the ecosystem C budget and managing overall soil conservation practices. Thus, the objectives of this study were to quantify SOC, total N, particulate organic matter, water-stable aggregates, and aggregate-associated C under switchgrass barriers and compare the results with cropped rows under conventional tillage and no-till conditions after 15 yr of management on a Typic Argiudoll in eastern Nebraska. We hypothesized that the addition of switchgrass barriers to conventional cropping systems would increase the SOC pool and enhance soil aggregation in the subsoil because of the extensive and deep-rooted system of switchgrass.

MATERIALS AND METHODS

Study Site Characteristics

This study was conducted at the University of Nebraska's Rogers Memorial Farm located 18 km east of Lincoln, NE. The Aksarben silty clay loam at the site developed in loess under prairie vegetation. The mean slope gradient at the study area was 5.4%. Five narrow (1.4 m wide) switchgrass barriers were established during 1998 at ~38-m intervals within the cropland

site in parallel rows following the contour of the land (Fig. 1). A specialized grass no-till drill (Truax Flex II-88; Truax Company Inc., Minneapolis, MN) was used in the seeding operation. The narrow grass barriers were part of a strip-cropping system where row crops were planted between the barriers. The switchgrass barriers were spaced at intervals along the hill slope that allowed multiple passes of the tillage equipment.

The study site had been cropped using a rotation of grain sorghum, soybean, and corn. Glyphosate [*N*-(phosphonomethyl)glycine] was applied as needed to control weed growth on the study areas that were not covered by a grass barrier. Special care was taken so that herbicide was not applied to the grass barrier. The cropped area between barriers was maintained under long-term no-till management. For research purposes, eight permanent areas had been randomly selected within this field between grass barriers and managed under the same tillage system for the past 15 yr (Fig. 1). Four of these areas were managed under no-till and four under conventional tillage conditions, resulting in two tillage treatments with four replications (Fig. 1). The areas under conventional tillage were tilled in mid-November using a chisel plow and then disked to about 10-cm depth in mid-April when corn and sorghum residue were present. When soybean residue was present, disking in mid-April was the only tillage operation that occurred on the tilled areas.

Soil Sampling and Analysis

Soil sampling for this study occurred after the grain sorghum harvest in the fall of 2013. We sampled soil from four positions: switchgrass barrier, deposition zone (0.5 m upslope of the barrier), the center of the cropped area (19 m between two barriers), and near the upper end of the cropped area (1.4 m below the upslope barrier). Undisturbed soil cores were obtained from each position within each plot. Soil cores (50 mm in diameter and 100 cm long) were extracted with a tractor-mounted Giddings hydraulic probe (Giddings Machine Co., Windsor, CO) and partitioned at the following depths: 0 to 15, 15 to 30, 30 to 45, 45 to 60, 60 to 80, and 80 to 100 cm.

In this study, we measured the following soil properties: bulk density, coarse and fine POM, SOC and total N, proportion of water-stable aggregates, aggregate-associated SOC, particle-size distribution, and pH. The soil properties were determined in the order listed.

Bulk Density. A subsample from each soil core was weighed and oven-dried at 105°C to determine bulk density by the core method for each depth increment (Grossman and Reinsch, 2002). The data on soil bulk density were used to compute soil porosity, assuming a soil particle density equal to 2.65 Mg m⁻³.

Particulate Organic Matter. Concentrations of coarse and fine POM were measured by weight loss on ignition as explained by Cambardella et al. (2001). A fraction of the soil sample from each soil core was gently and carefully broken apart by hand, air-dried, and passed or pushed through a 2-mm sieve. We did not sieve or push the soil samples when moist (before air-drying) because our samples, particularly for deeper depths, had a high soil water content, which required some air-drying before sieving. Thirty grams of the sieved samples were weighed and dispersed with 100 mL of sodium hexametaphosphate (5 g L⁻¹) in a reciprocal shaker for 24 h, and mechanically

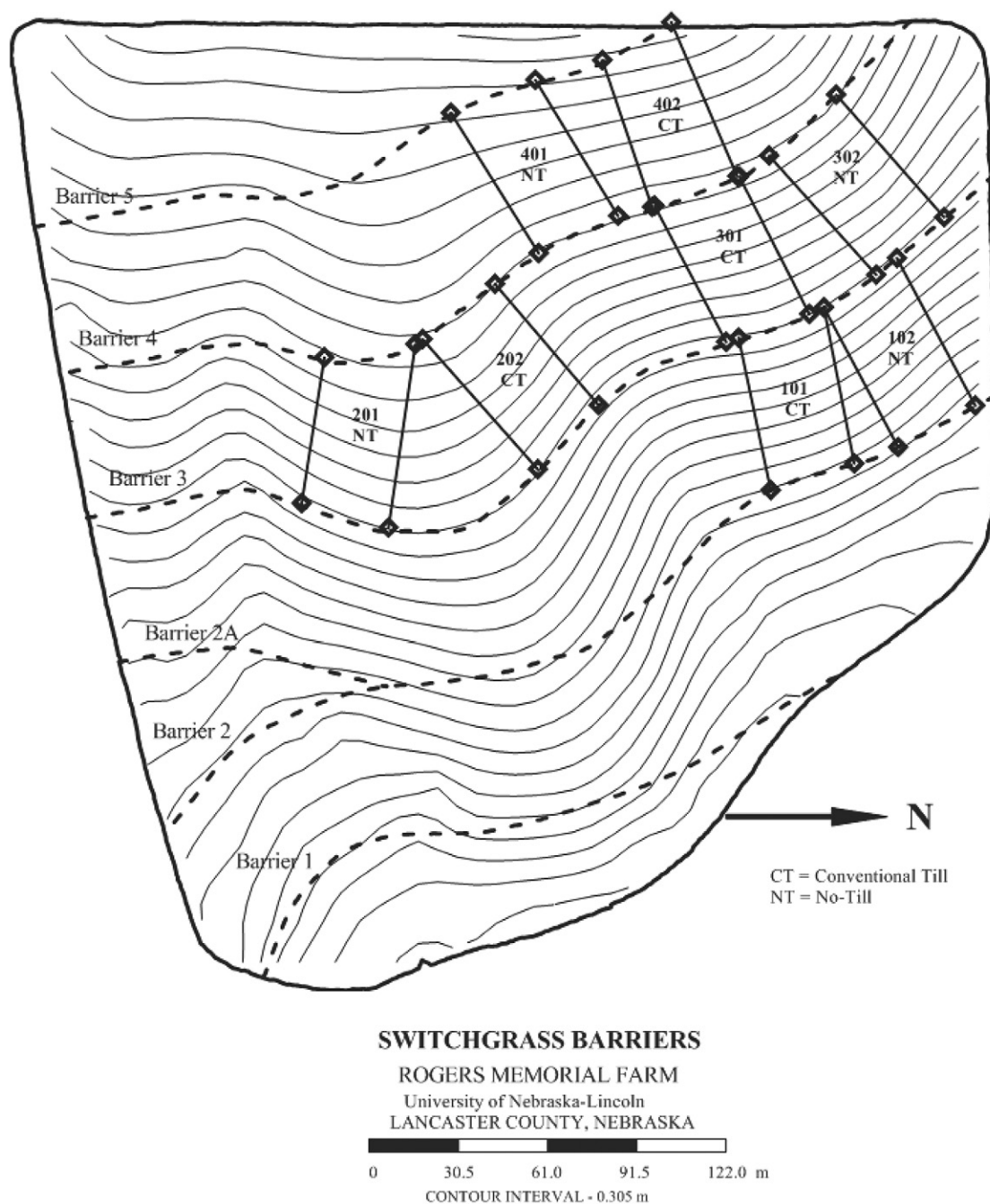


Fig. 1. Field layout of the five switchgrass barriers under no-till and conventional tillage at the Rogers Memorial Farm near Lincoln, NE.

stirred in a multi-mixer. The dispersed soil sample was then passed through 0.5- and 0.053-mm sieves. The sample retained on each sieve was transferred to preweighed aluminum pans, dried at 60°C, and ignited in a muffle furnace at 450°C for 4 h to determine POM by loss on ignition. The POM from the 0.5-mm sieve corresponds to coarse POM (0.5–2.0 mm); that from the 0.053-mm sieve corresponds to fine POM (0.053–0.5 mm; Cambardella et al., 2001). Total POM was computed as the sum of both coarse and fine POM concentrations.

Soil pH, Organic C, and Texture. Ten g of the air-dried soil sample that passed through the 2-mm sieve was used to determine soil pH with a Thermo Orion pH meter (model 525A, meter Thermo Electron Corp., Waltham, MA) on a 1:2 suspension (10 g of soil to 20 mL of water; Thomas, 1996).

Another portion of the sample that passed through the 2-mm sieve was roller milled for 24 h to determine SOC and total N concentration by the dry combustion method using a CN analyzer (LECO CN 2000, Leco Corp., St Joseph, MI) (Nelson and Sommers, 1996). Bulk density was used to compute soil C and total N pools. The SOC and total N pools were calculated on an equivalent mass basis to correct for any differences in bulk density values between the two tillage treatments and sampling positions as described by Ellert et al. (2001, 2002). The bulk density values associated with no-till management were used because using no-till practices has been promoted as a conservation tillage system, particularly in this region. The SOC and total N on a mass basis (g kg^{-1}), hereafter are referred to as SOC and total N concentration, whereas SOC and total N on

an equivalent mass basis (Mg ha^{-1}) are referred to as pools. Soil particle-size analysis was performed by the hydrometer method (Gee and Or, 2002).

Wet Aggregate Stability and Aggregate-Associated Carbon. Another portion of the air-dried soil sample was passed through 4.75- and 8-mm sieves to obtain aggregates with diameters between 4.75 and 8 mm for each depth interval. Water-stable aggregates were determined using 50 g of 4.75- to 8.0-mm air-dried aggregates by the wet sieving method (Nimmo and Perkins, 2002). Aggregates were placed on top of a stack of sieves with 0.25, 0.5, 1, 2, and 4.75 mm diameter openings, saturated by capillarity for 10 min, and mechanically sieved in water for another 10 min. Aggregates retained on each sieve were transferred to pre-weighed beakers, oven-dried at 60°C , and weighed. The dry samples were weighed and then treated with 100 mL of sodium hexametaphosphate (5 g L^{-1}) overnight to disperse soil aggregates into individual soil particles and perform sand correction in each aggregate-size fraction for all soil depths. The mixture was then passed through sieves with 0.053-mm openings. The sand retained on the 0.053-mm sieves was oven-dried at 105°C for 24 h and weighed to determine sand content. Sand correction was performed by determining the amount of sand within each aggregate-size fraction (<0.25 , $0.25\text{--}0.5$, $0.5\text{--}1$, $1\text{--}2$, $2\text{--}4.75$, and $4.75\text{--}8.0$ mm) and subtracting from the amount of soil sample retained in the aggregate-size fraction.

The amount of water-stable aggregates for each aggregate-size fraction was used to compute the mean weight diameter of aggregates for each depth interval (Nimmo and Perkins, 2002). Following determination of the water-stable aggregates, SOC associated with sand-free aggregates was measured in each sand-free aggregate-size fraction (<0.25 , $0.25\text{--}0.5$, $0.5\text{--}1.0$, $1.0\text{--}2.0$, $2.0\text{--}4.75$, and $4.75\text{--}8.0$ mm). The sand-free aggregates were oven-dried at 60°C , ground in a roller mill, and analyzed for SOC using a CN analyzer (Nelson and Sommers, 1996). Hereafter, for discussion purposes, aggregate-associated SOC refers to sand-free aggregate-associated SOC.

Statistical Analysis. Data on all soil properties were analyzed using PROC MIXED considering the four sampling position as split plots (SAS Institute, 2014). Tillage treatments and positions were the fixed factors and replicate was as the random variable. Statistical analysis was conducted by soil depth. Means were separated using LSMEANS at the $P = 0.05$ level unless otherwise specifically stated.

RESULTS AND DISCUSSION

Tillage systems (conventional tillage and no-till) had no significant effects on the soil properties studied. Sampling positions had significant effects but the effects were significantly different only between the switchgrass barriers and the three sampling positions within the cropped area (deposition zone or lower end of the cropped area, the center of the cropped area, and near the upper end of the cropped area). The tillage \times sampling position interaction was not significant for any soil property. Therefore, data on soil properties were averaged across the two tillage systems for discussion purposes. Similarly, because there were no significant differences among the three sampling positions within the cropped area, data were averaged across the three positions to compare the cropped area with the switchgrass

barrier. Tillage, position, and soil depth had no effect on particle-size distribution and pH. Averaged across tillage, position, and depth, the mean values were $512 \pm 17 \text{ g kg}^{-1}$ (mean \pm SD) for silt content, $457 \pm 12 \text{ g kg}^{-1}$ for clay content, and 6.6 ± 0.25 for pH. Switchgrass barrier had no effect on soil properties below a soil depth of 60 cm; therefore, only data between 0 and 60 cm depth are reported.

Soil Organic Carbon

Switchgrass barriers increased the SOC concentration (Fig. 2A) and pool (Fig. 2B) compared with row crops but the increase was significant only at the 0- to 15-cm depth. The SOC concentration and pool SOC within switchgrass barriers increased by 1.4 times relative to the cropped area. The difference in the SOC pool between switchgrass barriers and the cropped area after 15 yr was 12.8 Mg ha^{-1} , which indicates that switchgrass barriers accumulated $0.85 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ on average at the 0- to 15-cm soil depth.

Whereas data on the rates of SOC accumulation under switchgrass barriers are limited, studies from switchgrass grown in plots for bioenergy have found variable rates of SOC accumulation in this region. Follett et al. (2012) reported that annual increases in SOC under switchgrass plots exceeded $2 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$ in the first 9 yr after establishment in eastern Nebraska, which is greater than the rate of SOC accumulation ($0.85 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$) in our study. Our results were, however, within the range of SOC accumulation ($0.5\text{--}2.4 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$) reported by Schmer et al. (2011) for 10 switchgrass fields managed for bioenergy across North Dakota, South Dakota, and Nebraska after 5 yr of management. It is worth noting that SOC accumulation rates may not be linear and will depend on the length of time after switchgrass has been established. Switchgrass potential for storing SOC most probably also depends on site-specific conditions (land type, climate, etc.). In eastern Kansas, Evers et al. (2013) reported that SOC concentration between switchgrass plots managed for bioenergy and row crop plots did not differ after 5 yr of management, suggesting that switchgrass may have limited potential for increasing SOC storage in the short term.

In this study, the greater SOC pool within switchgrass barriers than in the cropped area at the 0- to 15-cm depth indicates that including switchgrass barriers in croplands can increase the SOC pool. Switchgrass barriers, however, increased the SOC pool mainly near the soil surface. Thus our hypothesis that the addition of switchgrass barriers to existing cropping systems would promote C storage in deeper depths was not supported by the experimental data. Our results for SOC concentrations (g kg^{-1}) after 15 yr appear to be similar to those of Rachman et al. (2004), who found that switchgrass barriers increased SOC concentrations (g kg^{-1}) at the 0- to 30-cm depth after 10 yr on a silt loam near Treynor, IA.

We expected that SOC in the deposition zone (just upslope from the barrier) could be greater than in the above cropped area because of possible accumulation of C-enriched sediment with time but that was not the case in this study. Rachman et al. (2004) found that the deposition area stored more SOC than the soil above cropped areas. Some studies have suggested that grass barriers can promote significant sediment

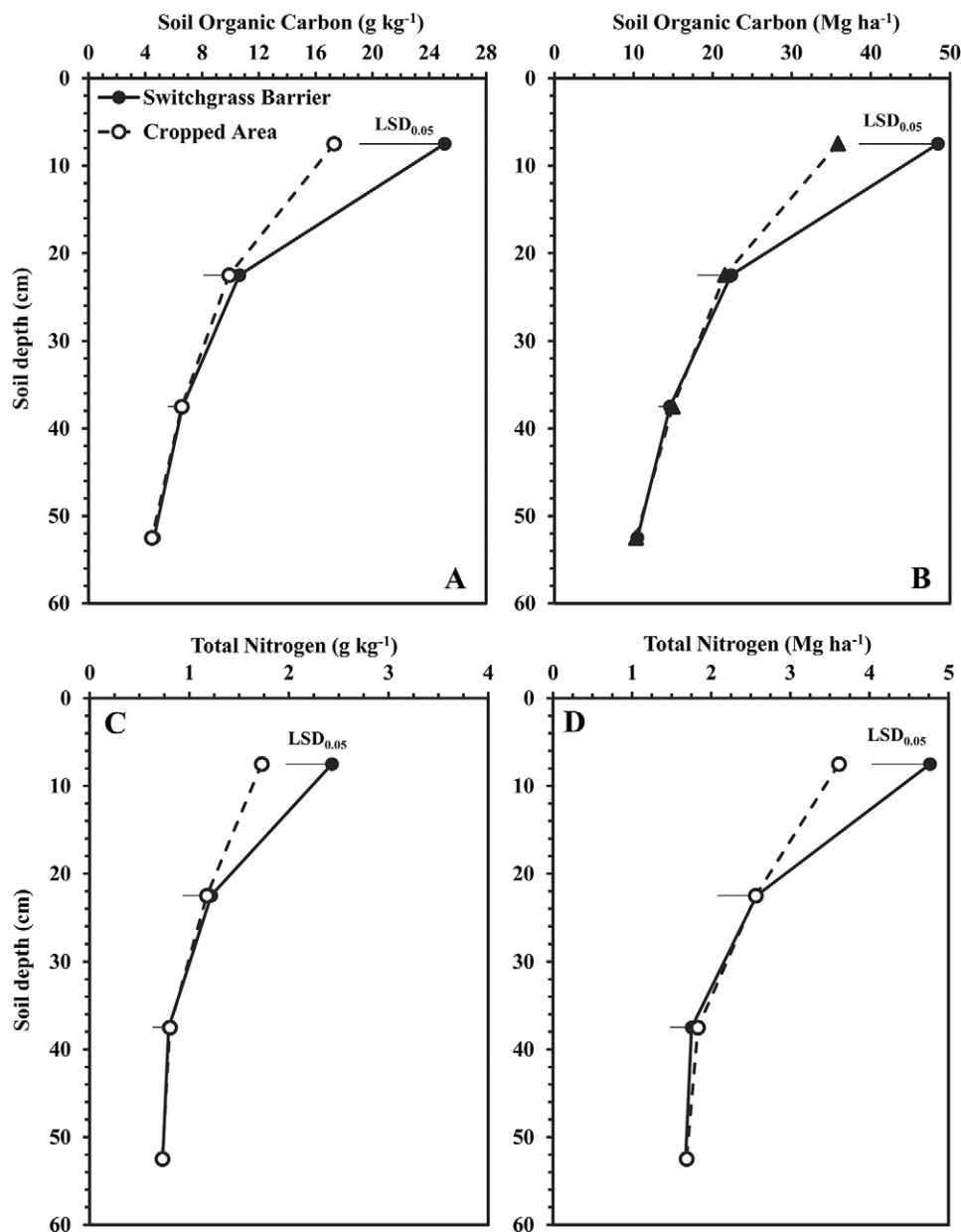


Fig. 2. Mean soil organic carbon concentration (A) and pool (B) and total N concentration (C) and pool (D) at the 0- to 60-cm soil depth under switchgrass barriers compared with the row-cropped areas after 15 yr of management in eastern Nebraska.

deposition or formation of mini-terraces just upslope from the barriers, altering the slope length in the long term (Dabney et al., 1999). Although we did not monitor sedimentation in the deposition zone in this study, the lack of differences in particle-size distribution among positions suggested that sediment deposition above the switchgrass barriers in this system was unlikely.

Switchgrass barriers also increased total N concentration (Fig. 2C) and pool (Fig. 2D) by 1.37 times compared with the cropped area at the 0- to 15-cm depth. On average, barriers increased total N pool at a rate of 80 kg ha⁻¹ per year. These results suggest that switchgrass barriers can also contribute significant amounts of total N to soil. Inclusion of switchgrass barriers in croplands may thus be an effective strategy for enhancing both SOC and total N accumulation. The SOC and total N accumulation under switchgrass is attributed mainly to the input of aboveground and root biomass (Tufekcioglu et al., 1998).

Particulate Organic Matter

The presence of switchgrass barriers resulted in an increase in coarse (53–2000 μ m) POM at the 0- to 15-cm depth (Fig. 3A). However, the differences in fine (<53 μ m) POM (Fig. 3B) and total POM (Fig. 3C) between switchgrass barriers and the cropped area were not statistically significant. Barriers increased coarse POM by 1.6 times compared with cropped rows at the 0- to 15-cm depth (Fig. 3A). In addition, coarse POM concentration under switchgrass barriers, in general, tended to be greater than under the cropped area at the 15- to 45-cm depth, but these differences were not statistically significant.

Particulate organic matter is one of the most biologically active forms of organic matter and often responds rapidly to changes in soil management (Cambardella et al., 2001). The few studies on soil POM from switchgrass grown for bioenergy have found increased total POM concentration. Across three sites

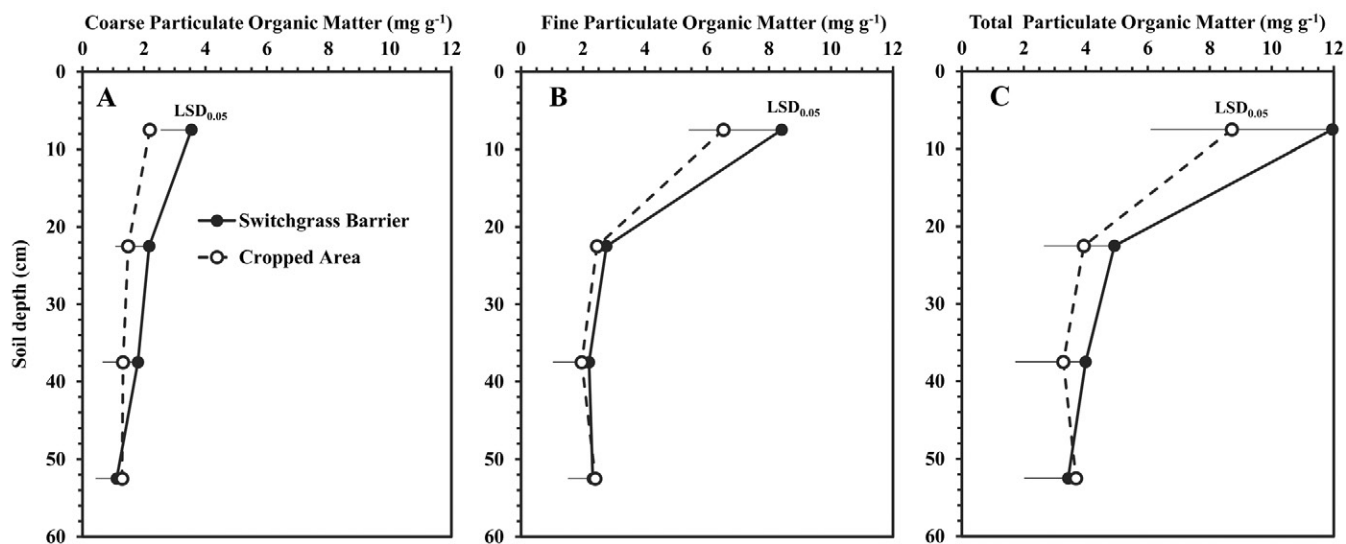


Fig. 3. Mean coarse particulate organic matter (A), fine particulate organic matter (B), and total particulate organic matter (C) concentration at the 0- to 60-cm soil depth under switchgrass barriers compared with the row-cropped areas after 15 yr of management in eastern Nebraska.

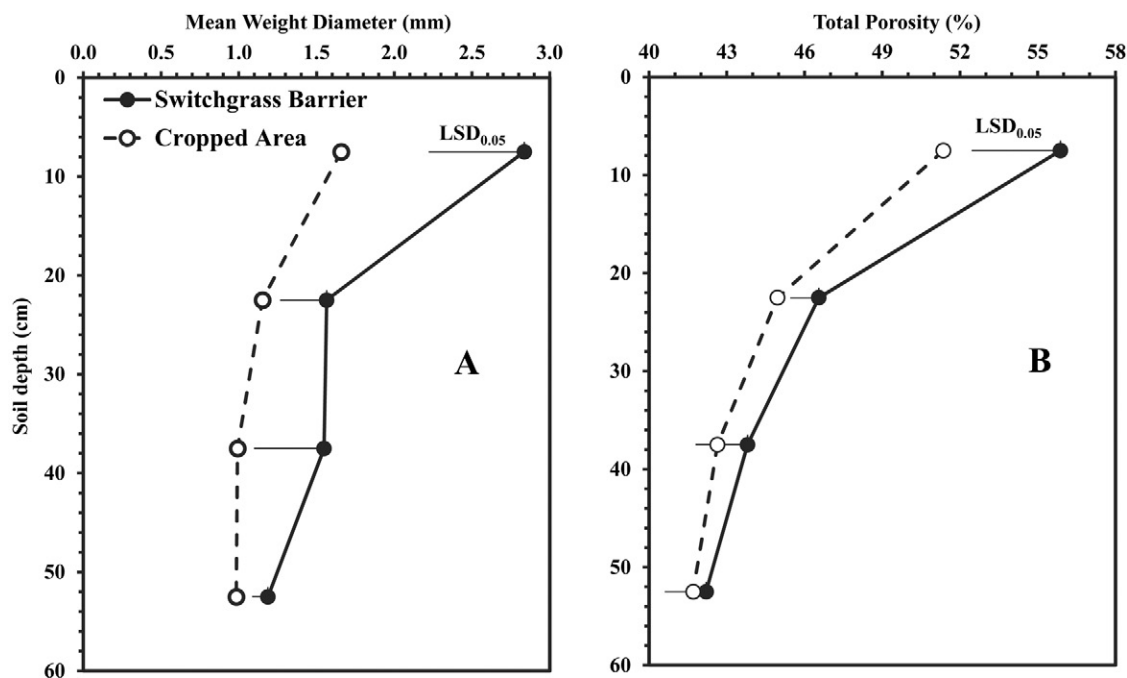


Fig. 4. Mean weight diameter of water-stable aggregates (A) and soil porosity (B) at the 0- to 60-cm soil depth under switchgrass barriers compared with the row cropped areas after 15 yr of management in eastern Nebraska.

in Texas, total POM measured in soil at a depth of <4.75 mm under switchgrass plantations was greater 4 yr (3–5 g kg⁻¹) and 9 yr (5–6 g kg⁻¹) after establishment compared with croplands (1–2 g kg⁻¹) at the 0- to 5-cm depth (Dou et al., 2013). In Iowa, total POM concentration in soil at a depth of <2 mm under switchgrass in multispecies riparian buffer strips was about 3 times greater than under croplands at the 0- to 35-cm depth (Marquez et al., 1998). In the present study, we found significant differences in coarse POM but not in total POM. Data on soil POM from switchgrass barriers are unavailable to compare with the results of this study.

Organic Carbon and POM Effects on Soil Structural Properties

The mean weight diameter of aggregates is a sensitive index of soil aggregation status (Nimmo and Perkins, 2002). It integrates all aggregate-size fractions into a single parameter. Switchgrass barriers increased the mean weight diameter of aggregates relative to the cropped rows at the 0- to 60-cm depth (Fig. 4A). The increase in mean weight diameter of aggregates was large at the 0- to 15-cm depth and small at the 15- to 45-cm depth relative to the cropped area (Fig. 4A). Switchgrass barriers increased the mean weight diameter by 1.7 times at the 0- to 15-cm depth, by 1.5 times at the 15- to 45-cm depth, and by 1.2 times at the 45- to 60-cm depth (Fig. 4A). Switchgrass barriers also increased soil porosity by 9%

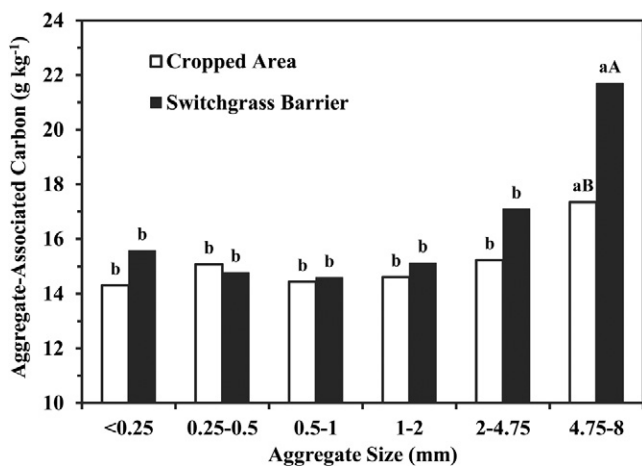


Fig. 5. Soil organic carbon associated with aggregate-size fractions at the 0- to 15-cm soil depth under switchgrass barriers compared with the row-cropped areas after 15 yr of management in eastern Nebraska. Bars followed by different lowercase letters within the cropped area or the switchgrass barrier indicate significant differences among aggregate-size fractions. Bars followed by different uppercase letters within the same aggregate-size fraction are significantly different.

at the 0- to 15-cm depth and by 4% at the 15- to 30-cm depth (Fig. 4B). The greater mean weight diameter of aggregates under switchgrass barriers than under cropped rows indicates that the addition of switchgrass barriers to croplands improved soil structural properties.

Although the presence of switchgrass barriers increased SOC and POM concentrations only at the 0- to 15-cm depth, it increased the mean weight diameter of aggregates at the 0- to 60-cm depth and soil porosity to 30-cm depth, suggesting that in this soil, the addition of switchgrass barriers to croplands can improve soil structural properties in the subsoil as well as topsoil. We did not quantify root biomass but deep roots under switchgrass probably contributed to improvements in soil aggregate stability and porosity in the subsoil. These results also show that the addition of switchgrass barriers to conventionally tilled and no-till systems not only can increase SOC concentration but also increase soil porosity and aggregate size and stability.

There was an association between SOC concentration and aggregate size (Fig. 5). Aggregate-associated C increased with increasing aggregate size from 0.5 to 8.0 mm for both switchgrass barriers and cropped areas, but this increase was larger under switchgrass barriers than under the cropped areas (Fig. 5), indicating that more SOC is stored in large macroaggregates under barriers. Large aggregates (4.75–8.0 mm) under switchgrass barriers contained 30% more C than those under the cropped area. Aggregate-associated C concentration in switchgrass barriers did not differ from that in the cropped area for aggregate-size fractions (<4.75 mm).

Correlation analysis indicated that the mean weight diameter of aggregates was strongly and positively correlated with SOC concentration (Fig. 6A) at the 0- to 15-cm depth. It also showed that the mean weight diameter of aggregates was moderately and positively correlated with coarse POM (Fig. 6B). Aggregate stability increased with an increase in SOC and POM concentration. Simple stepwise analysis showed that changes in SOC and coarse POM concentration were significantly related to changes in wet aggregate stability at the 0- to 15-cm depth ($r^2 = 0.87$; $P = 0.001$ (Eq. [1])).

Mean weight diameter

$$= -0.256 + 1.001 \times \text{SOC} + 0.371 \times \text{coarse POM} \quad [1]$$

Soil porosity was also positively and moderately correlated with changes in SOC concentration at the 0- to 15-cm ($r = 0.47$; $P = 0.05$) and 15- to 30-cm ($r = 0.81$; $P = 0.01$) depth increments (Fig. 6C). The significant correlations suggest the increase in SOC and POM concentration under switchgrass barriers was associated with improved soil aggregate stability and total porosity. The positive role of SOC in promoting soil aggregation is well recognized (Tisdall and Oades, 1982; Six et al., 2004). According to the conceptual model of Tisdall and Oades (1982), soil organic materials contain transient (polysaccharides), temporary (roots, hyphae of arbuscular mycorrhizal fungi), and permanent (aromatic humic materials, polyvalent metal cations) binding agents that form and stabilize macroaggregates

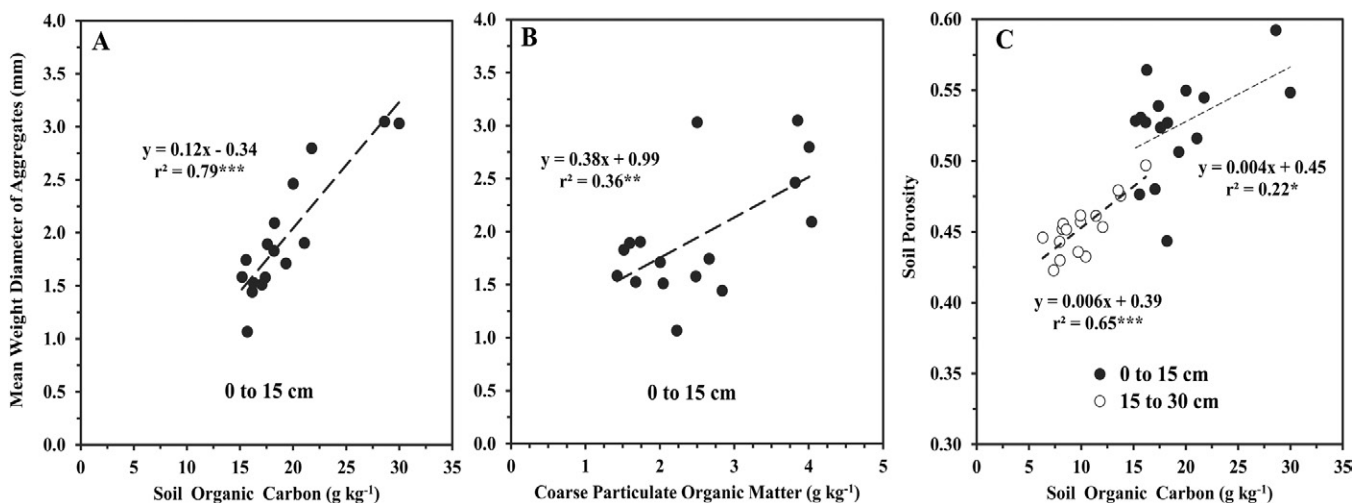


Fig. 6. Relationship of mean weight diameter of water-stable aggregates with soil organic carbon at the 0- to 15-m level (A), mean weight diameter of water-stable aggregates with coarse particulate organic matter at the 0- to 15-cm level (B), and soil porosity with soil organic carbon at depths of 0 to 15 cm and 15 to 30 cm (C).

(>0.25 mm). The increased macroaggregation may partly explain the increased soil porosity observed under switchgrass barriers. Aggregate-size distribution determines the size, continuity, tortuosity, and connectivity of soil pores. Macroaggregation results in larger pore size and more interconnected pores (Nimmo and Perkins, 2002).

CONCLUSIONS

This study indicates that the inclusion of switchgrass barriers as conservation buffers within conventionally tilled and no-till fields has the potential to increase the SOC pool and improve soil structural properties. Although the benefits of switchgrass barriers for storing SOC were mainly confined to the upper 15 cm of soil profile, their benefits for improving soil structural processes such as aggregation were measurable to a 60-cm depth, suggesting that switchgrass barriers can improve soil structural properties in the topsoil as well as the subsoil. Our results suggest that switchgrass barriers improve soil properties in addition to the previous well-documented benefits of reducing water erosion. Accumulation of SOC under switchgrass barriers was positively correlated with increased soil aggregation and porosity. The soil benefits associated with the incorporation of switchgrass barriers in croplands indicate the value of these systems to intensively managed agroecosystems. Overall, switchgrass barriers can be an important component of integrated and intensified agroecosystems for restoring SOC and improving soil properties while reducing non-point-source water pollution.

REFERENCES

- Blanco-Canqui, H., C.J. Gantzer, S.H. Anderson, E.E. Alberts, and A.L. Thompson. 2004. Grass barrier and vegetative filter strip effectiveness in reducing runoff, sediment, nitrogen, and phosphorus loss. *Soil Sci. Soc. Am. J.* 68:1670–1678. doi:10.2136/sssaj2004.1670
- Cambardella, C.A., A.M. Gajda, J.W. Doran, B.J. Weinhold, and T.A. Kettler. 2001. Estimation of particulate and total organic matter by weight loss-on-ignition. In: R. Lal, J.F. Kimble, R.F. Follett, and B.A. Stewart, editors, *Assessment methods for soil carbon*. Lewis Publishers, Boca Raton, FL. p. 349–359.
- Dabney, S.M., G.V. Wilson, and D.A.N. Vieira. 2012. Runoff through and upslope of contour switchgrass hedges. *Soil Sci. Soc. Am. J.* 76:210–219. doi:10.2136/sssaj2011.0019
- Dabney, S.M., Z. Liu, and D.C. Flanagan. 1999. Landscape benching from tillage erosion between grass hedges. *Soil Tillage Res.* 51:219–222. doi:10.1016/S0167-1987(99)00039-2
- Dou, F.G., F.M. Hons, W.R. Ocumpaugh, J.C. Read, M.A. Hussey, and J.P. Muir. 2013. Soil organic carbon pools under switchgrass grown as a bioenergy crop compared to other conventional crops. *Pedosphere* 23:409–416. doi:10.1016/S1002-0160(13)60033-8
- Ellert, B.H., H.H. Janzen, and T. Entz. 2002. Assessment of a method to measure temporal change in soil carbon storage. *Soil Sci. Soc. Am. J.* 66:1687–1695. doi:10.2136/sssaj2002.1687
- Ellert, B.H., H.H. Janzen, and B.G. McConkey. 2001. Measuring and comparing soil carbon storage. In: R. Lal, J.M. Kimble, R.F. Follett, and B.A. Stewart, editors, *Assessment methods for soil carbon*. CRC Press, Boca Raton. p. 131–1465.
- Evers, B.J., H. Blanco-Canqui, S.A. Staggenborg, and J. Tatarko. 2013. Dedicated bioenergy crop impacts on soil wind erodibility and organic carbon in Kansas. *Agron. J.* 105:1271–1276. doi:10.2134/agronj2013.0072
- Follett, R.F., K.P. Vogel, G.E. Varvel, R.B. Mitchell, and J. Kimble. 2012. Soil carbon sequestration by switchgrass and no-till maize grown for bioenergy. *Bioenergy Res.* 5:866–875. doi:10.1007/s12155-012-9198-y
- Gee, G.W., and D. Or. 2002. Particle-size analysis. In: J.H. Dane and G.C. Topp, editors, *Methods of soil analysis*. Part 4. SSSA Book Ser. 5. SSSA, Madison, WI. p. 255–293.
- Gilley, J.E., B. Eghball, L.A. Kramer, and T.B. Moorman. 2000. Narrow grass hedge effects on runoff and soil loss. *J. Soil Water Conserv.* 55:190–196.
- Gilley, J.E., L.M. Durso, R.A. Eigenberg, D.B. Marx, and B.L. Woodbury. 2011. Narrow grass hedge control of nutrient loads following variable manure applications. *Trans. ASABE* 54:847–855. doi:10.13031/2013.37110
- Grossman, R.B., and T.G. Reinsch. 2002. Bulk density and linear extensibility. In: J.H. Dane and G.C. Topp, editors, *Methods of soil analysis*. Part 4. SSSA Book Ser. 5. SSSA, Madison, WI. p. 201–225.
- Kemper, D., S. Dabney, L. Kramer, D. Dominick, and T. Keep. 1992. Hedging against erosion. *J. Soil Water Conserv.* 47:284–288.
- Marquez, C.O., C.A. Cambardella, T.M. Isenhardt, and R.C. Schultz. 1998. Assessing soil quality in a riparian buffer by testing organic matter fractions in central Iowa, USA. *Agrofor. Syst.* 44:133–140. doi:10.1023/A:1006261519080
- Nelson, D.W., and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter: Laboratory methods. In: D.L. Sparks, editor, *Methods of soil analysis*. Part 3. SSSA Book Ser. 5. SSSA, Madison, WI. p. 961–1010.
- Nimmo, J.R., and K.S. Perkins. 2002. Aggregate stability and size distribution. In: J.H. Dane and G.C. Topp, editors, *Methods of soil analysis*. Part 4. SSSA Book Ser. 5. SSSA, Madison, WI. p. 317–327.
- NRCS. 2003. Vegetative barrier, Code 601. <ftp://ftp-fc.sc.egov.usda.gov/NHQ/practice-standards/standards/601.pdf> (accessed 6 Mar. 2014). USDA, Washington, DC.
- Rachman, A., S.H. Anderson, C.J. Gantzer, and E.E. Alberts. 2004. Soil hydraulic properties influenced by stiff-stemmed grass hedge systems. *Soil Sci. Soc. Am. J.* 68:1386–1393. doi:10.2136/sssaj2004.1386
- SAS Institute. 2014. SAS OnlineDoc 9.1.3. <http://support.sas.com/onlinedoc/913/docMainpage.jsp> (accessed 1 Mar. 2014). SAS Inst., Cary, NC.
- Schmer, M.R., M.A. Liebig, K.P. Vogel, and R.B. Mitchell. 2011. Field-scale soil property changes under switchgrass managed for bioenergy. *Glob. Change Biol. Bioenergy* 3:439–448. doi:10.1111/j.1757-1707.2011.01099.x
- Six, J., H. Bossuyt, S. Degryze, and K. Denef. 2004. A history of research on the link between (micro)aggregates, soil biota, and soil organic matter dynamics. *Soil Tillage Res.* 79:7–31. doi:10.1016/j.still.2004.03.008
- Thomas, G.W. 1996. Soil pH and soil acidity. In: D.L. Sparks, editor, *Method of soil analysis*. Part 3. SSSA Book Ser. 5. SSSA, Madison, WI. p. 475–490.
- Tisdall, J.M., and J.M. Oades. 1982. Organic matter and water-stable aggregates in soils. *J. Soil Sci.* 33:141–163. doi:10.1111/j.1365-2389.1982.tb01755.x
- Tufekcioglu, A., J.W. Raich, T.M. Isenhardt, and R.C. Schultz. 1998. Fine root dynamics, coarse root biomass, root distribution, and soil respiration in a multispecies riparian buffer in Central Iowa, USA. *Agrofor. Syst.* 44:163–174. doi:10.1023/A:1006221921806