

ORIGINAL RESEARCH ARTICLE

Agrosystems

Effect of biochar application on quality of flooded sandy soils and corn growth under greenhouse conditions

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Abstract

Seasonal flooding following heavy rain deposits large amounts of sediments on productive lands in the lower parts of fields in western Tennessee. The deposited sediments have high proportion of sand particles that negatively affect soil physiochemical properties, which make the soil uneconomic for farming. Soil amendments such as biochar, a by-product of renewable energy production from organic waste materials, have the potential to remediate sandy soil left after flood events and improve crop yields by increasing water holding capacity and soil nutrient content. The objective of this project was to evaluate the effect of biochar produced from two types of hardwood feedstocks on water retention and corn (*Zea mays* L.) growth in sandy soil. A greenhouse experiment quantifying the growth of corn was conducted in a randomized complete block design with five replications. Sandy soil was amended with three biochar rates (0, 10, and 20% by volume) under two irrigation levels. The irrigation levels were control and a dry treatment based on the past 10 yr of rainfall data. Biochar application greatly improved water retention in the flooded sandy soil. Biochar increased soil K and P concentration. However, at the end of the study, corn growth was not different in biochar amended and non-amended sandy soil. This research demonstrated that biochar as a soil amendment has the potential to improve quality attributes of poor soil, such as the soil water and nutrient concentration in a previously flooded sandy soils.

1 | INTRODUCTION

Developing sustainable agricultural management practices that can be adopted and used by producers over the long term is important for maintaining and improving environmental quality. Seasonal flooding of agricultural fields caused by

heavy rainfall often deposits a large amount of sediment. The deposited sediments are typically dominated by sand-sized particles that negatively affect soil physiochemical properties. Deposition of sandy soils on productive lands in the lower parts of fields makes the soil less productive for farming by reducing the soil fertility, water holding capacity, and overall soil quality (Glaser, Lehmann, & Zech, 2002).

Soil amendments have the potential to improve soil quality in degraded soils. One amendment with potential for soil amelioration is biochar, a by-product of renewable energy

Abbreviations: CEC, cation exchange capacity; VWC, volumetric water content.

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production from organic waste material. Biochar is the solid material remaining after subjecting biomass to high temperatures in an oxygen-depleted environment (Lehmann & Joseph, 2009). Biochar has the potential to improve agricultural soil by modifying physico-chemical properties such as soil pH (Jeffery, Verheijen, vanderVelde, & Bastos, 2011), cation exchange capacity (CEC), surface area (Deenik & Cooney, 2016), and nutrient retention and availability (Clough & Condro, 2010; Major, Lehmann, Rondon, & Goodale, 2010). Thus, biochar can be used as a soil amendment in agricultural lands to improve soil quality (Kizito et al., 2019; Laghari et al., 2015; Tanure et al., 2019), reduce organic waste, and recover nutrient and energy from what would otherwise be unused by-product (Basiri Jahromi, Walker, Fulcher, Altland, & Wright, 2018; Kizito et al., 2019). Biochar's ability to improve water retention can ameliorate soils in arid regions that experience water scarcity and quality issues (Alkhasha, Al-Omran, & Aly, 2018).

The effects of biochar on crop yield and nutrient availability are higher in low fertility and productivity soils (Lehmann, Gaunt, & Rondon, 2006). The greatest impacts of biochar were reported in acidic and neutral soils, and in soils with a coarse or medium texture (Jeffery et al., 2011). However, biochar has not consistently increased crop yields. In fact, minimal to no impact of biochar on yields were reported in some studies on corn (*Zea mays* L.) (Haider, Steffens, Moser, Müller, & Kammann, 2017; Ramlow, Foster, Del Grosso, & Cotrufo, 2019). In Tennessee and neighboring states, it is likely that biochar use will be better suited to poor soils like sandy soils from flooding, and soils with low organic matter and low CEC.

Biochar also has the potential to improve soil hydraulic and physical properties, including porosity, available water, soil aggregate stability, hydraulic conductivity, infiltration rate, and water retention at higher and lower tensions (Alkhasha et al., 2018; Obia, Mulder, Martinsen, Cornelissen, & Børresen, 2016). Most studies evaluated the effect of biochar application on several soil hydraulic properties and water retention in the wet range of sandy soil (Brockhoff, Christians, Killorn, Horton, & Davis, 2010; Zhang, Chen, & You, 2016). However, few studies have focused on the effects of biochar on hydraulic properties of sandy soil under both dry and wet conditions (Chen et al., 2018).

Both municipalities and private companies are increasingly investing in alternative energy systems across the United States, but at significantly different rates. For example, the city of Lebanon, TN, is producing 3000–5000 kg of wood-based biochar per day and is challenged with identifying the beneficial ways to utilize this material. One option would be using the biochar as an amendment in agricultural and horticultural production systems to renovate soil and substrates to improve production and environmental quality. Our previous research using biochar as an amendment to

Core Ideas

- The effect of biochar produced from two types of hardwood feedstocks on water retention and corn growth in flooded sandy soil was investigated in this study.
- Biochar application greatly improved water retention in the flooded sandy soil.
- Biochar increased soil K and P concentration.
- Corn growth was not different in biochar amended and non-amended sandy soil.

pine bark-based soilless substrate demonstrated that biochar application reduced *Hydrangea paniculata* water use at least by one-third and increased substrate water and nutrient retention (Basiri Jahromi et al., 2018). The main objective of this study was to test the potential use of locally produced biochar in a previously flooded sandy soil for corn production under different irrigation levels of dry and control conditions that represent distinct rainfall patterns.

2 | MATERIALS AND METHODS

This experiment was conducted at the University of Tennessee North Greenhouse Complex in Knoxville, TN. The experiment was a randomized complete block design with five replications arranged in a $2 \times 2 \times 2$ factorial in sandy soil with two types of biochar, two biochar rates (10 and 20% by volume), and two irrigation levels (control and a dry treatment), plus sandy and native soils with no biochar at the two irrigation levels, for a total of 12 treatments. Treatments were blocked on location of containers to account for small variations in the greenhouse environment. Data were subjected to analysis of variance using mixed models (SAS v9.4, SAS Institute).

Biochar was obtained from two local biochar producers - Proton Power Inc., Lenoir City, TN (PP) and City of Lebanon (L). The PP biochar was produced from mixed hardwood with bark by fast pyrolysis at 1100 °C and the L biochar was produced from mixed hardwood without bark by gasification at 700 °C. The chemical and physical properties of both biochars are shown in Table 1 (Li, 2019).

Native soil from the study region, Collins silt loam (coarse-silty, mixed, active, acid, thermic Aquic Udifluvents) and sandy soil (sandy loam) deposits from the West Tennessee Research and Education Center, Jackson, TN, were collected from 0- to 45-cm depth of the field and transported to the greenhouse. Soil chemical properties are shown in Table 2. The 11.4-L containers were filled with the sandy soil and amended with 0, 10, and 20% by volume of biochar (sandy soil, 10% L, 20% L, 10% PP, 20% PP, and native soil). There

TABLE 1 Chemical and physical properties of the hardwood biochar used as a soil amendment^a

Parameter	Units	Proton power biochar (PP)	Lebanon biochar (L)
pH		10.4	8.9
EC	dS m ⁻¹	4.6	0.9
Total C	g kg ⁻¹	830	855
Total N	g kg ⁻¹	10.5	8.1
P	g kg ⁻¹	1	0.0013
K	g kg ⁻¹	5	0.2477
Cation exchange capacity	cmol _c kg ⁻¹	202	71.6
Surface area	m ² g ⁻¹	279	295

Note. EC, electrical conductivity.

^aThe results were obtained from Control Laboratories, Watsonville, CA.

TABLE 2 Chemical properties of the native soil and sandy soil used in this study^a

Parameter	Units	Native soil	Sandy soil
pH		6.7	5.6
NH ₄	mg kg ⁻¹	7.2	0.1
P	mg kg ⁻¹	45.0	18.7
K	mg kg ⁻¹	79.7	54.0
Ca	mg kg ⁻¹	919.0	203.2
Mg	mg kg ⁻¹	44.7	24.7
Fe	mg kg ⁻¹	128.7	17.5

^aThe results obtained from the University of Tennessee Soil, Plant and Pest Center Nashville, TN.

was also a native soil treatment with no biochar addition. Biochar was mixed with the top 7–10 cm soil in the container to simulate practices in field trials. Corn seeds (Local Seed) were sown at approximately 2.5-cm depth in the containers on 19 Mar. 2019. There was one fallow container per irrigation and biochar treatment combination as a reference for evaluating the moisture sensors' performance in estimating soil volumetric water content (VWC) to obtain the highest possible accuracy. Containers were fertilized with 5.5 g of urea per container 10 d after emergence and with 2 g of urea per container 30 d after emergence representing the field fertilizer application rates.

Moisture sensors (GS1, Meter Group Inc. Pullman, WA) were connected to a data logger (CR1000, Campbell Scientific Inc.) with two multiplexers (AM16/32, Campbell Scientific Inc.) to record soil moisture content. A 16-channel relay controller (SDM-CD16AC, Campbell Scientific Inc.) was connected to a data logger to control solenoid valves for automatic irrigation. Twelve independent irrigation lines were constructed with one irrigation line per biochar and irrigation treatment combination. Five plants were irrigated by each irrigation line with a dribble ring (Dramm Corp.) and a 3.8 L per hour emitter. The irrigation levels were based on the average of previous 10 yr rainfall data at Jackson, TN, to simulate distinct rainfall patterns. The control treatments received 19 mm

of water while the dry treatments received 10 mm every 5 d during the early growing season and every 2 d during the later growing season. Soil moisture sensors were placed vertically in the top 7 cm of soil where biochar was applied. Each moisture sensor was calibrated by soil type to accurately measure soil moisture content. There was one sensor per container and thus five sensors per each biochar and irrigation treatment combination. The irrigation treatments were initiated on 5 Apr. 2019.

Soil VWC and total amount of irrigation applied were calculated using the program and the data obtained from moisture sensors. Plant heights and stem circumferences were recorded biweekly during the experiment. The experiment was terminated after 90 d. The aboveground portions of plants were harvested and dried at 55°C until there was no change in mass and then weighed to obtain dry weight. The first fully developed leaf nearest to the top was chosen for tissue nutrient analysis. Samples from each treatment were thoroughly mixed and tissue samples were withdrawn for analysis. Dried leaves were ground to pass a 1.0-mm screen using a Wiley Mill (Thomas Scientific). Total N was determined using a combustion CHNS/O analyzer (CE Elantech). Tissue samples were digested with nitric acid and hydrogen peroxide in a microwave. The digested samples were analyzed on inductively coupled plasma-optical emission spectroscopy (ICP-OES) (Thermo Electron Corp.) for P, K, Ca, Mg, Na, and Fe concentration.

After harvesting the shoots, a vertical core of soil to the full depth of the container was taken from each container. Samples from each treatment were thoroughly mixed and soil samples were collected for analysis. Soil pH was measured with a pH meter (Denver Instrument, Bohemia, NY). Soil samples were extracted using Mehlich-1 solution and the extracts were analyzed in ICP-OES for soil P, K, Ca, Mg, Na, and Fe concentration. The nitrate (NO₃) and ammonium (NH₄) were extracted from the soil using 2 M potassium chloride, respectively following the Mulvaney (1996) method and analyzed using a flow injector analyzer (Lachat Quickchem 8500, HACH, Loveland, CO).

TABLE 3 Maximum volumetric water content (VWC), minimum VWC, and standard deviation from the moisture sensors data of sandy soil amended with 0, 10, or 25% by volume of Lebanon biochar (L) or 0%, 10, or 20% by volume of Proton Power biochar (PP) or native soil ($n = 5$)

Treatment	Maximum VWC	Minimum VWC	Standard deviation
	cm ³ cm ⁻³		
Dry			
0% (sandy soil)	0.19h ^a	0.13c	0.03
10% L	0.33bc	0.26a	0.03
20% L	0.31d	0.24a	0.02
10% PP	0.31d	0.21b	0.03
20% PP	0.29e	0.21b	0.04
0% (native soil)	0.20gh	0.13c	0.03
Control			
0% (sandy soil)	0.21fg	0.13c	0.03
10% L	0.33cd	0.26a	0.03
20% L	0.34 ab	0.26 a	0.03
10% PP	0.34 abc	0.21 b	0.07
20% PP	0.36 a	0.26 a	0.05
0% (native soil)	0.22 f	0.10 d	0.05
<i>P</i> value			
Biochar	<.0001	<.0001	–
Irrigation	<.0001	.5378	–
Biochar × irrigation	<.0001	.0008	–

^aMeans in same column followed by the same letter are not significantly different ($\alpha = 0.05$).

3 | RESULTS AND DISCUSSION

3.1 | Soil moisture content

Dry treatments received a total of 23 L of water during the experiment. Control treatments received 41.5 L of water in total, 80% more than dry treatments. Biochar treatments had higher soil VWC compared to unamended sandy soil and native soil under both the dry and control treatments (Supplemental Figures S1 and S2). The maximum ($P < .0001$), and minimum ($P < .0001$) VWC were all higher in biochar treatments (Table 3), which suggest that both sources of biochar improved soil water holding capacity. The maximum VWC was highest in 20% L and 20% PP biochar treatments under the control irrigation while the minimum VWC was in 0% biochar application rate in sandy and native soil. This is consistent with other studies in which biochar application increased the water content of sandy soils (Basso, Miguez, Laird, Horton, & Westgate, 2013; Dan, Zhong-Yi, Mang-Mang, Bo, & Yi-Jia, 2015; Omondi et al., 2016; Ramlow et al., 2019; Tanure et al., 2019).

Several factors affect the influence that biochar has on soil water retention, including soil texture, biochar pore size distribution and biochar surface area (Gray, Johnson, Dragila, & Kleber, 2014; Omondi et al., 2016; Sun, Hockaday, Masiello, & Zygourakis, 2012). The greatest improvement in available

water content as a result of biochar application was observed in soils with higher sand content (Dan et al., 2015; Omondi et al., 2016). Obia et al. (2016) reported that application of corn cob biochar to sandy loam and loamy sand soils in corn and soybean [*Glycine max* (L.) Merr.] fields increased water holding capacity and soil aggregate stability. Alkhasha et al. (2018) reported that amendment of date palm (*Phoenix dactylifera* L.) biochar to sandy soil improved soil hydraulic and physical properties, including water holding capacity and hydraulic conductivity.

3.2 | Total biomass, stem circumference, and height

There was no difference in the corn total biomass ($P = .6630$), stem circumference ($P = .8008$), or height ($P = .2366$) of the plants grown in sandy soil, sandy soils amended with either rate of biochar or the native soil (Table 4). Total biomass ($P < .0001$), stem circumference ($P = .0003$), and height ($P < .0001$) were higher in control irrigation treatments compared to the dry treatment. Biochar application rate did not affect crop growth attributes but amount of irrigation did.

Despite improving soil water retention and maintaining greater soil moisture content throughout the growing season, hardwood biochar amendments did not improve corn yield.

TABLE 4 Total biomass (g), stem circumference (cm), and height (cm) for corn grown in sandy soil amended with 0, 10, or 20% by volume of Lebanon biochar (L) or 0, 10, or 25% by volume of Proton Power biochar (PP) or native soil ($n = 5$)

Treatment	Total biomass	Stem circumference	Height
Biochar rate	g	cm	
0% (sandy soil)	111.26ns ^a	0.56ns	147.05ns
10% L	98.91	0.54	146.81
20% L	109.73	0.53	157.72
10% PP	108.94	0.55	157.74
20% PP	101.93	0.54	160.81
0% (native soil)	105.91	0.55	142.47
Irrigation			
Dry	79.15b ^b	0.50b	137.16b
Control	133.07a	0.57a	167.04a
<i>P</i> value			
Biochar	.6630	.8008	.2366
Irrigation	<.0001	.0003	<.0001
Time	–	<.001	<.0001
Biochar × time	–	.0026	.2275
Irrigation × time	–	.0022	<.0001
Biochar × irrigation	.9176	.6450	.6484
Biochar × irrigation × time	–	.8348	.0189

^aValues in same column followed by ns are not significantly different ($\alpha = .05$).

^bMeans in same column followed by the same letter are not significantly different ($\alpha = .05$).

This result is commensurate with several previous studies wherein wood biochar amendment increased soil moisture content without affecting corn yield (Haider et al., 2017; Ramlow et al., 2019). A meta-analysis of 177 biochar studies reported that crop growth did not change in corn and several other crops (Jeffery et al., 2011). Sistani, Simmons, Jn-Baptiste, and Novak (2019) reported that hardwood biochar application did not increase corn productivity in short term but has the potential to improve the yield in the long term. In another study, little to no effect of hardwood biochar on tomato (*Solanum lycopersicum* L.) growth was observed by Vaughn, Kenar, Thompson, and Peterson (2013). Crop yield variation in the studies might be due to differences in biochar quality, which is related to the feedstock type, production conditions, and native soil's inherent characteristics (Ronsee, Van Hecke, Dickinson, & Prins, 2013). Higher rates of wood-based biochar improved sandy soil fertility as well as corn nutritional status and growth (Tanure et al., 2019).

3.3 | Foliar nutrient analysis

Plant tissue N concentration ($P = .0068$) was higher in 10% L treatment compared to the native soil and other

biochar-amended treatments (Table 5). However, it was not different from the N concentration of the plants grown in sandy soil. Plant tissue K concentration ($P = .0014$) was highest in native soil compared to any other treatment. Foliar Ca concentration ($P = .0434$) was highest in native soil but it was not different than the 20% L treatment and 10% PP biochar treatment. There was no difference ($P > .10$) between plant tissue P, Mg, Na, and Fe concentration of the plants grown in non-amended sandy soil, biochar-amended sandy soils, and the native soil (Table 5). Hardwood biochar amendments did not improve plant tissue nutrient concentration compared to the non-flooded native and the flooded sandy soil.

A growing body of research indicates that hardwood biochar, such as we used in this experiment, has no effect on crops nutrient uptake (Ramlow et al., 2019; Rogovska, Laird, Rathke, & Karlen, 2014). Different feedstocks may result in biochars with different chemical properties even under the same manufacturing process (Evans, Jackson, Popp, & Sadaka, 2017). The effect of biochar depends on its chemical and physical properties, which relies on production conditions, feedstock material, and cropping system to which the biochar is applied (Basiri Jahromi, Walker, & Fulcher, 2019). So different soils and biochar treatment combinations may result in different nutrient concentration.

TABLE 5 Foliar N, P, K, Ca, Mg, Na, and Fe concentration of corn grown in sandy soil amended with 0, 10, or 25% by volume of Lebanon biochar (L) or 0, 10, or 20% by volume of Proton Power biochar (PP) or native soil ($n = 2$)

Biochar rate	N	P	K	Ca	Mg	Na	Fe
	%			mg kg ⁻¹			
0% (sandy soil)	0.93ab ^a	0.17ns ^b	1.30c	0.79b	0.43ns	40.07ns	183.22ns
10% L	0.98a	0.18	1.54b	0.75b	0.51	76.25	142.59
20% L	0.64c	0.12	1.25c	0.88ab	0.49	62.27	286.63
10% PP	0.54c	0.09	1.41bc	0.88ab	0.43	82.80	137.67
20% PP	0.55c	0.07	1.29c	0.79b	0.32	33.10	140.08
0% (native soil)	0.71bc	0.21	1.77a	1.00a	0.50	86.85	445.47
<i>P</i> value							
Biochar	.0068	.1315	.0014	.0434	.1220	.3303	.2160
Irrigation	.0078	.7553	.0001	.0003	.0145	.3846	.4400
Biochar × irrigation	.0475	.6101	.0722	.3019	.5274	.7112	.9367

^aMeans in same column followed by the same letter are not significantly different ($\alpha = .05$).

^bValues in same column followed by ns are not significantly different ($\alpha = .05$).

TABLE 6 Soil pH, nitrate (NO₃), P, K, Ca, Mg, Na, and Fe concentration of sandy soil amended with either 0, 10, or 25% by volume of Lebanon biochar (L) or 0, 10, or 20% by volume of Proton Power biochar (PP) and native soil ($n = 1$)

Biochar rate	pH	NO ₃	P	K	Ca	Mg	Na	Fe
		mg kg ⁻¹						
0% (sandy soil)	5.30 ^a	24.50	15.50	19.75	220.75	26.25	15.25	15.25
10% L	5.86	23.50	16.50	27.25	285.25	32.75	19.00	16.50
20% L	6.64	15.50	17.50	31.25	318.25	35.00	23.50	18.25
10% PP	6.04	8.00	18.50	25.25	262.75	28.50	17.50	20.25
20% PP	6.07	15.00	40.25	35.50	308.00	30.00	14.75	29.75
0% (native soil)	6.50	13.50	41.00	29.50	704.5	36.00	20.00	64.25

^aANOVA not conducted because there was only one sample for biochar × irrigation combination.

3.4 | Soil nutrient analysis

While based on a limited sample, biochar application numerically increased pH of sandy soil (Table 6), which is consistent with previous studies that also found that biochar application could increase soil pH (Rutigliano et al., 2014). Biochar increases pH due to its neutral to alkaline pH although that is contingent on the feedstock type, soil type, and application rate (Jeffery et al., 2011).

Sandy soil had higher NO₃ concentrations compared to the native soil. Application of biochar increased sandy soil P concentration and 20% PP biochar treatment had the highest concentration of P by more than double compared to other treatments (Table 6). Addition of biochar also increased sandy soil K concentration. The 20% L and 20% PP biochar treatments had higher K concentration in comparison to other treatments. Biochar amendment increased sandy soil Ca and Mg concentrations even though it was lower than native soil Ca and Mg concentration. Application of L biochar increased soil Na concentration. Addition of 20% PP biochar essentially doubled soil Fe concentration compared to the sandy soil although it

was one-third to one-half that found in the native soil. Biochar amendment increased soil nutrient content, but that was not translated into plant uptake. Soil NO₃ and K concentrations were higher in dry treatments. However, soil pH, P, Ca, Mg, Na, and Fe concentration were similar in dry and control treatments (data not shown).

Hardwood biochars used in this study increased soil P and K concentration. In other studies similar results lead to the conclusion that biochar enhance soil nutrient retention (Clough & Condro, 2010) and a possible fertilizer substitution (Altland & Locke, 2013; Basiri Jahromi et al., 2018). Other results were broadly aligned with our study and reported an increase in soil fertility as a result of biochar application. For instance, Dumroese, Heiskanen, Englund, and Tervahauta (2011) reported that increasing pelleted biochar increased soluble K and P in soil. Similarly, Brockhoff et al. (2010) reported that application of up to 25% switchgrass (*Panicum virgatum* L.) biochar amendment could increase P and K nutrient release in low fertile soil. In another study, Tanure et al. (2019) reported that wood biochar increased sandy soil P and K concentrations. In a meta-analysis of 124 published

studies application of biochar increased soil P availability (Gao, DeLuca, & Cleveland, 2019). However, in another study, Ramlow et al. (2019) reported that woody biochar did not affect N availability in corn field trials. Overall, soil amendment with biochar can be a viable option to utilize a by-product and improve quality of poor soil (Kizito et al., 2019). More research is needed to understand the relationship between soil applications and plant growth response to fully maximize the use of biochar.

4 | CONCLUSION

Application of hardwood biochar improved flooded sandy soil water retention and maintained greater soil moisture content throughout the growing season but did not affect corn growth attributes or biomass. Biochar application increased soil K and P concentrations but did not affect plant tissue nutrient concentration. Future research should include examining higher biochar application rates under different environmental and management conditions, and for longer period of time to evaluate the effectiveness of biochar as soil amendment to flooded sandy and other marginal soils.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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