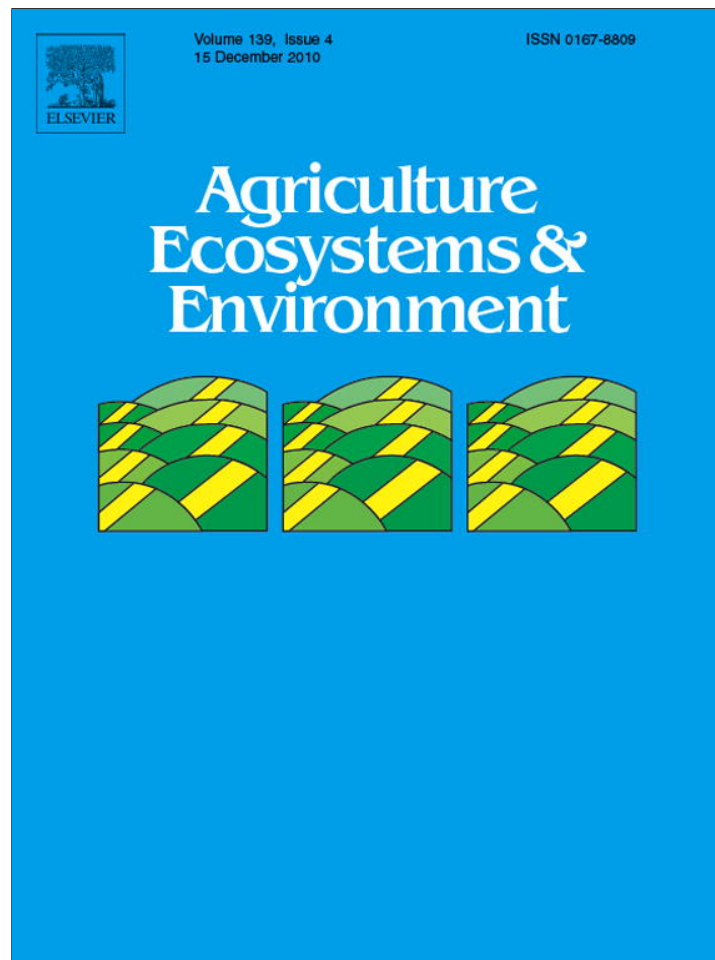


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Short communication

Soil microbial activity under different grass species: Underground impacts of biofuel cropping

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ABSTRACT

Microbial and plant communities interact to determine local nutrient cycling rates. As lands are converted to bioenergy crops, including corn and cellulosic grasses, focus has been on changes in soil carbon sequestration. Little attention has been paid to impacts of such land conversion on the activity of belowground communities. We hypothesized that in addition to affecting soil organic carbon (SOC), monoculture species establishments have appreciable effects on microbial community activity, as evidenced by N and C mineralization rates. We compared soil microbial response in soils under long-term corn (*Zea mays* L.) production to soils under 10-year old monocultures of four warm-season perennial grasses (switchgrass [*Panicum virgatum* L.], coastal bermudagrass [*Cynodon dactylon* (L.) Pers.], sideoats grama [*Bouteloua curtipendula* (Michaux) Torrey] and buffalo grass [*Bouteloua dactyloides* (Nutt.) Columbus]). All assayed perennial systems had higher SOC and water extractable organic C (WEOC) than the annual corn system. However, of all the perennial grasses, switchgrass soils had the lowest SOC and WEOC values, and the lowest 28-day C and N mineralization rates. This study indicates that soil microbial activities under buffalograss stands are more active than those under sideoats grama, switchgrass, coastal bermudagrass, or corn.

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1. Introduction

There is ample evidence for feedbacks between microbial soil communities and plant communities (Wedin and Tilman, 1990; Hobbie, 1992; Ehrenfeld et al., 2005). Microbial biomass function and pool size are controlled by soil C availability, which is determined by plant tissue quality and quantity. Microbial C and N have been linked to above ground net primary production. For example, soil microbial biomass C (SMBC) under tallgrass prairie has been measured at more than 50 times greater levels and makes up a much larger portion of the soil organic C pool (6.4% vs. 0.2%) than SMBC in shortgrass steppe soils (Zak et al., 1994). Additionally, N mineralization rates have been shown to be sensitive to plant species. Changing plant species cover changes plant litter production quality and quantity, affecting C and N pools and microbial biomass (Wedin and Tilman, 1990).

Switchgrass (*Panicum virgatum* L.), coastal bermudagrass [*Cynodon dactylon* (L.) Pers.], and corn (*Zea mays* L.) have all been proposed as potential biomass sources for ethanol based energy (McLaughlin and Kszos, 2005; Farrell et al., 2006; Sanderson and Adler, 2008). Sideoats grama [*Bouteloua curtipendula* (Michaux) Torrey] and buffalo grass [*Bouteloua dactyloides* (Nutt.) Columbus] production potentials have also been compared to switchgrass and

other potential biomass grasses (Robins, 2010).

It has been suggested that replacing row crops with perennial grasses, and switchgrass in particular, alters soil C biogeochemical characteristics, including elevating rates of C mineralization, increasing microbial biomass C and percentage of microbial biomass C in organic C (Ma et al., 2000).

Increasing net primary production typically increases SOC, but increasing decomposition rates decrease SOC (Wang and Hsieh, 2002). In perennial grass systems managed for biomass production, the majority of the aboveground biomass is harvested, so C input contributing to SOC storage must be primarily derived from root production (Bransby et al., 1998). Perennial warm-season grasses tend to have root biomass comparable to the annual aboveground biomass (McLaughlin and Walsh, 1998). Switchgrass can produce upwards of five times more root biomass as compared to corn (Zan et al., 1997; Tufekcioglu et al., 2003), so switchgrass cropping should yield to increased SOC as compared to corn cropping.

There are very few studies on soil N cycling as related to different grass types and their contributions to SOC (Omonode and Vyn, 2006). In this manuscript, we determine belowground impacts a decade after converting agronomically managed land to monocultures of switchgrass, coastal bermudagrass, buffalograss, and side oats grama as compared to corn. It is assumed that conversion of land to perennial grasses leads to an increase in annual SOC sequestration due to high below ground biomass production (Lemus and Lal, 2005). There is a whole suite of other benefits soil gains from improved SOC levels, including improved water and

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nutrient retention and decreased erosion. However, biomass quantity does not indicate SOC turn over rates. We hypothesized that the higher aboveground biomass yielding species (switchgrass and coastal bermudagrass) would have higher below ground biomass, which would contribute more C to the soil, contributing to higher SOM levels in the soil, which should support more SMB.

2. Materials and methods

2.1. Field site and plant species

All field plots were located at the USDA-ARS Grassland, Soil and Water Research Laboratory in Temple, TX (31°4'N and 97°13'W) on Houston Black clay 55% clay, 35% silt and 10% sand (fine, smectitic, thermic Udic Haplusters). The focus of this manuscript was on microbe mediated alterations of SOM, WEOC, and N under different monoculture crops. Therefore, sampling depth was limited to the upper 10 cm of the soil profile, which is where the majority of SMB activity occurs. Sampling occurred in spring time, when soil moisture should have been adequate to support seasonally maximum microbial biomass, limited by substrate availability. Soil samples were taken from plots used in previous experiments examining above-ground physiological plant function (Kiniry et al., 1999; Kiniry et al., 2007). All grass plots were established for at least 10 years in a field historically managed for row crops. Plots measured at least 5 m × 5 m. Ten surface soil samples (0–10 cm) were collected and homogenized from each of three replicate plots for each treatment. All soil samples were dried for 24 h at 40 °C and ground to pass a 2-mm sieve.

Plant species monocultures under which soil samples were collected included sideoats grama, buffalo grass, switchgrass, and coastal bermudagrass. A cultivated field under annual corn–wheat (*Triticum aestivum* L.) rotation served as a control plot. Side oats grama is a warm-season, native, perennial, mid-successional bunch grass, colonizing disturbed areas typically after buffalo grass appears (Osborn and Allan, 1949). Buffalograss, a warm-season native perennial sod-forming short grass, is co-dominant in the climax community of the shortgrass prairie, and is common in mixed-grass prairie and coastal prairie of Texas and Louisiana; though a climax species, buffalo grass establishes during the early to mid-stage secondary successional stages and persists (Judd, 1974; Andelt et al., 1987). Both buffalograss and sideoats grama favor fine-textured soils (Judd, 1974). Switchgrass is a warm-season, native, perennial bunchgrass adapted to tall grass prairie of Central and North America (Parrish and Fike, 2005). Coastal bermudagrass is an early successional species, a warm-season, matt forming grass native to Africa, but common throughout the US, particularly in subtropical areas.

2.2. Carbon mineralization

One hundred grams of homogenized soil were weighed out of air-dried samples. Soils were rewetted to approximately 50% water-filled pore space to stimulate microbial activity and incubated at 25 ± 1 °C in the dark. Soils were incubated individually in gas-tight, sterile 1-l glass jars with a vial containing 10 ml of 1.0 M KOH to trap evolved CO₂ and a vial of water to maintain humidity. Destructive soil sampling occurred at 1, 10, 14, and 28 days. Alkali traps were removed/replaced at days 1, 3, 10, 14, and 28. Unreacted alkali in the KOH traps following precipitation of CO₃ with BaCl₂ was titrated with 1.0 M HCl to determine CO₂-C evolution (Anderson, 1982).

2.3. Nitrogen mineralization

Destructively harvested soils were measured for net nitrogen (N) mineralization (mg N kg⁻¹ day⁻¹) over the incubation period, determined as the difference between initial water-extractable soil inorganic N concentrations (NH₄⁺-N + NO₂⁻-N + NO₃⁻-N) of non-incubated soil samples from soil N extracted after 28 days of incubation. Inorganic N was extracted from 4-g soil subsamples using 40 ml of 2.0 M KCl. Samples were shaken for 30 min on a reciprocal shaker, filtered and the extracts analyzed for NH₄-N and NO₂- plus NO₃-N using an OI Analytical rapid flow analyzer for NH₄-N, and NO₃-N. The sum of the above N forms was designated inorganic N.

2.4. Soil carbon analysis

Four grams sub-samples were weighed into 50-ml plastic centrifuge tubes. Forty milliliters of deionized water was added to each tube, shaken for 30 min and centrifuged for 5 min at 3500 rpm. The extracts were filtered through Whatman 2V filter paper and analyzed for water extractable organic C (WEOC) on a Teledyne-Tekmar Phoenix 8000 Carbon analyzer. Additionally, 2-g subsamples were analyzed on a Leco C analyzer for total soil organic C (SOC).

2.5. Soil microbial biomass C and N

A fumigation-incubation method (Jenkinson and Powlson, 1976) was used to determine soil microbial biomass carbon (SMBC). For each treatment, a 40-g soil sample was rewetted and incubated at 25 °C for 5 days prior to being exposed to alcohol-free CHCl₃ vapor for 24 h. Following evacuation and removal of vapors, the soil was incubated in the dark in 1-l gas-tight glass containers for 10 days at 25 °C. Carbon dioxide evolved during the 10-day incubation period following fumigation was trapped in 1.0 M KOH and determined as described previously. The quantity of evolved CO₂-C was divided by an efficiency factor of 0.41 to calculate microbial biomass C (Voroney and Paul, 1984).

Soil microbial biomass nitrogen (SMBN) was determined on the same samples, by analyzing soil NH₄-N concentrations of fumigated samples following the 10-day incubation period minus initial NH₄-N prior to fumigation, divided by an efficiency factor of 0.41 (Carter and Rennie, 1982). Extraction and analysis of NH₄-N was accomplished as previously described.

Statistics were analyzed using SigmaStat ver 3.5 and included one-way ANOVA Holm–Sidak method ($P < 0.05$).

3. Results

3.1. Carbon mineralization

Carbon mineralization was enhanced by perennial grass monoculture establishment as compared to the control corn monoculture (Fig. 1). On day 1, the highest C mineralization rates were observed under buffalograss (168.4 ± 3.6; mean ± one standard deviation) followed by sideoats grama (129.1 ± 7.7), bermudagrass (99.3 ± 6.2), switchgrass (85.8 ± 3.4) and corn (55.6 ± 2.3). The same relationships between plant species and C mineralization rates were observed at day 1 and day 28 of the incubation experiment, with each species separating out from each other ($P < 0.05$).

3.2. Nitrogen mineralization

Nitrogen mineralization was enhanced by perennial grass monoculture establishment as compared to the control corn monoculture (Fig. 2). N mineralization rates followed the same pattern as C mineralization rates. The highest N mineralization rates were

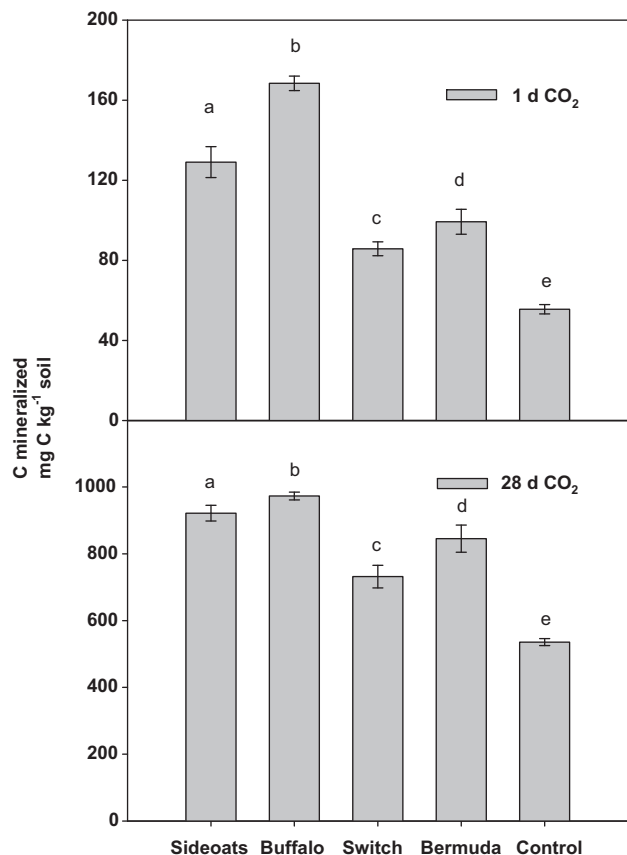


Fig. 1. Mean carbon mineralization rates under the five assayed species. Each species C mineralization rate was statistically different from the others using one-way ANOVA Holm–Sidak method ($P < 0.05$). Error bars are one standard deviation. Letters of the same are not significantly different at ($P < 0.05$).

observed under buffalograss (20.7 ± 1.6), followed by sideoats grama (17.9 ± 2.2), bermudagrass (13.3 ± 1.4), and switchgrass (7.6 ± 1.0). Corn actually showed immobilization of N rather than mineralization (-10.9 ± 1.9).

3.3. Soil carbon analysis

Soil organic C (SOC) was highest under buffalo grass (averaging 7.5%), followed by sideoats grama (6.1%), coastal bermudagrass

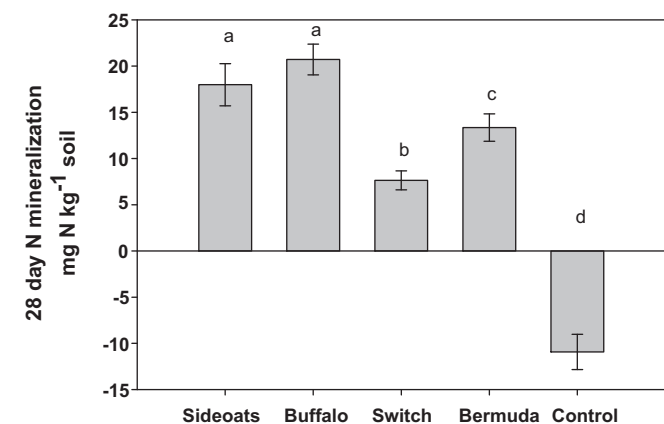


Fig. 2. Nitrogen mineralization rates under the five assayed species. Error bars signify one standard deviation. Each species N mineralization rate was statistically different ($P < 0.05$) from the others using one-way ANOVA Holm–Sidak method with the exception of sideoats and buffalo, which grouped together. Letters of the same are not significantly different at ($P < 0.05$).

(4.6%), switchgrass (3.9%) and corn (1.8%). SOC values under all five grasses were significantly different from each other ($P < 0.05$), as were water extractable organic C (WEOC) values, which followed the same order (Fig. 3).

3.4. Soil microbial biomass C and N

All perennial grass treatments supported significantly more SMBC and SMBN than the corn treatment. Soil microbial biomass C and N were both highest under buffalograss (SMBC 1983 ± 128) (SMBN 244 ± 22) though these values were not statistically higher than those observed under sideoats grama (1827 ± 226) (237 ± 17) (Fig. 4). Switchgrass (1095 ± 174) (161 ± 12) and coastal bermudagrass (1300 ± 211) (178 ± 11) also grouped out together as supporting the lowest SMBC and SMBN of the perennial grasses. Corn supported significantly less SMBC and SMBN (730 ± 42) (129 ± 2) than the perennial species.

4. Discussion

High C mineralization rates signify high soil microbial activity. Of the four perennial species assayed, switchgrass had the lowest C mineralization rate, signifying that it sustained the least active soil microbial activity of any of the four perennial grasses.

Nitrogen mineralization is a more sensitive soil measurement than SMB in terms of demonstrating N mineralization/immobilization (Figs. 2 and 4). The SMB C:N ratio was lowest for the control corn field, which would predictably result in the greatest levels of N mineralization occurring under corn. How-

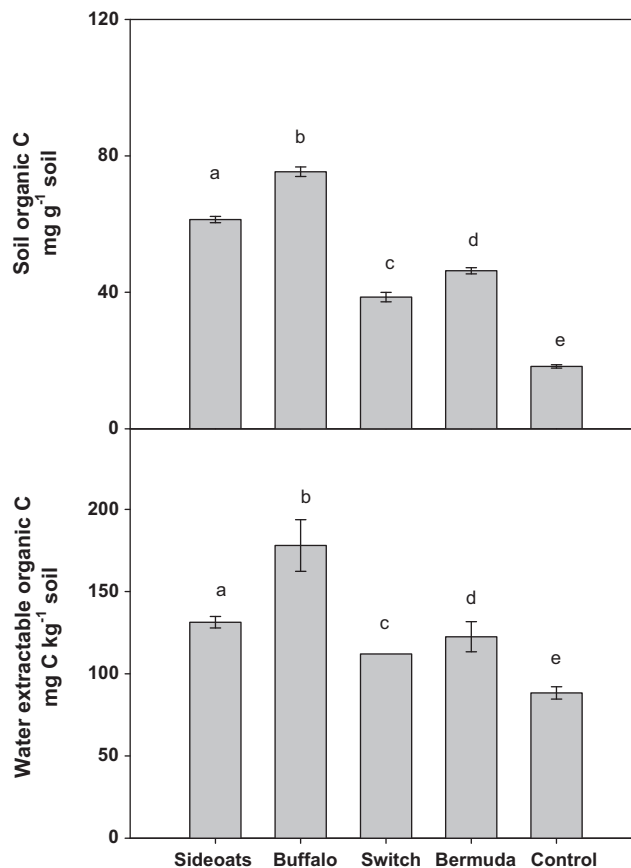


Fig. 3. SOC and WEOC followed the same order. Values in soil under each monoculture were significantly different from one another using one-way ANOVA Holm–Sidak method ($P < 0.05$). Error bars are one standard deviation. Letters of the same are not significantly different at ($P < 0.05$).

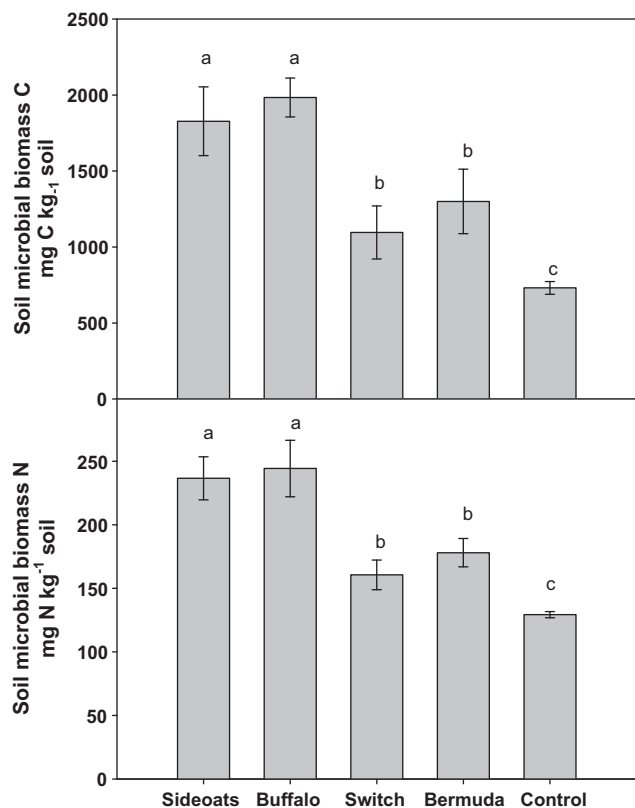


Fig. 4. Soil microbial biomass C and N under the various perennial grasses and corn (control). SMB C and SMB N followed the same pattern, with sideoats grama and buffalograss grouping together, switchgrass and coastal bermudagrass grouping together, and corn (control) as the significantly lowest SMB C and SMB N using one-way ANOVA Holm–Sidak method ($P < 0.05$). Error bars indicate one standard deviation. Letters of the same are not significantly different at ($P < 0.05$).

ever, the microbes in the cultivated corn soils were N limited, as evidenced by the negative 28-day N mineralization data, which showed N immobilization instead. The perennial grass with the lowest soil N mineralization rate was switchgrass. This finding is in keeping with studies that demonstrate soils planted with late successional grasses have lower N mineralization rates than earlier seral species (Wedin and Tilman, 1990).

Measured SOC under corn cultivation was lower than SOC in all prairie species monocultures. The corn plot being conventionally plowed demonstrates the stark difference between established perennial grasses and annual cultivation on C sequestration. Soil disturbance associated with corn cultivation increases the rate of decomposition, lowering SOC (Grandy and Robertson, 2007). Also, perennial grasses introduce more carbon to the soil than does corn (Anderson-Teixeira et al., 2009). Our perennial grass plots produced a minimum of twice the SOC as did the corn fields. Switchgrass produced 3 times the organic C as the corn field. This is in keeping with other work examining switchgrass and other large biomass producing perennial grass SOC (Corre et al., 1999; Anderson-Teixeira et al., 2009).

A novel finding in this study is that the SOC under the buffalograss and sideoats grama monocultures was nearly twice what it was under switchgrass. Therefore, although switchgrass may provide more soil C storage than does corn in the upper 10 cm of soil, the lower biomass buffalograss and sideoats grama outperform switchgrass in terms of SOC in this zone. This is surprising, considering that studies have shown switchgrass can produce more than twice the root biomass of sideoats grama (Scott, 1998).

This study was limited to the areas of the soil profile where microbes are most active (0–10 cm). Researchers interested in SOC,

WEOC, and N mineralization and C mineralization rates throughout the soil profile should consider measuring similar properties at deeper depths. Deeper rooting perennial grasses may move C deeper into the soil, storing C in locations not assayed herein. Both N mineralization and C mineralization have been demonstrated at depths of up to 7 m (Ajwa et al., 1998).

In this experiment, SOC separated treatments better than WEOC. However, WEOC may be a more environmentally sensitive pool than SOC given the sheer magnitude of scale. The range in WEOC is 50–200 mg C kg⁻¹ soil whereas SOC is 18–76 mg C g⁻¹ soil, WEOC being three orders of magnitude smaller. WEOC values signify microbial activity levels, as WEOC is the C from the SOC pool that is easily mineralizable (Hong et al., 2006; Wang et al., 2003).

Switchgrass, the only late-successional species in our study, produced more biomass than any of the other treatment species (Kiniry et al., 1999). In 1995 and 1997, mean sideoats grama yields were 400–1100 g m⁻² while switchgrass yields were 2300–4000 g m⁻². In 1998, 1999, and 2000, mean yields were 312 g m⁻² for sideoats grama, 1182 g m⁻² for switchgrass, 325 g m⁻² for buffalograss, and 618 g m⁻² for coastal bermudagrass. On the macro-scale, Zak et al. (1994) found late successional ecosystems aboveground net primary production to be significantly related to both labile organic C pools in the soil and microbial biomass. Tilman and Wedin (1991) found late successional grass species reduce soil N below values maintained by early and mid-successional grass species. Contrary to what one would have predicted based on Zak et al.'s (1994) findings, soil under our switchgrass, the highest aboveground biomass producer in our study, had lower soil N mineralization rates and lower SOC than the other perennial grasses.

This experiment did not address the mechanisms of plant–soil feedbacks responsible for the change in C and N dynamics evidenced by this work. For example, it is possible that different species, with substantially different growth forms and biomass yields, may alter soil aggregation patterns. However, previous studies found no effect on soil aggregate-size distribution related to monocultures of six grasses, including sideoats grama and switchgrass (Scott, 1998).

As large areas of the US are converted to switchgrass, corn, and coastal bermudagrass for biofuel production, often at the expense of native communities (herein represented by buffalograss and sideoats grama), there will be alterations of the N and C cycles in the soils. Long term C and N dynamic studies are needed as these conversions continue. This study is an important baseline study, which will be useful for future sequential sampling, which will provide researchers with further data and insight into the soil nutrient and microbial dynamics under this biomass for energy production systems.

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