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Dedicated Bioenergy Crop Impacts on Soil Wind Erodibility and Organic Carbon in Kansas

Byron J. Evers[1], Humberto Blanco-Canqui[2], Scott Staggenborg[1], and John Tatarko[3]

[1]Kansas State University, Department of Agronomy. 2004 Throckmorton Plant Sciences Center,
Manhattan, KS 66506

[2]University of Nebraska, Department of Agronomy and Horticulture, 261 Plant Science Hall,
Lincoln, NE 68583
*Corresponding author (hblancocanqui2@unl.edu)

[3]John Tatarko, USDA, Engineering & Wind Erosion Research Unit, Manhattan, KS

ABSTRACT

Dedicated bioenergy crops such as perennial warm-season grasses (WSGs) may reduce soil erosion and improve soil properties while providing biomass feedstock for biofuel. We quantified impacts of perennial WSGs and row crops on soil wind erodibility parameters (erodible fraction, geometric mean diameter of dry aggregates, and aggregate stability) and soil organic carbon (SOC) concentration under a dedicated bioenergy crop experiment in eastern Kansas after 4 and 5 yr of management. Soil properties were measured under switchgrass (*Panicum virgatum* L.), big bluestem (*Andropogon gerardii* L.), miscanthus (*Miscanthus* × *giganteus*), and annual row crops including continuous corn (*Zea mays* L.), photoperiod sorghum (*Sorghum bicolor* L. [Moench.]), sweet sorghum, and grain sorghum. Perennial WSGs reduced wind erodible fraction by 1.08 to 1.16 times compared with row crops. The geometric mean diameter of dry aggregates under switchgrass and miscanthus was 2.8 to 4.5 times greater than under row crops. Dry soil aggregate stability under miscanthus and big bluestem was greater than under row crops. After 5 yr, differences in SOC concentration between WSGs and row crops were not statistically significant for the 0- to 15-cm depth. Photoperiod sensitive and sweet sorghum had greater biomass yield than WSGs. In 2011, miscanthus yielded more biomass than corn by 5.3 Mg ha^{-1}. Overall, growing dedicated bioenergy crops can reduce the soil's susceptibility to wind erosion but may not significantly increase SOC concentration in this region in the short term.

***Abbreviations**:* SOC , soil organic carbon; WSGs, warm-season grasses.

Development of environmentally sustainable dedicated energy crops may address concerns about soil and environmental degradation. Dedicated energy crops such as perennial WSGs can be a potential alternative to crop residue removal to provide cellulosic biomass for renewable energy production while improving soil and environmental quality (Blanco-Canqui, 2010). Excessive crop residue removal can adversely affect soil structural stability, SOC pools, water transmission characteristics, soil microbial activity, and other soil properties (Wilhelm et al., 2004; Blanco-Canqui and Lal, 2009). In contrast, perennial WSGs due to their year-round surface cover may protect soil from erosion, improve soil properties, soil productivity, and wildlife habitat and diversity. In addition to their potential as biofuel, perennial WSGs may also serve as a valuable animal feedstock, which is particularly important in years of drought (Craine et al., 2010).

In the Great Plains, wind erosion is a major environmental concern. This region witnessed the worst dust storms in United States history during the 1930's (Colacicco et al., 1989). It is well recognized that herbaceous wind barriers can reduce wind erosion, improve crop yield, prevent sandblast damage to crops and trap snow to improve soil moisture (Bilbro and Fryrear, 1988). Similar to wind barriers, plantations of WSGs when grown for forage and biofuel may be an effective management practice to reduce wind erosion. Perennial WSGs provide permanent vegetative cover which can adsorb wind energy, reducing wind velocity (Bilbro and Fryrear, 1997). Extensive and deep root systems under perennial WSGs may also stabilize and anchor soil, increasing soil aggregate size and stability. In the Great Plains, wind erosion is usually the greatest between February and May when winds are strong and crops are sparse or not present to protect the soil surface. Presence of dormant WSGs in early spring may reduce wind erosion compared with row crops with limited surface residue cover. Bilbro and Fryrear (1997) concluded that tall and lodge-resistant plants, such as switchgrass, increased the effective distance of wind barriers. Grasses are able to absorb blowing soil particles and reduce the loss of windblown materials (Bilbro and Fryrear, 1997).

Current research on dedicated bioenergy crops mostly focuses on increasing production of biomass (Propheter et al., 2010). As a result, data on dedicated bioenergy crop impacts on soil and water conservation, soil physical properties, SOC dynamics, and other soil and environmental factors are limited, particularly in Kansas. This information is, however, needed to assess the potential benefits of growing dedicated energy crops under different regions. Benefits for WSGs for improving soil properties may be inconsistent, depending on the length of management, grass species, soil type, and climate (Schwartz et al., 2003).

Most dedicated bioenergy crops are expected to be grown in marginal lands to reduce concerns over competition for land with prime agricultural production (Kort et al., 1997; Cai et al., 2011). Throughout the central Great Plains in general and Kansas in particular, WSGs may fit the dedicated energy crop niche for marginal lands and dryland conditions. Stand establishment and biomass production may determine the feasibility and economic viability of growing perennial WSGs. More research is thus needed to fully understand the capabilities and limitations of growing dedicated energy crops and their impacts on soil and environment in the region.

Several recent studies have reported that converting cultivated lands to native WSGs may have the potential to be a C positive system (Liebig et al., 2005). Across the upper Midwest of the USA, Schmer et al. (2011) reported an average SOC increase of 0.5 to 2.4 Mg ha^{-1} yr^{-1} under switchgrass grown for biomass production. Across 10 locations in Indiana, Omonode and Vyn (2006) reported that WSGs had greater (22.4 g C kg^{-1}) SOC concentration than croplands (19.8 g C kg^{-1}) after 6 to 8 yr of management. Soil organic C sequestration by WSGs can be greater in soils with initial low SOC levels. Despite repeated harvest cycles, WSGs such as switchgrass may still increase SOC levels compared with land managed under row crops because of increased belowground biomass input under WSGs (Sanderson, 2008). In the long term, perennial WSGs may also store SOC in deeper soil profile due to their deep and extensive rooting systems (Lemus and Lal, 2005; Follett et al., 2012). More data on the potential of WSGs on increasing SOC concentration are needed for different soils and climatic conditions.

Therefore, the objective of this study was to quantify the effects of perennial WSGs and row crops on soil wind erodibility parameters and SOC concentration on a Hapludoll in eastern Kansas. Our study hypothesis was that growing perennial WSGs reduces soil wind erodibility and increases SOC concentration in this soil.

MATERIALS AND METHODS

Field Experiment Locations and Treatments

This study was conducted during spring 2011, fall 2011, and spring 2012 on an ongoing bioenergy crop experiment in eastern Kansas established in 2007. The experimental site was located at the Kansas State University’s Agronomy Research Farm at Manhattan (39º11’N, 96º35’W), KS. Mean annual precipitation for the site is 838 mm. The soil is a Kahola silt loam (fine-silty, mixed, super active, mesic Cumulic Hapludolls) with a slope <1%. The soil is formed in calcareous silty alluvium, very deep, and located on moderately permeable flood plains. The site is near a stream and is subject to occasional flooding under intense rainstorms. Indeed, in June 2011, a rainfall event produced over 120 mm of precipitation in a 24-h period, which flooded the study site and redistributed crop residues. This site may be considered as a relatively marginal cropland, which might fit the type of land that is being considered for large-scale production of dedicated bioenergy crops.

The experiment was a randomized complete block with four replications. The individual plot size was 6.1 m wide by 10.7 m long. The experiment consisted of three perennial warm-season grasses (‘Kanlow’ switchgrass, ‘Kaw’ big bluestem, and miscanthus), two native grass mixtures [indiangrass (*Sorghastrum nutans* L.)] /switchgrass/big bluestem mix and a switchgrass/big bluestem mix), continuous corn, corn-soybean, and three sorghum cultivars (photoperiod sensitive, sweet, and grain sorghum) in rotation with soybeans with each rotation phase present each year. For this study on soil properties, seven bioenergy crop treatments including switchgrass, big bluestem, and miscanthus, continuous corn, photoperiod sensitive sorghum, sweet sorghum, and grain sorghum were selected.

Detailed information on previous management history and baseline data on soil fertility parameters is reported by Propheter et al. (2010). Furthermore, fertilization, weed control, and other management protocols for both WSGs and row crops, particularly during experiment establishment, is presented by Propheter and Staggenborg (2010). Briefly, switchgrass and big bluestem were seeded at 4 kg ha^{-1} and 6.3 kg ha^{-1}, respectively, in late spring 2007. Each individual miscanthus plant was hand transplanted in early June 2007 in 1.2 by 1.0 m grid spacing. Weeds were controlled with the use of herbicides, mowing, and hand weeding in 2007 and 2008. Once WSGs were established, no weed control was necessary.

In 2007, miscanthus was fertilized at transplanting, but switchgrass and big bluestem were not fertilized to reduce weed pressure. Each miscanthus plant was fertilized with 10.5 g of Miracle-Gro (24-8-16). To correct for the low P and K soil test levels, 151 kg P_2O_5 ha^{-1} as triple super phosphate (0–46–0) and 336 kg K_2O ha^{-1} as potash (0–60–0) was applied in 2008. All plots under WSGs received 45 kg N ha^{-1} as urea (46–0–0) from 2008 to 2012. All row crops were planted in spring with a no-till planter on 0.76 m row spacing. Urea was surface applied to row crops at about 180 kg N ha^{-1} from 2007 to 2012. Weeds in annual row crops were controlled with atrazine [6-chloro-N-ethyl-N′-(1-methylethyl)-1,3,5-triazine-2,4-diamine] and S-metolachlor (2-Chloro-N-(2-ethyl-6-methylphenyl)-N-[(1S)-2-methoxy-1-methylethyl]acetamide; Propheter et al., 2010; Propheter and Staggenborg, 2010).

Measurement of Soil Properties

Soil attributes including aggregate size distribution, aggregate stability, wind erodible fraction, and geometric mean diameter of dry aggregates were used as parameters to evaluate the soil's susceptibility to wind erosion (Skidmore et al., 1990). Aggregate size distribution and aggregate stability were measured, while wind erodible fraction and aggregate geometric mean diameter were computed from aggregate size distribution data. Soil samples were collected at three different times (spring 2011, fall 2011, and spring 2012) to study how differences in biomass cover and precipitation input affected soil response to bioenergy crops. Soil samples for all analysis were collected in March (at the beginning the growing season of WSGs) in 2011 and 2012 and November (after harvest) in fall 2011.

Approximately, 4 kg of soil were sampled using a flat shovel for the 0 to 5 cm soil depth in each plot. Soil was carefully sampled to ensure that samples included intact aggregates. The samples were placed into collection pans, transported to the laboratory, and oven-dried at 60^{o} C for 2 days. The oven-dry samples were then sieved using a rotary sieve apparatus (Chepil, 1962; Lyles et al., 1970). Sieve size fractions were: <0.42, 0.42-0.84, 0.84-2.0, 2.0-6.35, 6.35-14.05, 14.05-44.45 and >44.45 mm. Aggregates from each sieve were weighed to determine the mass of aggregates for each size fraction. The wind erodible fraction was computed as the mass of <0.84 mm aggregates divided by the total mass of aggregates in different size fractions. The geometric mean diameter of dry aggregates using the mass of aggregates and aggregate size fractions was computed (Nimmo and Perkins, 2002).

Separate soil samples were collected for the determination of the dry stability of individual aggregates. Samples were collected using a flat shovel for a 5 cm soil depth and passed through a 19.0 mm diameter sieve in the field. The sieved samples were then air-dried for 72 h. A subsample of 30 aggregates were selected from each air-dry sample and were finger manipulated to obtain an approximate spherical shape. Each aggregate was then individually crushed using a crushing meter. The aggregate crushing-meter apparatus consisted of two parallel plates supported by a load cell, which was connected to a computer to measure the crushing energy of the aggregate (Boyd et al., 1983). Dry aggregate stability was expressed as the natural log of the crushing energy per unit mass (Skidmore and Powers. 1982; Layton et al., 1993). In this paper, the term dry aggregate stability is used to indicate the crushing strength of dry aggregates as defined by Skidmore and Powers (1982).

Total C and N concentrations were determined in bulk samples collected in spring 2012 for the 0- to 7.5- and 7.5- to 15.0-cm depth. The samples were air-dried for 72 h,ground in a roller mill, and pass through a 0.25 mm sieve. Total C and N concentration in the ground sample was analyzed by dry combustion using a LECO TruSpecCN analyzer (LECO Corp., St. Joseph, MI). Because the soil pH in the study plots was <7 (Propheter and Staggenborg, 2010), SOC was considered equivalent to total C for discussion purposes.

Biomass Production

Harvesting protocols and determination of dry biomass for both WSGs and row crops are also described by Propheter et al. (2010) and Propheter and Staggenborg (2010). Briefly, WSGs were harvested after the first killing frost in November using a walk-behind sickle mower. Biomass yields were determined by harvesting the center 1.2 m by 10.7 m area of the plot. Harvested biomass was then hand raked, collected, and weighed. A sample from the harvested biomass was dried at 65°C for 240 h for dry biomass yield. Average stubble height of WSGs after harvest was about 10 cm. Row crops were harvested at physiological maturity in September and October. A 4.6-m length from each of the center two rows was harvested to a stubble height of 10 cm. A biomass subsample was weighed, dried at 65°C for 240 h, and weighed again to calculate dry biomass yield. After sampling, WSG and row crop biomass remaining in each plot was removed from the plots after harvest.

Statistical Analysis

Data were statistically analyzed using PROC Mixed in SAS 9.2 (SAS Institute, 2012). Significance of main effect differences was determined with species as the fixed effect and replication as the random effect. Least square differences were used to determine differences in soil properties and biomass yields at the 0.05 probability levels (SAS Institute, 2012). Treatment effects were evaluated at the 0.05 probability level.

RESULTS

Wind Erodible Fraction and Aggregate Size

Perennial WSGs (switchgrass, miscanthus, and big bluestem) had large and significant effects on wind erodible fraction and geometric mean diameter of dry aggregates relative to row crops including continuous corn, photoperiod sorghum, sweet sorghum, and grain sorghum. In spring

2011 (4 yr after experiment establishment), switchgrass and miscanthus reduced the wind erodible fraction by about 1.08 times compared with row crops (Table 3). In this sampling period, wind erodible fraction in big bluestem did not differ from switchgrass, miscanthus, and row crops. In fall 2011, all WSG treatments had lower wind erodible fraction than row crops (Table 3). In this sampling period, wind erodible fraction under WSGs was, on average, 1.10 times lower than under row crops except that differences between grain sorghum and miscanthus were not significant. Perennial WSGs had greater effects on reducing wind erodible fraction in spring 2012 than in both spring and fall 2011. On average, WSGs reduced wind erodible fraction by 1.16 times compared with row crops(Table 3) . There were no differences in the wind erodible fraction among WSGs. While wind erodible fraction among row crops did not differ in 2011, sweet sorghum had lower wind erodible fraction than continuous corn in spring 2012 (Table 3).

Data on the geometric mean diameter of dry aggregates displayed trends similar to the wind erodible fraction data. In spring 2011, geometric mean diameter in switchgrass and miscanthus was, on average, 3.5 times greater than in row crops (Table 3) . However, differences between big bluestem and row crops were not significant. In fall 2011, switchgrass and miscanthus had about 4.6 times greater geometric mean diameter than row crops except grain sorghum, which did not differ from miscanthus and big bluestem (Table 3) . In spring 2012, magnitude of differences in geometric mean diameter between WSGs and row crops appeared to be smaller than in 2011, but WSGs had consistently greater geometric mean diameter than row crops (Table 3). Geometric mean diameter of aggregates in WSGs was 2.8 times greater than in row crops (Table 3) . At all sampling times, differences in geometric mean diameter of dry aggregates among row crops were not significant (Table 3).

Dry Aggregate Stability

Perennial WSGs appeared to have less consistent effects on dry aggregate stability than on the wind erodible fraction and geometric mean diameter of dry aggregates, but differences were significant (Table 3). In spring 2011, miscanthus had the highest dry aggregate stability (4.12 ln J kg^{-1}) of all treatments (Table 3). Both miscanthus and switchgrass had about 1.1 times greater dry aggregate stability than row crops in spring 2011. Big bluestem had also greater aggregate stability but only when compared with continuous corn and sweet sorghum. In fall 2011, switchgrass and big bluestem had about 1.2 times greater aggregate stability than sweet sorghum and grain sorghum but had similar values to the other two row crops. In spring 2012, miscanthus and big bluestem had 1.2 times greater aggregate stability than row crops and switchgrass. Unlike in spring and fall 2011, soil aggregate stability in switchgrass did not differ from that in row crops in spring 2012. Soil aggregate stability among row crops did not differ at any sampling date (Table 3)

Soil Organic Carbon and Nitrogen and Biomass Yield

Differences in SOC and N concentrations among treatments were not significant (Table 1). In the 0- to 7.5-cm depth, mean SOC averaged across switchgrass and miscanthus was 15.5 g kg^{-1}, while the mean SOC across row crops was only 13.6 g kg^{-1}. Likewise, in the 7.5- to 15-cm depth, mean SOC averaged across switchgrass and miscanthus was 14.8 g kg^{-1}, and that for row crops was 11.8 g kg^{-1}. While there were no statistical differences, the magnitude of differences in mean SOC between WSGs (switchgrass and miscanthus) and row crops appeared to be lower in the 0- to 7.5- cm depth (1.9 g kg^{-1}) than in the 7.5- to 15- cm depth (3 g kg^{-1}; Table 1), suggesting that WSGs may increase SOC concentration with depth in the long term.

There were significant differences in total biomass yields among the treatments in both years (Table 2). In 2010, photoperiod sensitive, sweet sorghum, and grain sorghum had greater biomass yield than WSGs, but, in 2011, only photoperiod sensitive and sweet sorghum had greater biomass yield than WSGs (Table 2). Biomass yield between continuous corn and WSGs did not differ in both years. In 2011, miscanthus had greater biomass yield than continuous corn by 5.3 Mg ha^{-1}. Unlike in 2010, biomass yield from WSGs did not differ from grain sorghum biomass yields. Also, photoperiod sensitive and sweet sorghum varieties had greater biomass yields than continuous corn and grain sorghum in both 2010 and 2011.

DISCUSSION

Data on soil wind erodibility showed that perennial WSGs can reduce soil's susceptibility to wind erosion and improve soil structural properties. Soils under WSGs, particularly miscanthus and switchgrass, had a greater fraction of large aggregates than soils managed under conventional cropping systems. Dry soil aggregates under WSGs were also more stable, less likely to abrade into small aggregates, and thus were less susceptible to wind erosion than those under row crops. The reduced wind erodible fraction, increased aggregate size, and improved aggregate stability in soils under WSGs could be attributed to the increased continuous uniform surface cover and extensive root system under WSGs relative to row crops (Table 3). The consistently lower wind erodible fraction and greater size of soil dry aggregates under WSGs than in row crops during both fall and spring sampling indicates that WSGs were effective at reducing soil erodibility across all seasons. Perennial WSGs probably maintained a permanent and effective soil cover even during winter, reducing effects of soil freezing-thawing cycles unlike under row crops. The stubble under WSGs was cut at 10 cm height during harvest, which left a significant amount of soil cover during winter. The smaller positive effects of big bluestem than miscanthus and switchgrass may be due to the lower biomass yield and slow establishment of this grass species in this climate.

The lack of significant differences in SOC concentration between WSGs and row crops after 5 yr of management was somewhat surprising, but not unexpected considering the short-term management of WSGs in this study. The lack of differences in SOC concentration among WSGs and continuous corn and grain sorghum is probably explained by the lack of differences in biomass yields. However, it is important to note that photoperiod and sweet sorghum row crops did not increase SOC concentration relative to WSGs in spite of producing higher amount of biomass than WSGs. On average, photoperiod and sweet sorghum (20.1 Mg ha^{-1}) produced about 1.7 times more biomass than WSGs (11.8 Mg ha^{-1}; Table 2). Because biomass was removed at maturity from all treatments, the lack of effect of photoperiod and sweet sorghum on SOC suggests that the belowground biomass production among photoperiod and sweet sorghum and WSGs did not differ. Perennial WSGs may have greater root biomass in deeper soil profile than row crops in the long term (Zan et al., 1997).

Results suggest that bioenergy crops may not rapidly increase SOC concentration in all soils, particularly in the short term. Similar studies have reported that potential of WSGs for increasing SOC can be site-specific. In Indiana, after 6 to 8 yr of management, SOC concentration in warm-season native grasses (22.4 g kg^{-1}) was higher than in corn-soybean (19.8 g kg^{-1}) only in 4 out of 10 paired fields for the 0- to 15-cm soil depth (Omonode and Vyn, 2006). . Although differences in mean SOC concentration under WSGs (switchgrass and miscanthus) were numerically larger than mean SOC concentration across row crops for both soil depth intervals, these differences were not statistically significant due in part, to the high variability in SOC data among replications. We hypothesize, however, that WSGs will increase SOC concentration relative to row crops in the long term as WSGs mature.

Our results on biomass yield support those reported for the same experiment for the 2007 and 2008 growing seasons by Propheter et al. (2010) who found that total biomass yield was the greatest for sweet sorghum. They also noted that biomass yields of perennial WSG significantly increased between 2007 and 2008, which suggests that WSG biomass production may continue to increase with time and may prove to be competitive with row crops in the long term. The lower WSGs biomass yield in 2010 compared with grain sorghum with no differences in 2011 (Table 2) can be attributed to an observed yield increase under perennial WSGs from 2010 to 2011 combined with a grain sorghum yield decline due to limited precipitation. The increased yield of the WSGs is likely due to increased stand maturity in addition, possibly, to the grasses ability to utilize stored profile water after winter and early season precipitation events.

It is important to note the variability of the wind erodibility parameters observed among the three sampling dates (Table 3). Variations in dry soil aggregate properties from year to year or even from season to season is not uncommon in this climate. Across 10 soils in Kansas, Skidmore and Layton (1992) observed a large variation in dry aggregate stability from year to year in silt loams. Similarly, in west central Kansas, Layton et al. (1993) found that soil wind erodibility parameters including size, stability, and density of dry aggregates varied between years and between fall and winter under different tillage (conventional till, reduce till, and no-till) and surface cover management scenarios. Dynamic dry aggregate properties can vary from season to season in response to differences in precipitation input and soil temperature, residue input, which can directly affect freezing and thawing, and wetting and drying cycles (Layton et al., 1993). Our results confirm the importance of monitoring changes in soil aggregate properties at different times under dedicated bioenergy crops to better understand the temporal changes in soil wind erodibility properties.

CONCLUSIONS

This study in eastern Kansas indicates that dedicated bioenergy crops such as perennial WSGs including switchgrass, big bluestem, and miscanthus reduce the soil's susceptibility to wind erosion relative to annual row crops. The significant reduction in wind erodible fraction and increase in dry aggregate size and stability under WSGs suggests that WSGs can improve soil structural quality compared with row crops. The beneficial effects of WSGs on reducing soil wind erodibility may be particularly important in agriculturally marginal lands. Results suggest that perennial WSGs grown for biofuel or livestock may improve soil and environmental quality in this region. Results also indicate that the potential of WSGs for increasing SOC concentration may be limited in the short term. Further research is needed to determine long-term soil benefits and identify the most appropriate WSG species in this climate. Overall, this study in eastern Kansas indicated that, in the short term, dedicated bioenergy crops can have more beneficial impacts on reducing risks of soil erosion than on increasing SOC concentration or biomass yields compared with row crops. Further research is needed to assess long-term impacts on soil functions and develop sustainable dedicated bioenergy crop systems in the region.

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Table 1. Impacts of dedicated bioenergy crops and annual row crops on soil nitrogen and carbon concentration for samples collected for two soil depths in spring 2012. Treatment effects were not significant at the $p<0.05$ level.

Treatment	Depth (cm)	Total Nitrogen (g kg^{-1})	Standard Deviation (±)	Total Carbon (g kg^{-1})	Standard Deviation (±)
Continuous corn	7.5	1.2	0.11	13.3	2.0
Photoperiod sorghum	7.5	1.3	0.31	14.9	3.8
Sweet sorghum	7.5	1.2	0.25	13.0	3.2
Grain sorghum	7.5	1.2	0.18	13.2	1.9
Miscanthus	7.5	1.3	0.24	14.7	2.8
Switchgrass	7.5	1.4	0.50	16.4	5.0
Big bluestem	7.5	1.1	0.13	12.2	1.8
Continuous corn	15	1.0	0.21	11.8	2.2
Photoperiod sorghum	15	1.1	0.19	11.6	2.4
Sweet sorghum	15	1.1	0.21	11.9	2.2
Grain sorghum	15	1.1	0.21	11.9	2.3
Miscanthus	15	1.2	0.30	13.9	3.3
Switchgrass	15	1.4	0.41	15.7	4.1
Big bluestem	15	1.2	0.28	13.2	3.5

Table 2. Total biomass dry matter yields for dedicated bioenergy crops and annual row crops in 2010 and 2011. Different letters indicate significant differences at the $p<0.05$ level.

Treatment	Biomass Yield	
	2010	2011
	Mg ha^{-1}	
Continuous Corn	7.26c	8.46c
Photo Period Sorghum	20.77a	20.77a
Sweet Sorghum	23.19a	19.44a
Grain Sorghum	13.8b	11.57bc
Big Bluestem	3.79d	10.93bc
Miscanthus	9.69c	13.78b
Switchgrass	7.9c	10.89bc

Table 3. Impacts of dedicated bioenergy crops and annual row crops on wind erodible fraction (<0.84 mm dry aggregates), geometric mean diameter of dry aggregates, and aggregate stability. Columns followed by the same letter within a sampling period and soil property are not significantly different at the $p<0.05$ level.

Treatment	Wind Erodible Fraction (%)	Geometric Mean Diameter (mm)	Aggregate Stability (ln J kg^{-1})
Spring 2011			
Continuous Corn	16.7a	9.1b	3.2d
Photo Period Sorghum	18.6a	10.2b	3.3cd
Sweet Sorghum	19a	8.1b	3.1d
Grain Sorghum	18.9a	6.8b	3.3cd
Miscanthus	6.9b	28.6a	4.1a
Switchgrass	7.9b	31.7a	3.7b
Big Bluestem	15.4ab	15ab	3.6bc
Fall 2011			
Continuous Corn	25.6a	4.0c	4.2ab
Photo Period Sorghum	24.9a	3.6c	4.5ab
Sweet Sorghum	26.3a	3.4c	4.0b
Grain Sorghum	23.4ab	4.9bc	3.9b
Miscanthus	13.2bc	13.3ab	4.5ab
Switchgrass	6.6c	21,0a	4.8a
Big Bluestem	10.9c	11.9bc	4.7a
Spring 2012			
Continuous Corn	43.1a	1.2c	3.2b
Photoperiod Sorghum	34.8ab	2.3c	3.2b
Sweet Sorghum	31.7b	2.6bc	3.2b
Grain Sorghum	33.9ab	2.6bc	3.1b
Miscanthus	13.6c	6.0ab	4.1a
Switchgrass	17.0c	6.6a	3.3b
Big Bluestem	16.7c	5.8abc	3.9b