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Biochar and Nitrogen Effects on Winter Wheat Growth

T. E. Zee
Kansas State University, tessazee@ksu.edu

N. O. Nelson
Kansas State University, nonelson@ksu.edu

G. Newdigger
Kansas State University, gnewdigg@ksu.edu

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Abstract

Biochar, a co-product of thermochemical bioenergy production, may be a valuable soil amendment, but little is known about its potential long-term effects on plant growth and soil fertility. In order to gain more information, this experiment was performed to see if the addition of biochar, in comparison to lime and fertilizer treatments, has the potential to return key nutrients back to the soil or increase crop yield. A field study to investigate the effects of biochar on plant growth was initiated in 2011 near St. John, KS. Treatments included biochar applied at 16.6 ton/a (biochar), lime and annual applications of phosphorus and potassium fertilizer (lime+P&K), and a control. Four rates of nitrogen (N) fertilizer were applied within each treatment (0, 45, 90, and 135 lb N/a). Winter wheat was planted in 2015 and harvested in 2016. The biochar treatment had greater wheat yield and better plant growth than the control but it was similar to the lime+P&K treatment. The greater yields from the biochar and the lime+P&K were likely due to increased soil pH from the lime and biochar. Biochar appears to be an effective method of supplying phosphorus (P), potassium (K), and increasing soil pH, and there was no effect on nitrogen availability.

Keywords

biochar, nitrogen, lime, soil pH, winter wheat

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T.E. Zee, N.O. Nelson, and G. Newdigger

Summary

Biochar, a co-product of thermochemical bioenergy production, may be a valuable soil amendment, but little is known about its potential long-term effects on plant growth and soil fertility. In order to gain more information, this experiment was performed to see if the addition of biochar, in comparison to lime and fertilizer treatments, has the potential to return key nutrients back to the soil or increase crop yield. A field study to investigate the effects of biochar on plant growth was initiated in 2011 near St. John, KS. Treatments included biochar applied at 16.6 ton/a (biochar), lime and annual applications of phosphorus and potassium fertilizer (lime+P&K), and a control. Four rates of nitrogen (N) fertilizer were applied within each treatment (0, 45, 90, and 135 lb N/a). Winter wheat was planted in 2015 and harvested in 2016. The biochar treatment had greater wheat yield and better plant growth than the control but it was similar to the lime+P&K treatment. The greater yields from the biochar and the lime+P&K were likely due to increased soil pH from the lime and biochar. Biochar appears to be an effective method of supplying phosphorus (P), potassium (K), and increasing soil pH, and there was no effect on nitrogen availability.

Introduction

Thermochemical methods of bioenergy production, such as pyrolysis and gasification, can be used to convert biomass feedstocks (such as crop residues, wood chips, or other bio-based products) into advanced biofuels. These processes produce a high carbon (C) by-product, biochar, that contains many of the nutrients in the original feedstock. Land application of biochar could improve crop growth by returning P, K, and other nutrients to the soil. There is evidence that biochar can improve soil properties such as increased water holding capacity and increased soil pH. The high C in the biochar could reduce N availability through immobilization. The goal of this study is to determine the effects of biochar application on winter wheat growth and production, soil nutrient availability, and crop nitrogen response.

Procedures

A field study was conducted at the Sandyland Experiment Field near St. John, KS. The soil series is mapped as a Carwile fine sandy loam (0 to 1% slopes); initial soil analysis is listed in Table 1. The experiment was a split-block study with whole-plot treatments consisting of a control (no lime, P, or K applied), a lime+P&K treatment (lime plus annual applications of 92 lb P_2O_5/a and 193 lb K_2O/a), and a biochar treatment (single application of 16.6 ton/a). Sub-plot treatments were 0, 45, 90, and 135 lb/a N. Treatments were replicated three times.

Biochar from the gasification of wheat middlings was applied at 16.6 ton/a (dry weight) to the biochar treatments and ag-lime was applied to the lime+P&K whole-plots at 1,150 lb/a effective calcium carbonate (ECC) on April 5, 2011. Biochar properties are listed in Table 2. Biochar and lime were incorporated with two passes of an offset disk on the day of application. Forage sorghum was grown on the plots for the 2011, 2012, 2013, and 2014 growing seasons (with 0, 54, 107, and 161 lb/a N as annual N rates). On October 9, 2015, Antero hard white winter wheat was planted. The wheat was harvested on June 17, 2016. Soil samples were collected at 0 to 6, 6 to 12, and 12 to 24 in. deep from every subplot in July 2016.

Results

There was a significant treatment by N-rate interaction for soil pH (Table 3). Soil pH was greater in the biochar and lime+P&K treatments compared to the control and soil pH declined with increasing N rate (Figure 1). However, increasing N rate decreased soil pH more in the control than in other treatments. Soil test P, K, and total carbon were only affected by the whole plot treatment (Table 3), where biochar increased P, K, and carbon (C) concentrations in the soil (Figure 2).

There was a significant interaction between the whole plot treatment and nitrogen rate for both plant height and yield (Table 3). Plant height increased to a maximum at 90 lb N/a. Plant height decreased at 135 lb N/a for the control, but not for other treatments (Figure 3). Grain yield in biochar and lime+P&K treatments followed a typical nitrogen response, increasing to 90 lb N/a followed by plateau (Figure 4). However, grain yield for the control decreased at nitrogen rates above 45 lb N/a. In general, lime+P&K resulted in wheat yields similar to when biochar was applied.

The control treatment had low wheat yield at high N rates due to soil acidification. The treatment by N-rate interaction indicates that growth-limiting factors are present for the control at high N rates that are not present for the biochar and lime+P&K treatments. Biochar and lime+P&K treatments had a greater soil pH than the control. It is likely that the low pH in the control, especially at high N rates, resulted in poor wheat yields. The liming effect of the biochar and the lime application in the lime+P&K treatment increased pH and maintained a higher pH at high nitrogen rate thus maximizing yield.

Although there are treatment effects on soil P, K, and C (Figure 2), these differences do not explain the treatment by N rate interaction observed for wheat yield. Soil test P concentrations are all above the critical level of 20 parts per million (ppm). Although control soils have lower extractable K, it is still above the critical level of 130. Biochar from gasification is an effective method of increasing soil pH, P, and K; resulting in wheat yield similar to that obtained with conventional lime, P, and K fertilizers.

Table 1. Soil analysis prior to biochar application (2011)

Cation exchange capacity	pH	Total carbon	Total nitrogen	Mehlich 3 phosphorus	Extractable potassium	Extractable calcium	Extractable magnesium
meq/100 g		------------ % ------------		------------------------------ ppm ------------------------------			
5.2	5.2	0.4	0.04	34	102	326	48

Table 2. Physical and chemical analysis of biochar co-produced from gasification of wheat middlings

Property	Result	Units
Volatile matter	17.8 ±1.4	%
Ash	23.1 ±0.9	%
Cation exchange capacity	28.4 ±5.4	meq/100 g
Carbon	63.5 ±6.1	%
Hydrogen	1.04 ±0.12	%
Nitrogen	4.00 ±0.29	%
Sulfur	0.25 ±0.02	%
Phosphorus	1.23 ±0.33	%
Water extractable phosphorus	41 ±9	% of total P
Potassium	1.11 ±0.25	%
Calcium	0.19 ±0.05	%
Magnesium	0.43 ±0.15	%
Iron	240 ±63	ppm
Zinc	119 ±24	ppm
Copper	24 ±16	ppm
Manganese	144 ±41	ppm

Table 3. Results from analysis of variance (*P*-values)

Effect	Plant height	Yield	pH	Mehlich 3 phosphorus	Extractable potassium	Total carbon
Treatment (whole plot)	0.017	0.006	0.126	<0.001	<0.001	<0.001
Nitrogen rate (sub plot)	<0.001	<0.001	<0.001	0.057	0.147	0.842
Treatment by nitrogen rate	0.046	<0.001	0.030	0.242	0.610	0.997

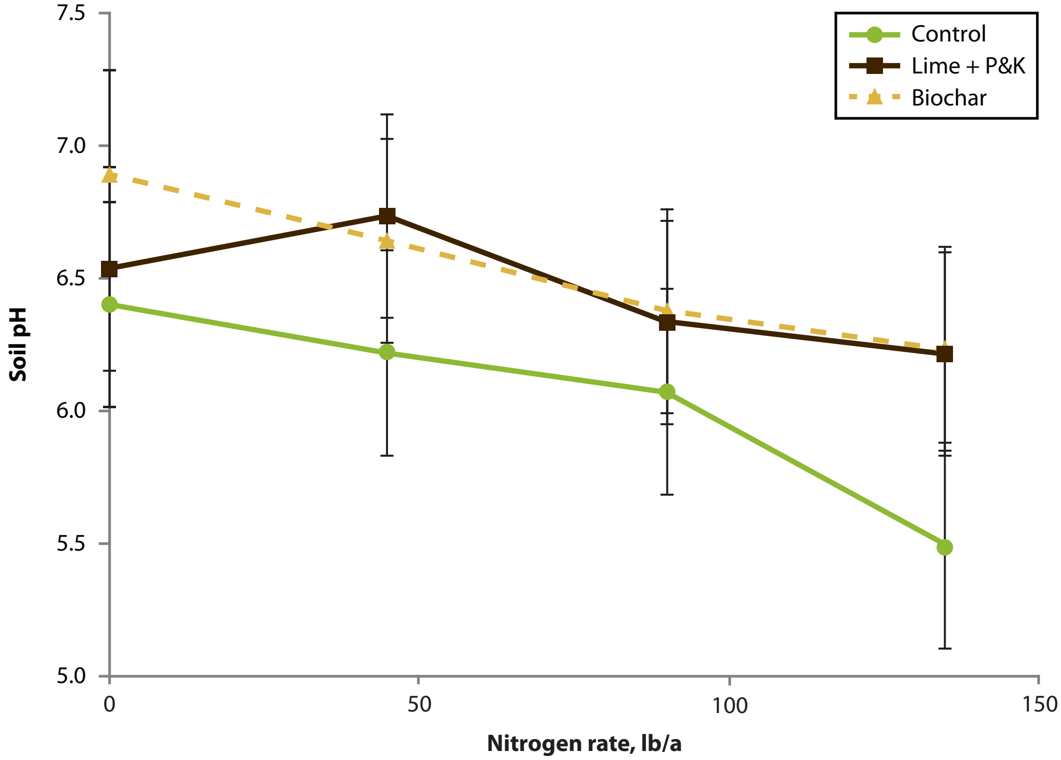

Figure 1. Soil pH response to nitrogen application for control, lime+P&K, and biochar treatments. Error bars indicate the 95% confidence interval for means.

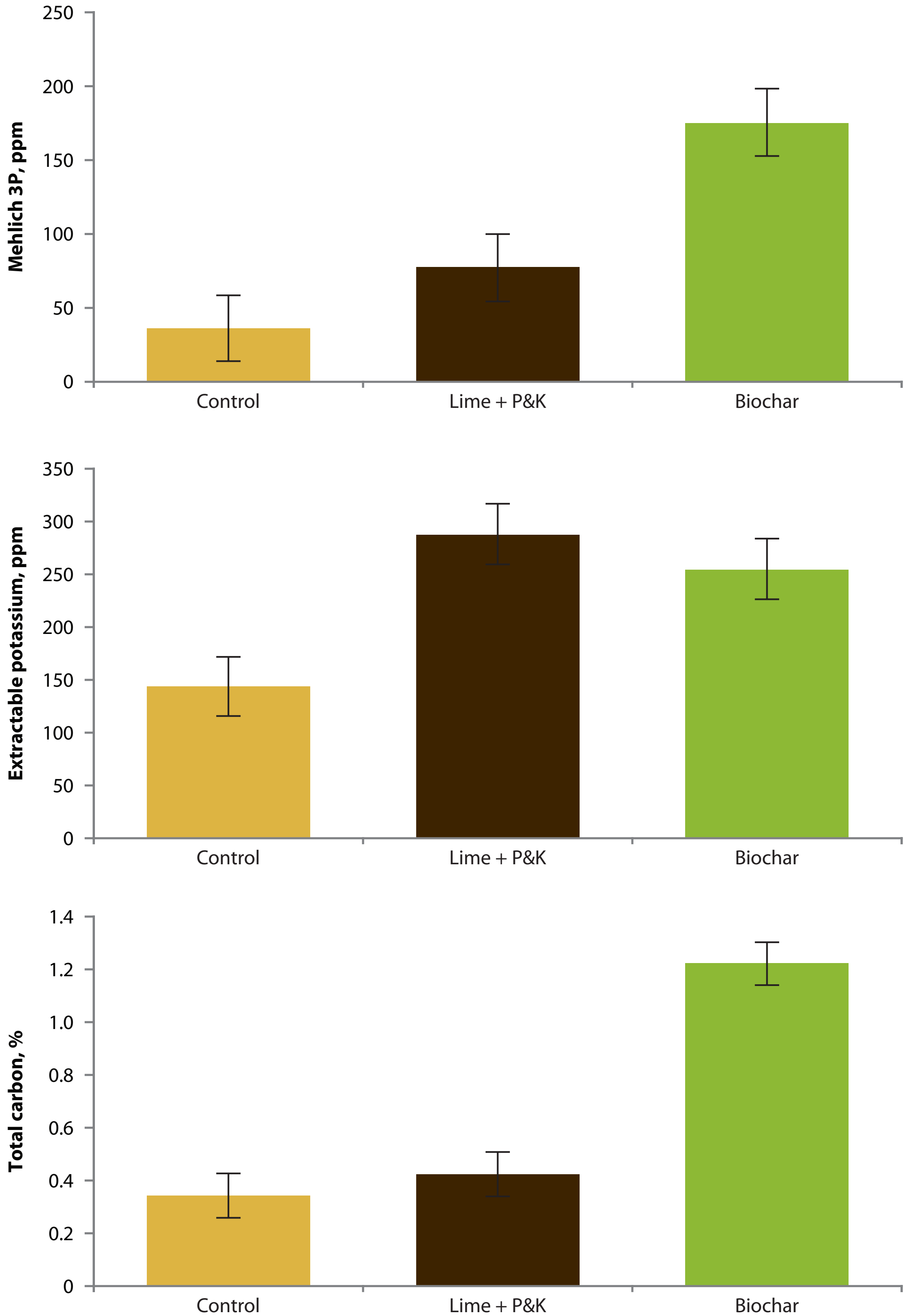

Figure 2. Mehlich 3P, extractable potassium (K), and total carbon (C) levels present in the control, lime+P&K, and biochar treatments. Error bars indicate the 95% confidence interval for means.

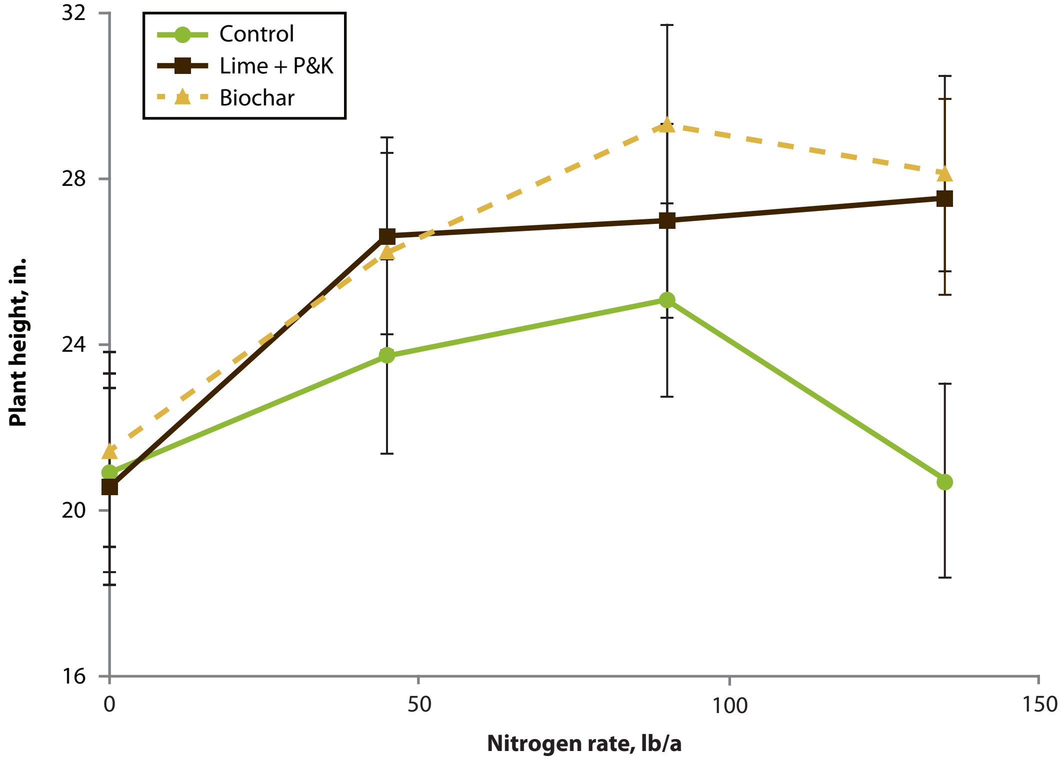

Figure 3. Wheat height response to nitrogen application for control, lime+P&K, and biochar treatments at Feekes growth stage 5. Error bars indicate the 95% confidence interval for means.

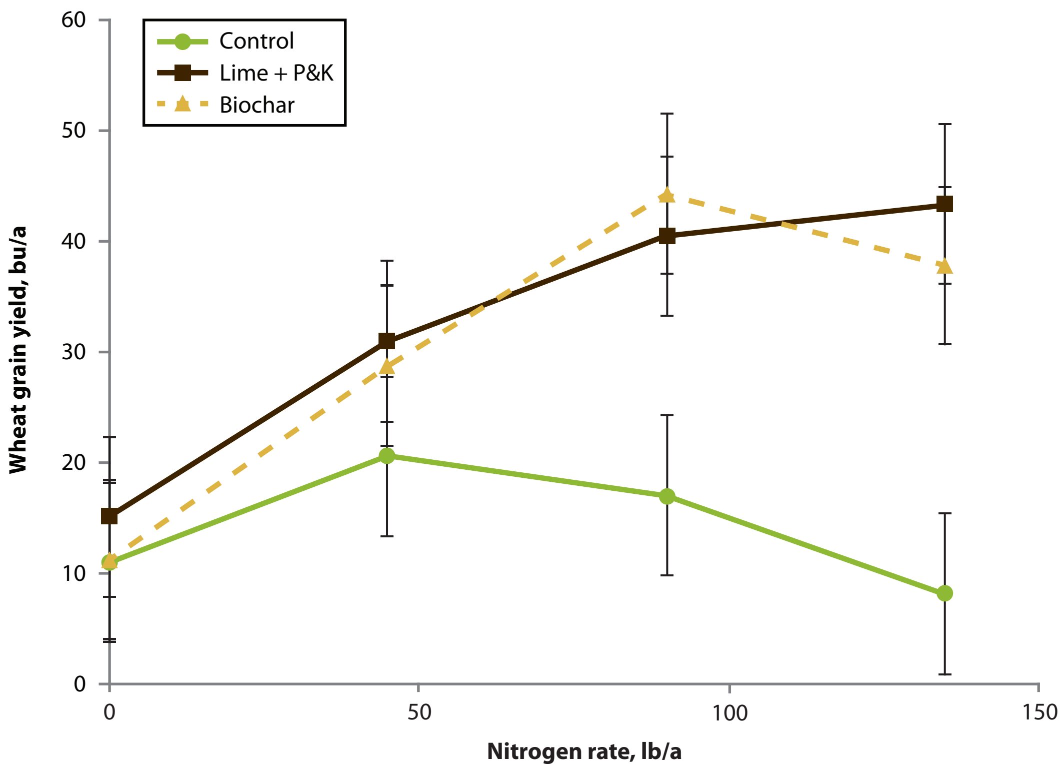

Figure 4. Wheat grain yield to nitrogen application for control, lime+P&K, and biochar treatments. Error bars indicate the 95% confidence interval for means.