Influence of Poultry-Litter Biochar on Early-Season Growth in Cotton

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Influence of Poultry-Litter Biochar on Early-Season Growth in Cotton

An Undergraduate Honors Thesis
in the
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I. Summary

Cotton (*Gossypium hirsutum* L.) is known for being sensitive to cool, wet soils, especially in the early stages of growth. Amendments such as soil fertilizers and manures added to soil can aid cotton seedlings in development and nutrient uptake. However, soil fertilizers and manures can be costly and detrimental to the environment, and alternatives such as the addition of biochar have been considered. Biochar is a high-carbon, nutrient-rich charcoal produced from organic matter that has gone through pyrolysis. Biochar has been shown to improve plant yield, soil microbial response, soil structure, soil cation-exchange capacity, and water-use efficiency, however research on biochar has not had consistent results and requires further study. This study was conducted to evaluate the effect of biochar on early-season cotton growth. The objective of this study was to determine whether biochar aids nutrient uptake and seedling development. 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$^{-1}$) and no biochar, and two biochar treatments (1500 or 3000 kg ha$^{-1}$) each with and without nitrogen fertilizer (0 or 56 kg N ha$^{-1}$). Plants were grown for eight weeks then harvested to collect plant height, plant fresh weight, plant dry weight, and leaf area to determine which treatment resulted in largest growth and development. Analysis of the data showed that the greatest level of biochar with additional fertilizer provided the statistically best growth response compared to the control group in plant height, fresh weight dry weight, and leaf area at 27.52 cm, 14.7 g, 1.87 g, and 419.48 cm$^2$, which is an increase of 38%, 142%, 114%, and 22% from the control with fertilizer, respectively. These results implicate biochar does aid in early season cotton growth, and that biochar applied at 3000 kg ha$^{-1}$ provides better growth conditions than 1500 kg ha$^{-1}$.
II. Introduction

Soil fertility in cropping systems can decline over time due to plants’ utilization of the soil’s valuable resources for the production of grain and stover. Replacing soil nutrients yearly with fertilizers or manure applications returns the removed nutrients to the soil, but over time, the soil may become less fertile, show a decrease in cation-exchange capacity, and have a reduction in ability to hold nutrients (Laird et al., 2010a). Soils also experience a decline in water-holding capacity (Kammann et al., 2010) and pH levels due to cropping (Uzoma et al., 2011). Yearly soil amendments, such as animal manures, can be added to preserve fertility, but while helpful, soil amendments are expensive and time consuming to apply due to cost of material and transportation (Uzoma et al., 2011). Other alternatives have been explored to replace these additives. One viable option is the addition of biochar.

Biochar 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 biochar can resist total decomposition for hundreds to thousands of years (Doydora et al., 2011). Biochar can be produced from virtually any organic material including plant wastes like peanut (Arachis hypogea) hulls (Kammann et al., 2010), coffee (Coffea) 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).

One study by Singh et al., (2010) compared biochar from five different feedstocks: Eucalyptus (Eucalyptus saligna) wood, eucalyptus (E. saligna) leaves, paper sludge, poultry litter, and cow manure. The biochar was pyrolysed at both 400 and 550°C with and without steam activation, dependent upon the feedstock, to compare nutrient concentration and pH levels...
between the biochar types. The results showed that nitrogen levels were greatest in the manure-based biochar, but that the manure-based biochars had the lowest carbon concentrations. Phosphorus concentrations were also greatest in the manure-based chars. Overall, greater pyrolysis temperatures increased the pH level, except in cow-manure biochar, which stayed the same throughout. Steam activation only increased pH levels in the wood-feedstock biochar (Singh et al., 2010). Other data show that biochar from plants is not as nutrient-rich or as effective compared to biochar from animal wastes because of low nitrogen levels (Chan et al., 2008) in plants that do not already have large nitrogen concentration, such as in legumes.

When biochar is pyrolysed at low temperatures as opposed to high temperatures, biochar retains some of its organic matter, which increases the partitioning of organic molecules. The chars pyrolysed at low temperatures may have the ability to retain or control the release of some soil-applied herbicides (Li et al., 2013). In a study using poplar (Populus euramericana) branch biochar and 2, 4-D and acetochlor herbicides to test herbicide retention by char, the amount of 2,4-D leached after 12 days was reduced by 50% to 75%, and the leached amount of acetochlor was decreased by almost 75%, compared to a control, no-char group in a ferralitic red soil from Southern China (Li et al., 2013). The char used for the experiment had a greater content of organic matter and a more porous structure than some of the other chars considered for the experiment, which resulted in researchers using the char with the most internal space and sorption potential for the trial (Li et al., 2013).

Current research on biochar started partially because of the soils of the Amazon Basin. Amazon Basin Oxisols have problems with nutrient leaching, which can affect soil quality and groundwater purity. The major particles in the soil are clays with lower cation-exchange capacities that cannot keep organic matter from decomposing quickly and cannot secure
nutrients. The ancient farmers cultivating this land put a mix of soil amendments, including biochar and animal manure, into the soil to aid soil fertility (Laird et al., 2010a). The farmer-amended soils of the Amazon Basin are referred to as Terra Preta soils (Portuguese for “dark earth”) (Adams et al., 2013). Terra Preta soils have greater concentrations than surrounding soils in carbon, nitrogen, calcium, potassium, and potassium, and can recycle these nutrients throughout numerous growing seasons. The Terra Preta soils also display greater cation-exchange capacity, base saturation, phosphorus concentration, and pH levels compared to the surrounding soils (Laird et al., 2010a; Artiola et al., 2012).

More recent studies have determined what biochar can do for the soil, plant, and water ecosystem and what processes biochar affects the most. Generally, biochar keeps soil fertility high and may increase sequestration of carbon in the soil due to biochar’s relative stable nature and long turnover time (Chan et al., 2008). Biochar can support retention of nutrients and other organic material in the soil because of its porosity, large surface area (Collins et al., 2013), and areas of both polarization and no polarization (Laird et al., 2010a). Adding biochar to a sandy soil can improve soil moisture content and soil cation-exchange capacity because of biochar’s large surface area and large charge density (Uzoma et al., 2011). Biochar has an average cation-exchange capacity of 40 to 80 cmol kg$^{-1}$ (Collins et al., 2013). Biochar can also be used as a tool for bioremediation (Adams et al., 2013; Collins et al., 2013).

Biochar addition to soil has increased both plant growth and yield especially when nitrogen-based fertilizer is added contemporaneously (Kammann et al., 2010). One study conducted with peanut-hull biochar and quinoa (Chenopodium quinoa Willd) cultivated in a sandy soil showed that grain yield, water-use efficiency, and leaf nitrogen efficiency were all increased with the addition of biochar. The greatest water-use efficiency was at the intermediate
biochar application rate of 100,000 kg ha\(^{-1}\) (100 Mg ha\(^{-1}\)) with reduced water, showing that there is a point at which biochar application can be too high (Kammann et al., 2010). Another study conducted with cow-manure biochar’s influence on maize (\textit{Zea mays L.}) productivity and demonstrated that grain yield in this study was 150\% greater when 15,000 kg biochar ha\(^{-1}\) (15 Mg ha\(^{-1}\)) were applied to the soil compared to the control group of no added biochar. The height and number of leaves in the maize also increased when any amount of biochar was applied to the crop (Uzoma et al., 2011). However, in a study with potatoes (\textit{Solanum tuberosum}) treated with dairy-manure-effluent-treated biochar, non-amended biochar, or mono-ammonium-phosphate fertilizer, “Ranger Russet” potato biomass was larger in the dairy-effluent-treated-biochar treatment than the control or non-amended biochar treatments, which did not differ. Total and tuber biomass did not differ between the treatment with the largest rate of effluent-treated biochar and the mono-ammonium-phosphate treatment (Collins et al., 2013).

Biochar application can increase yield in various crops. Biochar increased rice (\textit{Oryza sativa}) yield increased in both cycles of a two-year study in China using multiple rates of wheat (\textit{Triticum aestivum L.}) straw biochar. Yield increase was greater in the second year (9-28\%) than the first year (9-12\%), but the yield was not linearly correlated with the rates of biochar application. The greatest yield was observed in the 10,000 kg ha\(^{-1}\) application rate and the 40,000 kg ha\(^{-1}\) (40 Mg ha\(^{-1}\)) application rate, rather than the intermediate application rate of 20,000 kg ha\(^{-1}\) (20 Mg ha\(^{-1}\)) (Zhang et al., 2012). Similar results were reported in a two-year trial with Romaine lettuce (\textit{Lactuca sativa}) and pine (\textit{Pinus}) wood biochar (Artiola et al., 2012). During the first year, the control treatment and the 2\%-by-volume biochar treatment yields did not significantly differ, however, both treatments produced greater yields than the 4\%-by-volume biochar treatments. In the second year, both the 2\%- and 4\%-by-volume biochar treatments
produced significantly greater yields than the control treatment. These results show that negative effects following an addition of fresh biochar are overcome and disappear after 2 to 3 months of soil wet-dry cycles (Artiola et al., 2012). An additional experiment with bermudagrass (*Cynodon dactylon*) and pine wood biochar showed that grass biomass was greatest in the 2%-biochar treatment, which was greater than the control and 4%-biochar treatment (Artiola et al., 2012).

After those measurements were taken, irrigation was halted on all pots. After a month, the 4%- and the 2%-biochar application rates had significantly greater biomass than the control. When irrigation resumed, the control pots had no living plants, the 2% biochar rate had approximately 50% growth, and the 4% biochar rate fully recovered from the period of water stress (Artiola et al., 2012). A three-year field trial with common ash (*Fraxinus excelsior* L.), beech (*Fagus sylvatica* L.), and English oak (*Quercus robur* L.) tree trunk biochar applied to a field planted in maize followed by hay showed an increase in foliar N content in the biochar-amended hay in year two, and a significant increase in hay biomass in the biochar amended treatments in year three (Jones et al., 2012). In a Chilean study using soybean (*Glycine max*) and quail litter biochar, soybean yield, number of pods per plant, and seeds per pod increased as biochar application rate increased until a 16,000 kg biochar ha\(^{-1}\) (1.6 kg m\(^{-2}\)) rate. The 20,000 kg biochar ha\(^{-1}\) (2 kg m\(^{-2}\)) rate produced lower yields, number of pods per plant, and seeds per pod than the 16,000 kg biochar ha\(^{-1}\) rate (Suppadit et al., 2012).

Biochar can increase shoot mass of rice compared to earthworm activity. In a study comparing the effect of biochar and earthworms on soil, biochar treatments increased the shoot mass of rice more than earthworm treatment or the control treatment (Noguera et al., 2012). Biochar also significantly increased the number of leaves on rice plants, where the earthworms did not (+87% versus 3%, respectively). Biochar was shown to increase the proteolytic activity,
where earthworms did not, and the biochar significantly increased the expression level of three out of six genes linked to protein catabolism and two of the genes linked to protein anabolism (Noguera et al., 2012). The increase in the number of leaves and increase in leaf turnover in the biochar treatment relates to faster protein turnover and therefore a faster pace in rice development compared to the control group (Nogura et al., 2012).

Biochar is a form of black carbon, which is an important carbon pool in North American prairies, comprising between 4 and 18% of the soil organic carbon (Adams et al., 2013). Fire deposits black carbon in the form of charred plant material into these prairie soils. In systems where fire is absent, this black carbon could be replaced by biochar. Evidence has shown that big bluestem (Andropogon gerardii Vitman) height, shoot dry weight, and leaf dry weight were greater in sandy soils amended with 1% and 2% loblolly pine (Pinus taeda) and switchgrass (Panicum virgatum) biochar than in the control group or sandy soils amended with 4% biochar, reinforcing the belief that biochar application can reach an optimum level, and application over that level is detrimental to plant growth (Adams et al., 2013). Biochar application to prairie systems could slow down the plant succession rate increased by human activity. The positive effect of biochar on growth of big bluestem shows that biochar could be an option to aid with prairie restoration (Adams et al., 2013).

Biochar has been shown to increase germination in wheat at low application rates, such as between 10,000 and 50,000 kg ha\(^{-1}\) (10 and 50 Mg ha\(^{-1}\), respectively). Greater application rates, such as those at 100,000 kg ha\(^{-1}\), had no effect and, in some instances, even decreased wheat germination rate, further showing that there are biochar application rates that can be detrimental for plant growth and development (Solaiman et al., 2012; Bargmann et al., 2013). In spring barley (Elyhordeum Mansf), all types of biochar treatments at 10% by volume char
produced barley grains that formed both cotyledons and radicles, where hydrochar inhibited germination. Hydrochars are carbon materials like biochars, however they are made through a process called hydrothermal carbonization (Bargmann et al., 2013). In a study comparing six different biochar extracts to nutrient solutions that corresponded to nutritional contents of biochars as solutions for corn germination, extracts of hardwood biochar had the same effects on seedling growth as a control group with just deionized water, while biochar produced from high temperature pyrolysis suppressed seedling growth. It is suspected that high temperature pyrolysis increases the amount or availability of polycyclic aromatic hydrocarbons in biochar. Polycyclic aromatic hydrocarbons have negative environmental and agronomic consequences (Rogovska et al., 2011).

Biochar has shown the capacity to reduce greenhouse gas emissions from the soil along with increased methane (CH₄) sequestration; however, data is varied in different studies. Methane sequestration increased but there was no decline in nitrous oxide (N₂O) emissions using birch (Betula pendula) biochar at an application rate of 9 Mg ha⁻¹ (Karhu et al, 2011). In a study in urine patches in a pasture using biochar at 67,259 kg ha⁻¹ (30 t/acre), an N₂O flux reduction of 50% was observed (Taghizadeh-Toozi et al., 2011). In a two-year trial in rice paddies in China with wheat straw biochar at three different rates and a control, the greatest N₂O emission reduction of 58% was measured in the first year and the intermediate biochar application rate of 20,000 kg ha⁻¹ (20 Mg ha⁻¹). In the other rates of biochar application, the second year had a greater N₂O emission reduction than the first year. However, in this same trial, CH₄ emissions increased with the addition of biochar (Zhang et al., 2012).

Beesley et al., (2013) mixed 30%-by-volume orchard-prune-residue biochar with arsenic-contaminated soil and tomato (Solanum lycopersicum L.) plantlets to determine the availability
and transfer of arsenic to tomatoes in biochar-fertilized soil. A week after the soil received no treatment, a biochar treatment, and a biochar plus fertilizer treatment, the pore-water concentration of arsenic was 5-fold greater in the biochar and biochar plus fertilizer treatments with plants, and 9-fold greater in the biochar and biochar plus fertilizer treatments without plants compared to the control with no biochar. However, the biochar-amended treatments reduced the arsenic concentration in the tomato plants. Using biochar as a bioremediation tool to fix arsenic in the soil reduces plant uptake, however, biochar makes arsenic more mobile in the soil, so precautions would need to be taken before biochar was applied (Beesley et al., 2013).

Biochar has been shown to stimulate bacterial and fungal growth in soil. Tree trunk biochar on a sandy clay loam increased bacterial growth from $47.6 \pm 6.9$ pmol leucine to $85.5 \pm 10.8$ pmol leucine in the biochar treatment (Jones et al., 2012). Fungal growth also increased by around 21% in the control treatment compared to the biochar treatment in the first two years of the study. Bacterial and fungal activity stimulation was no different by the third year of the trial between the control and the biochar treatments (Jones et al., 2012). In a study with wheat, radishes (*Raphanus sativus*), and nitrogen and biochar applications, 10,000 kg ha$^{-1}$ (10 t ha$^{-1}$) application was shown to increase soil microbial activity. Application of nitrogen fertilizer had no effect on microbial activity (van Zwieten et al., 2010).

Soil carbon has been shown to increase by up to 0.51% after two years of 9 Mg ha$^{-1}$ of poultry litter biochar application on forage fields grown in silt loam soils (Revell et al., 2012a). Poultry litter biochar applied at 10,000 kg ha$^{-1}$ (10 Mg ha$^{-1}$) increased soil carbon by up to 0.38% (Chan et al., 2007). Soil organic carbon was increased in a rice paddy in proportion to the rate of wheat straw biochar added (Zhang et al., 2012). An increase in total soil carbon was apparent in years two and three of a three-year study with maize and hay on a sandy clay loam using ash,
beech, and English oak tree trunk biochar (Jones et al., 2012). Laird et al. (2010a) reported soil potassium, magnesium, zinc, and calcium that leached from hardwood biochar amended soils increased with the level of biochar added to the soil columns, showing that with increased biochar, increased nutrients are added to the soil and those nutrients are at least partly mobile. In the same study, there was a large reduction in the levels of total dissolved phosphorus in the leachate in the biochar-amended soils after manure was added. In the manure with no biochar soil columns, 29% of the phosphorus from the manure leached, but in the columns with 20 g biochar kg⁻¹ soil, only 5% of the phosphorus leached, showing that biochar has the capacity to reduce phosphorus leaching and could be used as a bioremediation tool (Laird et al., 2010a). Less than 20% of the manure carbon was recovered; however, there was no loss of biochar carbon in the soil columns (Laird et al., 2010b). Uzoma et al. (2011) reported that soil carbon and nitrogen were increased in post-maize-harvest soils after applying cow manure biochar, and that soil carbon increased with biochar application rate.

Biochar can decrease soil bulk density and increase soil water-holding capacities. Zhang et al. (2012) showed that soil bulk density decreased in proportion to wheat straw biochar amendment rates. Fine-loamy Mollisols with hardwood biochar have been shown to have significantly lower bulk densities than a control group after 45 weeks of weekly rainfall event simulation (Laird et al., 2010a). Poultry litter biochar was shown to decrease bulk density linearly with biochar application in a sandy loam, but did not affect bulk densities in a silt loam (Revell et al., 2012b). However, the water-holding capacities of both the sandy-loam and silt-loam soil increased linearly with addition of the poultry litter biochar (Revell et al., 2012b). Water-holding capacities of pine-forest biochar ranged from 185% to 200%, which indicates that biochar can hold up to twice its weight in water (Artiola et al., 2012). In the same trial,
gravimetric soil moisture with biochar added increased from 18% in the control to 21 and 26% in 2%- and 4%- biochar treatments, respectively (Artiola et al., 2012). Laird et al. (2010b) reported soil columns treated with 55, 110, and 220 kg biochar ha$^{-1}$ (5, 10, and 20 g biochar kg$^{-1}$) retained 10, 12, and 15% more water than the control treatment, respectively. Sandy soils amended with cow-manure biochar were shown to have decreased field saturated hydraulic conductivity, implying increased water retention (Uzoma et al., 2011). Soils that can hold more water with the addition of biochar have the potential to increase crop yields when crops experience drought stress (Laird et al., 2010b).

Biochar has also been shown to increase soil pH, since most chars in the literature are alkaline in nature. In a trial with peppers (Capsicum annuum) and forages on silt loam with poultry-litter biochar, all field sites showed pH increases after two year of biochar additions (Revell et al., 2012a). Soil pH increased by an average of 0.19 units for each 1000 kg ha$^{-1}$ of biochar applied on forage sites and 0.15 units for each 1000 kg ha$^{-1}$ biochar applied on green pepper sites (Revell et al., 2012a). The use of biochar on acidic soils could have a positive effect on soil acidity especially if the soil will need liming anyway. Soil pH increased over a two-year trial in a rice paddy and increases were proportional to the rates of biochar applied (Zhang et al., 2012). Ash, beech, and English Oak tree trunk biochar raised soil pH as much as 0.32 units after two years in a sandy-clay-loam soil (Jones et al., 2012). Soil pH in columns treated with 220 kg biochar ha$^{-1}$ (20 g hardwood biochar kg$^{-1}$) soil increased almost 1 pH unit because the pH of the char was 8.2 (Laird et al., 2010b). Hass et al. (2011) studied alkaline poultry-manure biochar and its affect on acidic Appalachian soils compared to an industrial agricultural liming product in an eight week study. Both the biochar and the liming product increased soil pH, but after four weeks, the biochar’s soil pH increase plateaud, while the liming product increased until near the
end of the eight weeks. At rates of greater than 17 kg biochar ha\(^{-1}\) (20 g biochar kg\(^{-1}\)), soil pH increased with application rate and increased the most in the activated biochar treatments. Activated biochar is biochar that is slow pyrolysed then exposed to high temperature steam activation. However, the biochar with greatest soil pH increase would have to be applied at a rate 14-fold greater than what it was to raise soil pH to the level 2.55 kg ha\(^{-1}\) (3 g kg\(^{-1}\)) of liming product did (Hass et al., 2011).

Poultry-litter biochar is of special interest because of the amount of litter produced by poultry houses in the United States, and especially in northwest Arkansas. Every day, 4627 Mg of poultry manure are produced in chicken farms in Arkansas (Hishaw, 2006). Poultry litter has a large concentration of phosphorus and nitrogen, making poultry litter an ideal amendment to agricultural soils. Applying poultry litter directly onto agricultural fields, however, can lead to ammonia volatilization and phosphorus runoff. When nitrogen is deposited to the soil through wet or dry deposition, soil nitrogen 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 elevated levels 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 biochar, mass is reduced by 60%, and this reduces transportation costs of moving the phosphorus fertilizer to where the fertilizer is needed (Revell et al., 2012a; Kim et al., 2009), but the biochar also becomes a stable soil amendment with seemingly few to no hazardous effects. Poultry-litter biochar has been shown to increase soil pH, soil nutrients, water-holding capacity, and decrease soil bulk density
(Revell et al., 2012a). Radish yield has been shown to increase by 42% with the application of 10,000 kg poultry-litter biochar ha$^{-1}$ (10 Mg ha$^{-1}$) (Chan et al., 2007). Poultry-litter biochar has been researched, however, the effect poultry-litter biochar has on early cotton growth is lacking.

III. Research Objectives and Hypotheses

Research has shown that biochar can improve many aspects of growing conditions in the soil, and that poultry-litter biochar can be beneficial when pyrolysed, however, there is little research on biochar effects on cotton. Therefore, the objectives of this study were to assess the affect of biochar on cotton height, weight, and leaf area, and to observe whether there was a biochar-nitrogen fertilizer interaction. It was hypothesized that the non-biochar amended control groups would have the shortest height with the smallest dry matter weight and smallest leaf area, but plants receiving moderate amounts of biochar with additional fertilizer would have the greatest height, dry matter, and leaf area at time of harvest. It was also hypothesized that the largest rates of biochar application would be detrimental to cotton growth, as has been recorded in previous research.

IV. Materials and Methods

*Greenhouse experiment*

This study was conducted for eight weeks through October, November, and December 2012 in the greenhouse at the Rosen Center at the University of Arkansas. The study featured a randomized complete block design with three replications. Eighteen 2 L pots (approximately 9820 cm$^3$ volume) were filled with the same amount of dried soil, approximately 5.2 kg per pot. As soil was added to the pots, the biochar was incorporated. Six treatments were administered to
the plants. The treatments included 0 kg ha\(^{-1}\) poultry litter biochar with fertilizer (56 kg N ha\(^{-1}\)), 0 kg ha\(^{-1}\) poultry-litter biochar without fertilizer, 1500 kg ha\(^{-1}\) poultry-litter biochar with fertilizer, 1500 kg ha\(^{-1}\) poultry-litter biochar without fertilizer, 3000 kg ha\(^{-1}\) poultry-litter biochar with fertilizer, and 3000 kg ha\(^{-1}\) poultry-litter without fertilizer (Table 1).

**Table 1. Six Biochar and Fertilizer Treatment Combination Descriptions and Abbreviations**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control +F(^1)</td>
<td>No biochar – 56 kg ha(^{-1}) N (50 lb ac(^{-1}) N)</td>
</tr>
<tr>
<td>Control –F</td>
<td>No biochar – No fertilizer</td>
</tr>
<tr>
<td>Biochar 1 +F</td>
<td>1500 kg ha(^{-1}) biochar – 56 kg ha(^{-1}) N (50 lb ac(^{-1}) N)</td>
</tr>
<tr>
<td>Biochar 1 –F</td>
<td>1500 kg ha(^{-1}) biochar – No fertilizer</td>
</tr>
<tr>
<td>Biochar 2 +F</td>
<td>3000 kg ha(^{-1}) biochar – 56 kg ha(^{-1}) N (50 lb ac(^{-1}) N)</td>
</tr>
<tr>
<td>Biochar 2 –F</td>
<td>3000 kg ha(^{-1}) biochar – No fertilizer</td>
</tr>
</tbody>
</table>

\(^1\)F=Fertilizer

The soils were flushed by pouring water through the pots until water dripped out the bottom and drained to field capacity. After which, 10 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 pulled from the soil to remove the roots. Pots were well watered with approximately 200 mL water added daily. for the continuation of the study. Height of each plant was recorded weekly and plants were randomized on the greenhouse bench to avoid any biases. After 4.5 weeks, the nitrogen fertilizer urea (46-0-0, 56 kg ha\(^{-1}\) or 50 lb ac\(^{-1}\)) was applied and to the pots designated for additional fertilizer by pushing the individual urea prills into the soil.
Soil

The soil used in the experiment was Captina silt loam (Fine-silty, siliceous, active, mesic Typic Fragiudult), a common Arkansas soil with a history of cotton cropping that was obtained from the Arkansas Agricultural Research and Extension Center farm in Fayetteville, AR in September 2012. The soil was taken from the top 10-20 cm of the profile. The soil was dried in a greenhouse then sieved through a box sieve with approximately 1 cm mesh to remove rocks and large organic matter clumps.

Biochar

The biochar used in the experiment was composed of pyrolysed poultry litter. The poultry litter biochar was obtained from a local source, BioEnergy Systems LLC (Fayetteville, AR). The poultry-litter biochar was analyzed for chemical properties and nutrient composition. Biochar pH was determined using a 1:2 soil ratio. Nutrient concentrations were obtained through Mehlich 3 extractable on a 1:10 ratio. Concentrations of total recoverable metals were obtained through EPA method 3050 and total C and N by combustion. The results from a single analysis of biochar are shown in Table 2.
Table 2. Compositional analysis of BioEnergy Systems, LLC (BES) Biochar

<table>
<thead>
<tr>
<th>Measured Property (unit)</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>pH (pH units)</td>
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<tr>
<td>Electrical Conductivity (μmhos cm⁻¹)</td>
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<tr>
<td>P¹ (mg kg⁻¹)</td>
<td>7076</td>
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<td>K¹ (mg kg⁻¹)</td>
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<tr>
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<tr>
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<tr>
<td>%Total C³</td>
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¹pH (1:2 soil ratio), Mehlich 3 extractable (1:10 ratio) Analysis by SPECTRO ARCOS ICP
²Total Recoverable Metals, EPA method 3050, measured on Spectro Arcos ICP
³Total N and C by combustion, Elementar Variomax

Cotton Seed

The cotton cultivar Stoneville 5288 B2F was selected for planting. Stoneville 5288 B2F is one of the most widely grown cotton genotypes in Arkansas. For results to be beneficial for advancing agricultural practices in Arkansas, materials need to be well-representative of what is already being done in the state.

Measurements

After eight weeks of growth, the 18 plants were cut at the soil surface using a box cutter and immediately weighed for fresh weight. Their leaves were cut from the plant, and the leaf
area was measured using a LI-COR leaf area meter (LI-3100C Area Meter, LI-COR, Lincoln, NE). The plants including the cut leaves were then dried in an oven for 48 hours at approximately 100°C, and weighed again. Root systems of one replication from each treatment not receiving nitrogen fertilizer were removed and rinsed, then the root area was measured using a LI-COR leaf area meter and dried in an oven at approximately 100°C, then weighed.

*Statistical Analyses*

Data were analyzed using JMP 8.0 from SAS Inc (SAS Institute Inc., SAS Campus Drive, Cary, North Carolina). Treatment means were compared using the student’s t-test based on least significant differences. Differences judged were significant at $P < 0.05$.

**V. Results**

Cotton plant heights were significantly ($P < 0.05$) greatest in the biochar 2 + F treatment (27.52 cm) and least in the control groups with and without fertilizer which did not differ (Figure 1; Table 3). However, cotton height in biochar 2 + F treatment did not differ from the plants in the other treatments receiving biochar, with or without fertilizer applications (Figure 1; Table 3).

Cotton fresh weight was greater ($P < 0.05$) in the biochar 2 + F group (14.7 g) than the plants in the control +F, control –F, and biochar2 –F groups. Though, not significantly ($P > 0.05$), plants in the biochar 2 +F group had greater numerically greater fresh weight than those in the biochar1 +F and the biochar1 –F groups (Figure 2; Table 3).

Dry weight of the cotton plants was greatest ($P < 0.05$) in the biochar 2+F treatment (1.87 g) compared to the control treatments and the biochar 2 -F treatment. The biochar 2+ F dry weight was numerically greater than the biochar 1 treatments (Figure 3; Table 3).
The biochar 2 +F group had the largest leaf area (419.48 cm²) but did not differ \( (P > 0.05) \) than that from the biochar 1 +F or biochar 1 –F groups. However, the biochar 2 +F was significantly \( (P < 0.05) \) larger than the control +F group (176.31 cm²), which had the smallest leaf area, the control –F, and the biochar 2 –F groups (Figure 4; Table 3).

Root area numerically increased, however not significantly, as biochar application rate increased (Figure 5; Table 3). Root weight also numerically increased, however not significantly, by 123% and 143% in the biochar 1-F and the biochar 2-F treatment groups, respectively, compared to the control group (Figure 6; Table 3).

**VI. Discussion**

For 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, biochar can aid cotton growth and development. However, the biochar-nitrogen interaction was obvious because of the better performance in all the biochar +F groups than the control +F groups. The biochar 1 (low rate) groups had better growth than the control +F in for all properties measured, but did not grow as well as the biochar 2+F (high rate), which was also significantly greater in plant growth parameters than the control.

Plant height data in this study was both similar and different than that of Uzoma et al. (2011) with maize growth and cow-manure biochar on a sandy soil. The tallest plants resulted from an intermediate biochar rate of 5000 kg ha⁻¹ instead of the largest biochar application rate and the shortest plants from the control (no biochar) group (Uzoma et al., 2011). Results from this study indicated that the largest rate of 3000 kg ha⁻¹ resulted in the tallest plants of the three
rates used, but the biochar application rate had not reached the overload rate Uzoma et al. (2011) discovered in their study. However, in a study conducted with quinoa and peanut hull biochar on a sandy soil, results indicated that plant height was unchanged due to biochar treatment with reduced water supply (Kammann et al., 2011). Soybean showed the largest plant height response to 10,000 kg biochar ha\(^{-1}\) applied, which was a moderate amount of biochar (Yin et al., 2012). These data are contradictory to that of this study since in this study, tallest plants came from the largest biochar application rate; however, these studies used different plants species.

Studies of the relationship between dry weight and biochar application rate reported a large range of results and require further study. The results of Chan et al. (2007) from using radish and greenwaste biochar on an Alfisol, indicated that biochar alone did not increase radish dry weight, however, the largest rate of nitrogen added to all biochar treatments results in significant increases in radish dry weight, confirming the biochar-nitrogen interaction again (Chan et al., 2007). However, a year later, Chan (2008) conducted another study with poultry-litter biochar and radishes, and the results indicated that even without nitrogen, biochar increased dry weight, even at the lowest rate (Chan et al., 2008). The differences between greenwaste and poultry litter biochar could be the difference between these two study results (Chan et al., 2008). When van Zwieten et al. (2010) added biochar and nitrogen fertilizer to wheat, it was reported that maximum biomass accrued with a moderate biochar application rate of 2.2% by weight and largest nitrogen fertilizer rate of 177 kg N ha\(^{-1}\), and at low rates of nitrogen application, adding more biochar had a positive impact on growth. In the current research, the largest biochar fertilizer rate with nitrogen produced the greatest dry weight. In the same set of experiments by Chan et al. (2008), it was shown that radish plants took up more nitrogen when biochar was added than in the control treatment. In fact, that study concluded that it was possible to reduce
nitrogen fertilizer inputs by up to 90% while achieving the same crop response if biochar was applied (van Zwieten et al., 2010). The present research showed that the biochar –F groups did not experience significant differences between biochar application rates, but biochar +F groups did, confirming a nitrogen-biochar interaction in cotton seedlings.

A study conducted with quinoa and peanut hull biochar on a sandy soil indicated that biochar application significantly increased leaf area both with a sufficient as well as a reduced water supply (Kammann et al., 2011). A study with rice and biochar on an Inceptisol showed that the biochar treatment significantly increased number of leaves compared to treatments of earthworms and a control, but treatments with earthworms and biochar and only earthworms had the largest foliar area (Nogura et al., 2012). Soybean leaf area increased in all treatments of quail-litter biochar at various stages in soybean development. The treatment resulting in the largest leaf area was the 16,000 kg biochar ha\(^{-1}\) (Suppadit et al., 2012), however, in this study, results 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.

Root area and dry weight numerically increased as biochar application rate increased in this study. In a study by Yin et al. (2012), various rates of peanut hull biochar increased soybean root dry weight, main root length, lateral root number and lateral root length in each stage of development tested. The largest root dry mass in the V3, R2, and R7 stages occurred at the biochar rate of 15 Mg ha\(^{-1}\) applied. The most lateral roots occurred at 10,000 and 20,000 kg ha\(^{-1}\) in the V3 stage, and at 15,000 kg ha\(^{-1}\) in the R7 stage. There was little statistical difference in the R2 stage across biochar treatments (Yin et al., 2012). The 10,000, 15,000, and 20,000 kg ha\(^{-1}\) in the Yin et al. (2012) were all intermediate biochar application rates and resulted in the largest
root weight and area. The current research observed that largest root weight and area came from the highest biochar application rate, not the intermediate biochar application rate.

Future research should include a larger field trial with the same biochar application rates. Field trials would more accurately represent how biochar could affect crop response for farmers. Future research could also compare poultry-litter biochar to differing sources of biochars that have been shown to increase crop yields, such as wheat straw and pine wood (Zhang et al., 2012; Artiola et al., 2012). In a study using potatoes and biochar, some of the biochar was treated with anaerobic digested dairy manure effluent (Collins et al., 2013). The effluent-treated biochar increased biomass of potatoes and increased the phosphorus concentration of the biochar (Collins et al., 2013). Manure outputs in the United States from cattle, dairy, and swine contains 2.3 Tg of phosphorus, which is more than the current amount of phosphorus applied as commercial fertilizers. Using the manure to treat biochar after having the manure anaerobically digested instead of applying the manure straight to agricultural fields reduces environmental odor, greenhouse gas emissions, and gives an alternative use of the fiber to reduce solid waste (Collins et al., 2013). Treating the biochar used in the current experiment with dairy-manure or poultry-manure effluent could provide even more phosphorus than the biochar alone. Greenhouse and field trials with more biochar and nitrogen fertilizer application rates are also needed to learn the optimum rate of biochar application for the poultry-litter biochar and soil present in Arkansas for local crops. Many studies have shown that maximum crop production is accomplished with moderate biochar application rates (van Zwieten et al., 2010; Kammann et al., 2010; Adams et al., 2013). Finding the rate that optimizes crop production without exceeding the threshold limit will be crucial in making biochar a viable fertilizer and amendment option. Finally, there is a lack of knowledge about the long-term effects and behavior of biochar in the soil, so more multi-
year studies are needed to fully understand how biochar will react years after application (Jones et al., 2012).

VII. Summaries and Conclusions

In summary, the data indicated that the largest rate of level biochar +F had significantly ($P < 0.05$) greater plant height, fresh weight, dry weight and leaf area compared both controls. The biochar 2 +F treatments also had significantly ($P < 0.05$) greater fresh weight, dry weight, and leaf area compared to the largest biochar treatment without fertilizer. The hypothesis that the intermediate rate of biochar would be conducive for best crop growth was incorrect. Based on the results of this research, a full-scale, season long, multi-year study of the influence of biochar on cotton growth and development is necessary and warranted. Findings from this research implicate that the large amounts of poultry litter produced in Arkansas could by pyrolysed into poultry-litter biochar and could be used in the agricultural regions of Arkansas as an alternative to costly annual soil amendments.

Acknowledgements

Thanks to BioEnergy Systems LLC for use of their biochar for this project. Mr. John Guerber at the Rosen Alternative Pest Control Center on the University of Arkansas campus helped establish the greenhouse experiment, and James Burke, an M.S. student studying with Dr. Oosterhuis, aided in soil acquisition. Dr. Dimitra Loka conducted statistical analyses for this experiment.
Literature Cited


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**Tables and Figures**

**Table 3. Effect of poultry-litter biochar on cotton growth after eight weeks**

¹F=Fertilizer
² Values within columns not sharing a common letter are significantly different (P < 0.05)
Figure 1. Effect of biochar and fertilizer treatments on average height (cm) of cotton after eight weeks of growth. Columns not sharing a common letter are significantly different (P<0.05)

Figure 2. Effect of biochar and fertilizer treatments on average fresh weight (g) of cotton after eight weeks of growth. Columns not sharing a common letter are significantly different (P<0.05)
Figure 3. Effect of biochar and fertilizer treatments on average dry weight (g) of cotton after eight weeks of growth. Columns not sharing a common letter are significantly different (P<0.05)

Figure 4. Effect of biochar and fertilizer treatments on average leaf area (cm²) of cotton after eight weeks of growth. Columns not sharing a common letter are significantly different (P<0.05)
Figure 5. Effect of biochar treatments on root area (cm²) of cotton after eight weeks of growth.

Figure 6. Effect of biochar treatments on root weight (g) of cotton after eight weeks of growth.