Chemosphere 145 (2016) 135–141

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Impact of switchgrass biochars with supplemental nitrogen on carbon-nitrogen mineralization in highly weathered Coastal Plain Ultisols

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HIGHLIGHTS

- Carbon dioxide evolution was increased by the additions of switchgrass biochars and residues.
- Application of switchgrass biochar may cause N immobilization.
- Biochar application may need supplemental N to avoid crop growth retardation.

ARTICLE INFO

Article history:
Received 7 September 2015
Received in revised form
4 November 2015
Accepted 17 November 2015
Available online 11 December 2015

Handling Editor: X. Cao.

Keywords:
Switchgrass biochars
Switchgrass residues
Carbon mineralization
Highly weathered soils
Coastal Plain Ultisols
Total inorganic nitrogen

ABSTRACT

Although an increase in soil fertility is the most frequently reported benefit linked to adding biochar to soils, there is still a need to pursue additional research that will improve our understanding on the impact of soil fertility enhancement because the effect could vary greatly between switchgrass (*Panicum virgatum*, L) residues (USG) and switchgrass biochars (SG). We hypothesized that SG with supplemental nitrogen (N) would deliver more positive effects on carbon (C) and N mineralization than USG. The objective of this study was to evaluate the effects of USG and SG, with or without supplemental inorganic N fertilizer on C and N mineralization in highly weathered Coastal Plain Ultisols. The application rate for SG and USG based on a corn yield goal of 112 kg ha^{-1} was 40 Mg ha^{-1}. Inorganic N was added at the rate of 100 kg N ha^{-1}, also based on a corn yield of 7.03 tons ha^{-1}. Experimental treatments were: control (CONT) soil; control with N (CONT + N); switchgrass residues (USG); USG with N (USG + N); switchgrass biochars at 250 °C (250SG); SG at 250 °C with N (250SG + N); SG at 500 °C (500SG); and SG at 500 °C with N (500SG + N). Cumulative and net CO_2–C evolution was increased by the additions of SG and USG especially when supplemented with N. Soils treated with 250SG (8.6 mg kg^{-1}) had the least concentration of total inorganic nitrogen (TIN) while the greatest amount of TIN was observed from the CONT + N (19.0 mg kg^{-1}). Our results suggest that application of SG in the short term may cause N immobilization resulting in the reduction of TIN.

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1. Introduction

Through years of extensive research elsewhere, the use of biochars has gained widespread attention as a potential amendment to boost soil fertility (Chan et al., 2008; Novak et al., 2009a; Manya, 2012). While intensive crop production depletes nutrients and reduces organic carbon in soils, biochar produced by pyrolysis has the potential to enhance soil fertility and reduce greenhouse gas emissions. Early studies have shown that biochar contains inorganic nutrients (Chan and Xu, 2009) along with a structural matrix composed of an assemblage of carbon structures, some components are even resistant to microbial oxidation (Lehmann et al., 2011). Everything else being equal, materials added to the soil with a C:N ratio greater than 24:1 will result in a temporary N deficit (immobilization), and those with a C:N ratio less than 24:1 will result in a temporary N surplus.

The fertility of highly weathered Ultisols in the southeastern Coastal Plain region of United States is low. Research has shown organic residues added to soils to improve soil organic carbon content and fertility levels in the southeast Coastal Plain region

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http://dx.doi.org/10.1016/j.chemosphere.2015.11.063
0045-6535/Published by Elsevier Ltd.

have made minimal gains because materials decompose easily due to the region's sandy-textured soils, warm climate and abundant rainfall (Sigua et al., 2014; Novak and Busscher, 2012). The application of organic residues is critically needed for fertility maintenance of Ultisols as it leads to the formation of humus. Incorporation of crop residues in agricultural systems is an important factor in sustaining soil fertility level and nutrient cycling (Nicolardo et al., 1995; Ambus and Jensen, 1997; Jensen, 1994). Proper management of crop residues for the maintenance of soil fertility cannot be overstressed. Production and export of large amounts of biomass for bioenergy and grain production removes substantial amounts of mineral nutrients from soil (Heggenstaller et al., 2008; Sigua et al., 2004a, 2004b, 2003). Repeated annual harvest of crop residues could reduce soil organic C levels (Sigua and Coleman, 2010; Laird et al., 2009; Sigua, 2009; Sigua et al., 2009).

Applying organic amendments (i.e. biosolids, organic waste, manure, crop residues) to improve soil physical and chemical properties are well known in the literature (Larney and Angers, 2012; Busscher et al., 2011), but the impact of the enhancement varied greatly between amendment sources (Larney and Angers, 2012). The longevity of easily decomposable organic amendments raises the specter of their long-term contribution to soil carbon sequestration and length of duration for the carbon and nitrogen mineralization in the soils. Estimates of net carbon mineralized or converted to CO_2 from biochars decomposition are needed to improve our understanding on both the efficacies of biochars in enhancing soil quality, carbon sequestration and biochar stability in soils. Results of a recent study published by Sigua et al. (2014) showed that feedstock processed into pellets will have lower rate of C mineralization in soils compared with smaller-size (dust; <0.42 mm) biochar particles produced from similar feedstock. Although most soil properties could be improved following application of crop residues and/or pyrolyzed crop residues, there is still a need to pursue additional research that will enhance our understanding of the impact on soil fertility in terms of carbon and nitrogen mineralization because the effect could vary greatly between uncharred and pyrolyzed residues.

With respect to both positive and negative aspect of biochar on short- and long-term functioning in the agroecosystem, there are few studies that dealt with the utilization of crop residues (uncharred) versus pyrolyzed materials from the same feedstock source of plant biomass productivity (Sigua et al., 2014; Novak and Watts, 2013). Gaskin et al. (2010) reported that nitrogen from biochar might not be available to plants. Addition of biochar to soils has been shown to result in slower mineralization of the biochar materials than the uncharred material (Knoblauch et al., 2012) and decrease net N mineralization (Dempster et al., 2012; Castaldi et al., 2012). Inconsistencies between reported effects of biochar derived from pyrolysis of crop biomass and those for other sources suggest additional research is needed. The use of more stable compounds such as carbonized materials from incomplete combustion of organic materials such as black carbon, pyrogenic feedstocks and charcoal could provide a long-term stability for maintaining high levels of soil organic matter and available nutrients in the soil (Glaser et al., 2002). We hypothesized that pyrolyzed switchgrass would deliver more positive effects on carbon and nitrogen mineralization than uncharred switchgrass residues. Understanding the nature of the short-term carbon and nitrogen mineralization and the mechanisms behind it is important for accepting both short- and long-term stability and obtaining reliable estimates of degradation rates. The objective of this study was to evaluate the effects of switchgrass residues and switchgrass biochars, with or without supplemental inorganic nitrogen fertilizer on carbon and nitrogen mineralization in highly weathered Coastal Plain Ultisols.

2. Materials and methods

2.1. Soil and site description

A Norfolk soil (fine loamy, kaolinitic, thermic, Typic Kandiudult) collected from the Clemson University, Pee Dee Research and Education Center, Darlington, South Carolina was used in the study. This soil belongs to the Ultisols order (US Soil Taxonomy) formed in extensively weathered Coastal Plain marine sediments with the clay fraction dominated by kaolinite. The Norfolk soil is a well drained soil located in upland landscape position (Daniels et al., 1999). The collection site has a long history of row crop production (>30 yrs), which in 2007, was converted to switchgrass (*Panicum virgatum*) for biofuel production.

Soils were collected from the top 15 cm and the 15–30 cm layers, respectively. The soil samples were air-dried; and then passed through a 2 mm sieve to remove plant material and large aggregates. Particle size analyses were carried out using the hydrometer method (Soil Characterization Laboratory, The Ohio State University, Columbus, Ohio). Both the Norfolk's Ap and E horizon organic carbon (SOC) and total nitrogen (TN) contents were measured using a LECO TruSpec CN analyzer (LECO Corp., St. Joseph, Michigan). Table 1 summarized some selected soil chemical properties of Norfolk's Ap and E horizons.

2.2. Feedstock selection, biochar pyrolysis and characterization

The switchgrass (*P. virgatum*) feedstock used in this study was obtained by harvesting switchgrass at the Clemson University Pee Dee Research and Education Center. The switchgrass feedstock was processed before pyrolysis by air-drying and grinding to pass a 6-mm sieve. The switchgrass biochars were produced at North Carolina Agricultural and Technical State University as outlined by Novak et al (2013). The biochars were made using slow pyrolysis procedure at 250° and 500 °C under a continual stream of N_2 gas. After recovery from the pyrolyzer, all biochars and the uncharred switchgrass were ground to pass a 0.42-mm sieve using a Wiley Mini-Mill (Thomas Scientific, Swedesboro, NJ, USA). All samples were then further sieved to pass through a 0.25-mm sieve, placed in a sealable plastic bag and stored in a desiccator.

The uncharred switchgrass and switchgrass biochar samples were characterized for their physical and chemical properties that

Table 1
Selected soil chemical properties of soil and chemical properties of switchgrass residues and switchgrass biochars at 250 °C and 500 °C (dry-weight) used in the study.

Soil properties	Ap horizon	E horizon
pH	5.6	5.4
P (mg/kg)	50	10
K (mg/kg)	85	70
Ca (mg/kg)	277	176
Mg (mg/kg)	56	42
Zn (mg/kg)	3.9	2.2
Mn (mg/kg)	11	6
Cu (mg/kg)	0.9	0.4
B (mg/kg)	0.1	0.1
Na (mg/kg)	6	6
CEC (meq	1.8	1.5

Pyrolysis (°C)	pH[a]	Ash[a]	C[a]	H[a]	O[a]	N[a]	O/C	H/C
		———————— g kg^{-1}———————						
Residues	5.8	22	483	62	427	5.1	0.66	1.53
250	6.4	26	553	60	356	4.3	0.49	1.29
500	9.2	78	844	24	43	3.4	0.04	0.34

[a] Published in Bioenergy Research (Novak et al., 2012).