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ABSTRACT

Cotton is known for being sensitive to cool, wet soils, especially in the early stages of growth. Amendments to soil can aid cotton seedlings in development and nutrient uptake. However, soil amendments can be costly and detrimental to the environment, and alternatives such as the addition of biochar have been considered. Biochar is produced from biomass that has gone through pyrolysis and has been shown to improve plant yield, microbial response, soil structure, soil cation–exchange capacity, and water use efficiency. This study was conducted to evaluate the effect of biochar on early season cotton growth. The aim of this study was to determine whether biochar aids nutrient uptake and seedling development during the seedling's life cycle. The study was established in October 2013 in the greenhouse at the University of Arkansas using a randomized complete block design with three replications. Treatments included a control with no fertilizer or biochar, a control with fertilizer (56 kg N/ ha) and no biochar, and two fertilizer treatments (0 or 56 kg N/ ha) each with 1500 or 3000 kg/ha biochar. Plants were grown for eight weeks then harvested to collect plant height, plant fresh weight, plant dry weight, and leaf area. Data showed that the highest level of biochar with additional fertilizer provided the best growth response in plant height, fresh weight dry weight, and leaf area at 27.52 cm, 14.7g, 1.87 g, and 419.48 cm^2, respectively.

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MEET THE STUDENT-AUTHOR

Taylor D. Coomer

I grew up on a family cotton farm in Piggott, Arkansas, where I graduated from Piggott High School. I came to the University of Arkansas as a pre-med student, but decided to pursue a career in the field I knew from childhood. I am a senior Environmental, Soil, and Water Sciences student and am particularly interested in soil science and plant nutrition. I will begin my M.S. with Dr. Oosterhuis in the spring of 2014 studying potassium in cotton. I am involved with the University of Arkansas Crop, Soil, and Environmental Sciences Club on campus, and I am also involved with various volunteer groups in the community. In my spare time I enjoy running, teaching kickboxing and yoga classes, fishing, and hiking.

INTRODUCTION

Over time, soil fertility declines due to plants' harvesting of the soil's valuable resources for the production of grain and residue. Replacing soil nutrients yearly does put them back into the soil, but over time, the soil may become less fertile, and its cation-exchange capacity will decline, reducing the soil's ability to hold nutrients (Laird et al., 2010a). Soils also experience decline in water holding capacity (Kammann et al., 2010) and pH levels (Uzoma et al., 2011). Yearly soil amendments such as manures can be added to the soil to preserve fertility, and while helpful, they are expensive and time consuming to apply (Uzoma et al., 2011). Other alternatives have been explored to replace these additives. One viable option is the addition of biochar.

Biochar (BC) is produced from biomass that has gone through pyrolysis. Pyrolysis is the process of heating in the absence of oxygen (Chan et al., 2008). Biochar is composed of mostly decomposition-resistant polyaromatic carbon. Scientists estimate that BC can resist total decomposition for hundreds to thousands of years (Doydora et al., 2011). Biochar can be produced from virtually any biomass including plant wastes like peanut hulls (Kammann et al., 2010), coffee husks (Dias et al., 2009), animal wastes (Uzoma et al., 2011; Chan et al., 2008), industrial wastes (Van Zwieten et al., 2009), and woody materials (Laird et al., 2010b). Some data show that BC from plants is not as nutrient-rich or as effective compared to BC from animal wastes because of low nitrogen levels (Chan et al., 2008) in plants that do not already have high nitrogen content, such as legumes.

In recent times, studies have been completed to determine what BC can do for the soil, plant, and water ecosystem and what processes BC affects the most. Generally, BC keeps soil fertility high and may increase sequestration of carbon in the soil (Chan et al., 2008). Biochar can support retention of nutrients and other organic material in the soil because of its porosity, high surface area, and areas of both polarization and no polarization (Laird et al., 2010a). Adding BC to a sandy soil can improve soil moisture content and soil cation-exchange capacity because of its high surface area and large charge density (Uzoma et al., 2011).

Biochar addition to soil has increased both plant growth and yield especially when nitrogen-based fertilizer is added (Kammann et al., 2010). One study conducted with peanut hull BC and quinoa (*Chenopodium quinoa* Willd) cultivated in a poor sandy soil showed that grain yield and water use efficiency were both increased with the addition of BC. The highest water use efficiency was at the intermediate BC application rate of 100,088.84 kg/ha (100 metric t/ha) with reduced water, showing that there is a point at which BC application can be too high (Kammann et al., 2010).

Poultry litter BC is of special interest because of the incredible amount of litter produced by poultry houses in the United States, and especially in northwest Arkansas. Every day, 4627 megagrams of poultry manure are produced in chicken farms in Arkansas (Hishaw, 2006). Poultry litter has a high concentration of phosphorus and nitrogen, making it an ideal amendment to agricultural soils. Applying poultry litter directly onto agricultural fields, however, can lead to ammonia volatilization. When nitrogen is deposited to the soil through wet or dry deposition, it can be conducive to nitrogen loading of lakes, acidification of soils, and damage to crops that are sensitive to changes in nitrogen levels. Not only is ammonia volatilization a hazard of direct application of poultry litter, but land application of poultry litter can also contaminate surface water with a high level of phosphorus (Doydora et al., 2011). This is of major importance in Arkansas, especially in the sensitive Illinois River watershed. Scientists faced with the issue of how to deal with excessive amounts of poultry litter discovered that once poultry litter undergoes pyrolysis to become BC, it not only reduces in volume by 75%, but it becomes a stable soil amendment with seemingly few to no hazardous effects.

Research shows that BC can improve many aspects of growing conditions in the soil, and that poultry litter BC can be very beneficial when pyrolysed. It was hypothesized that our control groups lacking BC would have the shortest height with the lightest weight and smallest leaf area, but plants receiving moderate amounts of BC with additional fertilizer would be the tallest and heaviest with the largest leaf area at time of harvest. It was also hypothesized that the highest rates of BC application would be detrimental to growth for cotton, as has been recorded in previous research found in literature.

MATERIALS AND METHODS

Soil. Soil used in the experiment was Captina silt loam (Typic Fragiudult), a common Arkansas soil with a long history of cropping. It was obtained from the University of Arkansas System Agricultural Research and Extension Center farm in Fayetteville, Ark.

Biochar. The BC employed in the experiment was composed of pyrolysed poultry litter. The poultry litter BC was obtained from a local source, BioEnergy Systems LLC. Once the poultry litter BC was obtained, it was tested for nutrient content, as shown in Table 1.

Cotton Seed. Cotton (*Gossypium hirsutum* L.) cultivar Stoneville 5288 2BRF cotton was planted because it is one of the most common cotton genotypes grown in Arkansas.

Greenhouse Experiment. This study was conducted for eight weeks through October, November and December 2013 in the greenhouse at the Rosen Center at the University of Arkansas. The study used a randomized complete block design with three replications. We began with eighteen 2-L pots. Six treatments were administered to the plants with three replications per treatment. The treatments included 0 kg/ha poultry litter BC with fertilizer (56 kg N/ha), 0 kg/ha poultry litter BC without fertilizer, 1500 kg/ha poultry litter BC with fertilizer, 1500 kg/ha poultry litter BC without fertilizer, 3000 kg/ha poultry litter BC with fertilizer, and 3000 kg/ha poultry litter without fertilizer (Table 2).

As soil was added to the pots, the BC was applied. The same amount of soil, approximately 5.2 kg dry, was added to each pot. The soils were flushed by pouring water through the pots until water was dripping out the bottom and drained for 24 h. Then ten seeds were planted in each pot, and after germination and seedling emergence (approximately 10 days), the most uniform plant in each pot was chosen and the rest were removed. Pots were watered daily to field capacity. Height of each plant was recorded weekly and plants were randomized on the greenhouse bench to avoid any biases. After four and one half weeks, the nitrogen fertilizer urea (46-0-0, 56 kg /ha or 50 lb/ac) was applied to the pots designated for additional fertilizer. After eight weeks of growth, the 18 plants were cut at the soil surface and immediately weighed for fresh weight and their leaf area was measured using a LI-COR leaf area meter (LI-3100C Area Meter, LI-COR Environmental and Biotechnology Research Systems, Lincoln, Neb.), dried in an oven for 48 h, and weighed again.

Statistical Analysis. Data was analyzed using JMP 8.0 from SAS Inc (SAS Institute, Inc., Cary, N.C.). Means were calculated using the student's *t*-test based on least significant differences. Differences were significant at $P = 0.05$.

RESULTS AND DISCUSSION

The plants at 27.52 cm in the BC2 + F treatment were significantly ($P < 0.05$) taller than the control with and without fertilizer groups (Table 3). However, cotton in BC2 + F was not significantly taller than the plants in the other treatments receiving biochar, with or without fertilizer applications. (Table 3).

Fresh weight was highest in the plants in the BC2 +F group at 14.7 g. They were significantly ($P < 0.05$) heavier than the plants in the control +F, control –F, and BC2 –F groups. They were heavier, but not significantly ($P < 0.05$) heavier than the BC1 +F and the BC1 –F groups (Table 3).

The average dry weight was highest in the BC2 +F group at 1.87 g and it was significantly ($P < 0.05$) heavier. than the control +F, control –F, and BC2 –F groups. It was not significantly ($P < 0.05$) heavier than the BC1 +F or BC1 –F groups (Table 3).

The BC2 +F group had the largest leaf area at 419.48 cm^2. It was not significantly ($P < 0.05$) larger than the BC1 +F or BC1 –F groups. However, it was significantly ($P < 0.05$) larger than the group with the smallest leaf area, the control +F group at 176.31 cm^2, the control –F, and the BC2 –F groups (Table 3).

In each seedling growth parameter tested, the control group with fertilizer underperformed compared to the low and high rate of biochar application with fertilizer and the low rate of biochar without fertilizer, showing that even compared to the addition of nitrogen fertilizer alone, BC can aid cotton growth and development. However, the BC–nitrogen interaction was obvious because of the better performance in all the BC +F groups than the control +F groups. The BC1 groups had better growth than the control +F in for all properties measured, but did not grow as well as the BC2+F, which was also significantly greater in plant growth parameters than the control.

Plant height data in our study was both similar and different than that of the data Uzoma (2011) collected in the study with maize (*Zea mays* L.) and cow manure BC on a sandy soil. The tallest plants in that study resulted from an intermediate BC rate of 5000 kg/ha, and the shortest plants from the control (no BC) group (Uzoma et al., 2011). Results from our study indicated that the highest rate of 3000 kg/ha was conducive to tallest height of the three rates used, but it had not reached the overload point Uzoma (2011) discovered. However, in a study conducted with quinoa and peanut hull BC on a sandy soil, results indicated that plant height was unchanged due to BC treatment with reduced water supply (Kammann et al., 2011).

Studies of the relationship between dry weight and BC have a large range of results and require further study. Results from Chan et al. 2007 using radish (*Raphanus sativus*) and greenwaste BC on an Alfisol indicated that BC alone did not increase radish dry weight, however, the highest rate of nitrogen added to all BC rates showed significant increase, confirming the BC-nitrogen interaction again. Our research showed that the BC –F groups did not experience significant differences between rates, but BC +F groups did. However, a year later, Chan (2008) conducted another study with poultry litter BC and radishes. Results indicated that even without nitrogen, BC increased dry weight, even at the lowest rate (Chan et al., 2008).

A study conducted with quinoa and peanut hull BC on a sandy soil indicated that BC application significantly increased leaf area both with a sufficient and a reduced water supply (Kammann et al., 2011). Our research did not demonstrate a leaf area increase in the absence of additional fertilizer. Biochar rates alone did not significantly ($P < 0.05$) increase leaf area.

In summary, the data indicate that the high level BC +F showed significant ($P < 0.05$) increases in plant height, fresh weight, dry weight and leaf area over both controls. It also showed significant ($P < 0.05$) increases in fresh weight, dry weight, and leaf area over the high level BC treatment without fertilizer. Based upon the results of this research, a full-scale, season long, multi-year study of the influence of BC on cotton growth and development would seem justified.

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Table 1. Compositional analysis of BioEnergy Systems, LLC (BES) Biochar.

pH units	**μmhos/ cm**				**mg/kg**				
pH	EC	P	K	Ca	Mg	S	Na	Fe	Mn[1]
10.2	16680	7076	26412	3271	3071	3525	6880	32	190
					mg/kg				
P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu[2]
46915	72298	67904	15298	10486	19919	2453	1397	1261	801
				%TN	%TC[3]				
				3.00	32.02				

[1]pH (1:2 soil ratio), Mehlich-3 extractable (1:10 ratio) Analysis by SPECTRO ARCOS Inductively Coupled Plasma (ICP; Spectro Analytical Instruments GmbH, Kleve, Germany).
[2]Total Recoverable Metals, Environmental Protection Agency (EPA) method 3050, measured on SPECTRO ARCOS ICP.
[3]Total N and C by combustion, Elementar vario MAX (Elementar Analysensysteme GmbH, Hanau, Germany).

Table 2. Biochar and Fertilizer Treatment Combinations.

Treatment	**Description**
Control +F	No biochar – 56 kg/ha N (50 lb/ac N)
Control –F	No biochar – No fertilizer
BC1 +F	1500 kg/ha biochar – 56 kg/ha N (50 lb/ac N)
BC1 –F	1500 kg/ha biochar – No fertilizer
BC2 +F	3000 kg/ha biochar –56 kg/ha N (50 lb/ac N)
BC2 -F	3000 kg/ha biochar – No fertilizer

Table 3. Cotton Physical Data after Eight Weeks of Growth

	Average Height (cm)	Average Fresh Weight (g)	Average Dry Weight (g)	Average Leaf Area (cm^2)
Control +F	19.90 C[1]	6.07 C	0.87 C	176.31 C
Control -F	22.23 BC	8.03 BC	1.03 BC	225.82 BC
BC1 +F	24.55 AB	11.07 AB	1.43 AB	304.98 AB
BC1 -F	25.19 AB	11.37 AB	1.47 AB	312.75 AB
BC2 +F	27.52 A	14.7 A	1.87 A	419.48 A
BC2 -F	24.97 AB	8.47 BC	1.07 BC	215.57 BC

[1]Means in the same column with the same letter are not significantly different at the 0.05 alpha level determined by least significant difference values.