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Ameliorating soil chemical properties of a hard setting subsoil layer in Coastal Plain USA with different designer biochars

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HIGHLIGHTS

- Biochar was used to ameliorate chemical properties of Norfolk soils.
- Additions of designer biochars have variable effects on soil chemical properties.
- Designer biochars did improve chemical properties of hard-setting Norfolk subsoil.

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ABSTRACT

Biochar application is an emerging management option to increase soil fertility. Biochars could improve chemical properties of soils with hard setting subsoil layer. However, biochar effect can be inconsistent because different biochars react differently in soils. We hypothesized that addition of designer biochars will have variable effects on improving the chemical properties of hard setting layers. The objective of this study was to investigate the effects of biochars on soil properties in Norfolk's soil with a hard setting subsoil layer grown with winter wheat (*Triticum aestivum* L.). All designer biochars were added at the rate of 40 Mg ha^{-1}. Feedstocks used for biochars production were: plant-based (pine chips, 100% PC); animal-based (poultry litter, 100% PL); 50:50 blend (50% PC:50% PL); 80:20 blend (80% PC:20% PL); and hardwood (100% HW). Higher nutrient availability was found after additions of biochars especially additions of 100% PL and 50:50 blend of PC and PL. On the average, applications of 100% PL and 50:50 blend of PC:PL had the greatest amount of soil total nitrogen with means of $1.94 \pm 0.3\%$ and $1.44 \pm 0.3\%$, respectively. When compared with the control and other biochars, 50:50 blend of PC:PL additions resulted in increase of 669% for P, 830% for K, 307% for Ca, 687% for Mg and 2315% for Na while application of 100% PL increased the concentration of extractable P, K, Ca, Mg, and Na by 363%, 1349%, 152%, 363%, and 3152%, respectively. Overall, our results showed promising significance since biochars did improve chemical properties of a Norfolk's soil.

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1. Introduction

The rising global population growth combined with global food supply and security necessitates a major optimization in agricultural productivity. This will require preservation and replenishment of soil organic matter to sustain nutrient cycling, improve water- and nutrient-use efficiency and mitigate against climate change (Jones et al., 2012). The fertility of highly weathered Ultisols in the southeastern Coastal Plains region of United States is low. In this region, intensive crop production depletes soil nutrients and reduces soil organic carbon.

Norfolk soils in the southeastern U.S. Coastal Plain region have meager soil fertility characteristics because of their sandy textures, acidic pH values, kaolinitic clays and with depleted organic C contents. Extensive clay mineral weathering and clay eluviations along with intensive leaching of bases and high levels of exchangeable Al (Gamble and Daniels, 1974; Daniels et al., 1978) has promoted the formation of a hard setting subsoil layers. These soil characteristics severely limit fertility and crop productivity, which leaves few management options for improvements (Novak et al., 2009a).

Application of mulches, composts and manures have frequently been shown to increase soil fertility but because of hot and humid conditions, organic matter is usually mineralized rapidly. As an alternate, biochar has been described as a possible means to improve soil fertility and sequester C (Lehmann et al.,

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2006, 2011; Sohi et al., 2010; Lehmann, 2007). An increase in soil fertility is the most frequently reported benefit linked to adding biochar to soils (Manya, 2012; Novak et al., 2014). The increase in the availability of major plant nutrients due to application of biochar was also reported by Glaser et al. (2002) and Lehmann et al. (2002).

The relationship between biochar properties and its potential to enhance soil fertility is still unclear and does not always allow the establishment of appropriate process conditions to produce a biochar with desired characteristics (Novak and Busscher, 2012; Manya, 2012; Keiluweit et al., 2010; Sanchez et al., 2009; Brewer et al., 2009; Hammes et al., 2008). The influence of biochar on soil properties and crop productivity is likely to vary significantly among biochars because biochar's effectiveness is governed by biomass sources and pyrolysis conditions (Chan et al., 2007, 2008; Gaskin et al., 2008; Chan and Xu, 2009; Nguyen et al., 2010). Gaskin et al. (2010) reported that N from biochar might not be available to plants. Other researchers reported that the increase of soil nutrients due to biochars may be short-lived, declining with plant uptake and leaching (Gaskin et al., 2010; Rondon et al., 2007; Steiner et al., 2007). Inconsistencies between reported effects of biochar derived from pyrolysis of crop biomass and those for other sources suggest additional research is needed.

Biochar quality can be variable and different biochars react differently in soils (Sigua et al., 2014; Novak and Busscher, 2012). Novak et al. (2009b) recognized that biochars could be designed with specific chemical and physical properties to target specific soil deficiencies. Biochar could be designed to improve the tilth of a hard setting subsoil layer. Since one biochar type will not resolve all issues in all soils, there is a need to conduct additional research on the efficacy of designer biochars in improving fertility and tilth of soils with hard setting subsoil layer. We hypothesized that the addition of different designer biochars to a hard setting subsoil layer will have variable effects on improving the chemical conditions of this soil layer. The objective of this study was to investigate the contrasting effects of multiple designer biochars on ameliorating chemical properties in hard setting subsoil layer grown with winter wheat in the Coastal Plain regions of the southeastern USA.

2. Materials and methods

2.1. Soil and site description

The Norfolk soil series (fine loamy, kaolinitic, thermic, Typic Kandiudult) was used in the study. This soil is classified as an Ultisols order (US Soil Taxonomy) that formed in extensively weathered Coastal Plain marine sediments with the clay fraction dominated by kaolinite. The Norfolk is a well drained soil located in upland landscapes (Daniels et al., 1978). This soil was collected from the Clemson University, Pee Dee Research and Education Center, Darlington, South Carolina. The collection site has a long history of row crop production (>30 yrs), which in 2007, was converted to switchgrass (*Panicum virgatum*) production.

The hard setting subsoil layer of the Norfolk was collected by removing the top 0–15 cm Ap horizon using a front-end loader. Using a shovel, soils were collected between 15 and 40 cm soil depths. The soil samples were air-dried; and then passed through a 2 mm sieve to remove plant material. Particle size analyses were carried out using the hydrometer method (Gee and Bauder, 1986). The organic carbon (SOC) and total nitrogen (TN) contents of Norfolk subsoil were measured using a LECO Truspec analyzer (LECO Corp., St. Joseph, Michigan). Table 1 summarizes some selected soil physical and chemical properties of the soil used in the study.

Table 1
Selected physical and chemical properties of the hardsetting Norfolk subsoil used in the study.

Soil properties	Norfolk soil
1. Physical	
Sand (%)	80.7
Silt (%)	16.7
Clay (%)	2.6
Soil texture	Loamy sand
Bulk density ($Mg\ m^{-3}$)	1.5
Porosity (%)	44
Penetration resistance (MPa)	1.1
2. Chemical	
pH	5.93
C (%)	5.81
N (%)	0.82
P ($mg\ kg^{-1}$)	20.3
K ($mg\ kg^{-1}$)	121.5
Ca ($mg\ kg^{-1}$)	244.5
Mg ($mg\ kg^{-1}$)	54.7
Na ($mg\ kg^{-1}$)	29.6
Al ($mg\ kg^{-1}$)	83.0
Fe ($mg\ kg^{-1}$)	10.7
Cu ($mg\ kg^{-1}$)	0.18
Zn ($mg\ kg^{-1}$)	3.8
CEC ($cmol\ kg^{-1}$)[a]	2.5

[a] *Source:* Busscher et al. (2010). Soil Science. Volume 175:10–14.

2.2. Feedstock description, biochar production, and characterization

The three feedstocks consisted of pine chips (PC), poultry litter (PL) and hardwood (HW). The blending, pelletilization and pyrolysis procedures that were followed in this study were reported in the early papers of Sigua et al. (2014) and Novak et al. (2014). Biochars were produced from each of the pelletized feedstocks using a slow pyrolysis procedure at 500 °C (Cantrell and Martin, 2012). Each pelletized biochar particle had a length of between 10–20 mm and diameter of about 6–8 mm.

Hardwood biochar was also used in this study for comparison. The HW biochar was processed to <0.5 mm particle size to test if smaller size biochar was more effective at improving the hard setting subsoil layer. The HW biochar was manufactured from oak and hickory hardwood sawdust using fast pyrolysis at 500 °C. It had a 14% ash content, an O:C ratio of 0.22, and a surface area of $0.75\ m^2\ g^{-1}$. The pH was determined in a 2:1 (water:solid) ratio using distilled water after stirring for 24 h. Ash content of the biochar was determined using ASTM methods for wood charcoal (600 °C). Selected chemical properties of the biochars used in the study are presented in Table 2.

2.3. Experimental design and set-up

The experimental treatments consisted of a control, 50:50 blend of pine chips (PC) and poultry litters (PL); 80:20 blend of PC and PL; PL (100%); and PC (100%). The blending ratios of the PC:PL were chosen to reduce the amount of plant available P and other salts potentially causing nutrient imbalances and resulting burns to the wheat plants (Novak et al., 2014). The treatments were replicated four times using pots that were arranged in a completely randomized block design. Biochars were added to Norfolk's hard setting subsoil layer at the rate of $40\ Mg\ ha^{-1}$. Each pot also received blanket applications of $45\ kg\ N\ ha^{-1}$, $60\ kg\ P\ ha^{-1}$ and $80\ kg\ K\ ha^{-1}$ before planting. This application rate was chosen because previously published work identified it as suitable rate for obtaining significant improvement in fertility characteristics of a Norfolk's Ap horizon (Novak et al., 2009a). Each pot was planted with 14 wheat seeds (Pioneer, Variety: 26R20) following