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Soil Carbon and Nitrogen in Response to Perennial Bioenergy Grass, Cover Crop and Nitrogen Fertilization

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ABSTRACT

Cover crop and nitrogen (N) fertilization may maintain soil organic matter under bioenergy perennial grass where removal of aboveground biomass for feedstock to produce cellulosic ethanol can reduce soil quality. We evaluated the effects of cover crops and N fertilization rates on soil organic carbon (C) (SOC), total N (STN), ammonium N (NH_4-N), and nitrate N (NO_3-N) contents at the 0–5, 5–15, and 15–30 cm depths under perennial bioenergy grass from 2010 to 2014 in the southeastern USA. Treatments included unbalanced combinations of perennial bioenergy grass, energy cane (*Saccharum spontaneum* L.) or elephant grass (*Pennisetum purpureum* Schumach.), cover crop, crimson clover (*Trifolium incarnatum* L.), and N fertilization rates (0, 100, and 200 kg N ha^{-1}). Cover crop biomass and C and N contents were greater in the treatment of energy cane with cover crop and 100 kg N ha^{-1} than in the treatment of energy cane and elephant grass. The SOC and STN contents at 0–5 and 5–15 cm were 9%–20% greater in the treatments of elephant grass with cover crop and with or without 100 kg N ha^{-1} than in most of the other treatments. The soil NO_3-N content at 0–5 cm was 31%–45% greater in the treatment of energy cane with cover crop and 100 kg N ha^{-1} than in most of the other treatments. The SOC sequestration increased from 0.1 to 1.0 Mg C ha^{-1} year^{-1} and the STN sequestration from 0.03 to 0.11 Mg N ha^{-1} year^{-1} from 2010 to 2014 for various treatments and depths. In contrast, the soil NH_4-N and NO_3-N contents varied among treatments, depths, and years. Soil C and N storages can be enriched and residual NO_3-N content can be reduced by using elephant grass with cover crop and with or without N fertilization at a moderate rate.

Key Words: C and N storages, C sequestration, feedstock, management practices, N cycling, nitrate, soil organic matter

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INTRODUCTION

Interest is growing to use ligno-cellulosic feedstock materials, such as perennial grasses, for bioenergy production (Pacala and Solocolow, 2004; USDOE, 2007; Blanco-Canqui, 2010). Biomass from such crops can be used either to produce ethanol or generate electricity, which can substantially reduce the use of fossil fuel and the amount of petroleum imported from foreign countries (Adler *et al.*, 2007). Perennial grasses have additional advantages compared with food crops, such as corn (*Zea mays* L.), for producing bioenergy: 1) they reduce pressure for using food crops for bioenergy, 2) they require reduced amounts of chemicals, such as fertilizers, herbicides, and pesticides, and 3) they can be easily grow on marginal lands (Pacala and Solocolow, 2004; USDOE, 2007). Removal of aboveground biomass for bioenergy, however, can adversely affect soil and environmental quality (Blanco-Canqui, 2010). Improved management practices, such as cover crop, nitrogen (N) fertilization, and ideal species of grass, are needed to enhance soil and environmental quality by increasing soil organic matter, reducing carbon (C) pollution in the atmosphere, and decreasing the potential for N leaching while sustaining aboveground biomass yield.

Warm-season perennial grasses, such as energy cane and elephant grass (C4 grasses), have great potential for bioenergy crops because of their higher aboveground biomass yield, extensive root system, low maintenance, greater adaptability, and higher drought tolerance compared with other common grasses (Sanderson *et al.*, 1996; Blanco-Canqui, 2010). Reduced soil disturbance and higher belowground (root) biomass of perennial grasses can sequester C and N, reduce soil erosion, decrease N leaching, enhance nutrient cycling, and mitigate greenhouse gas emissions compared with row crops (Post and Kwon, 2000; Bronson *et al.*, 2004; Blanco-Canqui, 2010). Warm-season grasses can sequester soil organic C (SOC) of 0.3–0.5 Mg C ha^{-1}

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year^{-1} to a depth of 30 cm while sustaining feedstock biomass yield for cellulosic ethanol production compared with grain crops where removal of aboveground biomass can reduce SOC storage by 1–1.5 Mg C ha^{-1} year^{-1} (Anderson-Teixeira *et al.*, 2009; Blanco-Canqui and Lal, 2009). Warm-season grasses can also remove greater levels of ammonium N (NH_4-N) and nitrate N (NO_3-N) than no grass, thereby reducing N losses through leaching and volatilization (Eghball *et al.*, 2000). The performance of these grasses, however, depends on soil and climatic conditions, topography, harvest frequency, cutting height, and management type and duration (Kemper *et al.*, 1992; Sanderson *et al.*, 1996).

Cover crops can increase soil C and N storage compared with no cover crop by providing additional biomass residues that supply C and N to the soil (Kuo *et al.*, 1997a, b; Sainju *et al.*, 2003). Cover crops can also reduce the potential for N leaching by removing residual NO_3-N from the soil profile (Meisinger *et al.*, 1991; McCracken *et al.*, 1994). Legume cover crops can fix N from the atmosphere, thereby supplying additional N and reducing N fertilization rates to subsequent crops compared with nonlegume cover crops or no cover crop (Clark *et al.*, 1994; Kuo *et al.*, 1997b). Nitrogen fertilization has a variable effect on SOC and soil total N (STN) storage (Gregorich *et al.*, 1996; Halvorson *et al.*, 2002; Russell *et al.*, 2005). While information on the effect of cover crops and N fertilization rates on soil C and N under cereal crops is available, little is known on that under bioenergy perennial grasses. Perennial grasses differ from cereal crops in the production of above- and belowground biomass, management practices, amounts of inputs (*e.g.*, no-till *vs.* till and high *vs.* low inputs), and types of land used for crop production (cropland *vs.* marginal land) (Bronson *et al.*, 2004; Sainju *et al.*, 2014).

Soil inorganic N (NH_4-N and NO_3-N) content after crop harvest in the autumn represents residual N that results from lack of efficient uptake of N by plants with applications of N fertilizers, manures, and other amendments (Varvel and Peterson, 1990). Because plants can remove about 40%–60% of applied N, the residual N after crop harvest can be lost to the environment through leaching, denitrification, volatilization, surface runoff, soil erosion, and nitrous oxide (N_2O) emissions (Smil, 1999; Janzen *et al.*, 2003; Eickhout *et al.*, 2006). Nitrogen-use efficiency for crops can be further reduced at high N fertilization rates. Varvel and Peterson (1990) have reported that N removed by plants accounts for 50% of the applied N at low N rates and 20%–30% at high N rates. Therefore, improved management practices are needed to reduce soil residual N and the potential for N losses to the environment while maintaining crop yields and quality.

We used combinations of perennial bioenergy grass, cover crop, and N fertilization rate to evaluate their effects on soil C and N contents. Our objectives were to: 1) quantify the effects of combinations of perennial bioenergy grass (energy cane or elephant grass), cover crop, and N fertilization rate on SOC, STN, NH_4-N, and NO_3-N contents from 2010 to 2014 in the southeastern USA and 2) determine which combination is most effective in enhancing soil C and N storage and reducing residual soil NO_3-N content. Because cover crops can enhance soil C and N storage and reduce residual soil N compared with no cover crop (Kuo *et al.*, 1997a, b; McCracken *et al.*, 1994) and biomass yield is greater with elephant grass (*Pennisetum purpureum* Schumach.) than energy cane (*Saccharum spontaneum* L.) (Leon *et al.*, 2015; Singh *et al.*, 2015), we hypothesized that the combination of elephant grass with the cover crop crimson clover (*Trifolium incarnatum* L.) and 100 kg N ha^{-1} would increase SOC and STN contents and reduce soil inorganic N content compared with other combinations.

MATERIALS AND METHODS

Experimental site and management

A field experiment was conducted at the Agricultural Research Station Farm, Fort Valley State University, Fort Valley, Georgia, USA, from 2010 to 2014. The soil was a Dothan sandy loam (fine-loamy, kaolinitic, thermic, Plinthic Kandiudult), with a pH of 6.5–6.7, sand content of 650 g kg^{-1}, silt content of 250 g kg^{-1}, and clay content of 100 g kg^{-1} at the 0–30-cm depth. The clay content increased to 350 g kg^{-1} below 30 cm. At the initiation of the experiment in November 2010, the SOC content at 0–5, 5–15, and 15–30 cm was 10.1, 7.4, and 3.5 g C kg^{-1}, respectively, and the STN content was 0.86, 0.66, and 0.39 g N kg^{-1}, respectively. The NH_4-N content at 0–5, 5–15, and 15–30 cm was 1.4, 1.4, and 1.5 mg N kg^{-1}, respectively, and the NO_3-N content was 0.4, 0.8, and 0.5 mg N kg^{-1}, respectively. Average (56-year) air temperature ranges from 2 °C in January to 33 °C in July and total annual precipitation is 1 240 mm. Previous cropping history was native vegetation dominated by henbit (*Lamium amplexicaule* L.), cut-leaf evening primrose (*Oenothera laciniata* L.), and wild mustard (*Brassica juncea* L.). The resident vegetation was killed by applying glyphosate (*N*-(phosphonomethyl) glycine)) at 3.5 kg active ingredient ha^{-1} at the initiation of the