INNSPUB

International Journal of Agronomy and Agricultural Research (IJAAR)
ISSN: 2223-7054 (Print) 2225-3610 (Online)
http://www.innspub.net
Vol. 12, No. 3, p. 46-51, 2018

RESEARCH PAPER OPEN ACCESS

Effect of biochar on maize yield and yield components in rainfed conditions

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Article published on March 30, 2018

Key words: Biochar, Wheat straw, Sugarcane bagasse, Maize yield, Rainfed.

Abstract

To investigate the maize yield and nutrient concentration in its leaves as affected by biochar from different organic materials (wheat straw and sugarcane bagasse), a field experiment was conducted on maize crop during 2013 at koont research farm chakwal. The treatments were control, wheat straw biochar at 5t ha^{-1}, and 10t ha^{-1}, sugarcane bagasse biochar at 5t $ha^{-1}$and 10t ha^{-1}. The experiment was conducted in RCBD. Maize was grown in 4m × 6m sized plots. Soil samples were taken before sowing of crop for determination of soil pH, electrical conductivity, total organic carbon and texture. The plant parameters were grain yield, plant biomass, macro nutrients and micro nutrients. Wheat straw biochar 10 t/ha showed an increase of 16.1% N, 38.8% P, 33% K, 28.9% biomass and 20.8% grain yield. Sugarcane bagasse biochar at a rate of 10 t/ha showed significant increase of 14.9% N, 27.7% P, 30% K, 27.6% biomass and 22.1% grain yield. None of the biochar treatment showed any significant increase in micronutrient concentration in plant.

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Introduction

Modern world facing some great and alarming problems, are climate change, increase in human population, shortage of food and waning of food reserves (Lehmann and Joseph., 2009). Scientists have warned that this climate change will severely affect the areas of low rainfall i.e. arid and semi-arid regions, where yield of primary foods (maize, wheat and pulses) will decrease considerably (Chan and Xu., 2009). To minimize the effect of this climate change to agricultural soils and crop production biochar has been introduced since last two decades (Laird.,2008; Lehmann and Joseph., 2009). When biochar is applied to the soil, its health is improved in terms of increased water retention, sorption capacity, nutrients availability, plant growth, carbon sequestration and less runoff and leaching (Laird, 2008). Biochar made from different sources and at different temperatures have different chemical composition (Lehman *et al.,* 2011).

Most of the oxygen and hydrogen present in organic matters, are lost when subjected to pyrolysis. On the other hand, Biochar is much more stable carbon contents than original organic matter. (Keiluweit., 2010). By using biochar as soil amendment, CO_2 emission can be reduced in atmosphere, which helps mitigating global warming (Lehman., 2007) Biochar contain almost all plant nutrients but their concentration may vary depending on the type of parent material beside nitrogen, all other nutrients are retained in biochar after pyrolysis (Chan and Xu., 2009). Chan *et al.* (2007) observed that plant nutrient uptake and availability of elements such as phosphorus, potassium and calcium are typically increased, while free aluminum is decreased in solution in biochar-amended soils. Chan *et al.* (2008) recorded yield increase of 42% at 10t/ha and up to 96% at 50t/ha biochar application. In a study on nutrient management and biochar application, statistically a higher first year rice yield was observed only when nitrogen fertilizer was applied with biochar (Asai *et al.*, 2009). When biochar was added to the soil did not show any significant increase on maize yield in first year. While in next three years in same field without further biochar application maize yield increased 28,30 and 140% respectively (Major *et al.*, 2010). Biochar at the rates of 20 and 40t/ha with nitrogenous fertilization on maize showed 5.8% and 7.3% increase in yield respectively, while with the same rates of biochar when nitrogen is added, an increase of 8.8% and 12.1% respectively was observed (Zhang *et al.*, 2011). Northern part of Pakistani Punjab is known as Potohar region which lies between 32.5°N to 36.00°N latitude and from 72E to 74E longitude and falls into semi-arid and humid climate (Chaudry and Rasul., 2004). Crops grown here in summer are groundnut, bajra, maize and sunflower. And winter crops are wheat, barley and gram. Which mainly depends on rainfall (Chaudry *et al.,* 2004).

Materials and methods

Biochar Production

For biochar production two types of organic wastes i.e. Sugarcane bagasse and wheat straw were collected and used. Air dried materials were placed in a locally made biochar production tank. After grinding, material was placed. After 3 hours of heat supply to tank on a temperature of about 300-350°C biochar was collected and stored in plastic bags.

Field Experiment

Soil and plant samples from each plot were collected for basic chemical properties of soil (pH, electrical conductivity, total organic carbon, soil texture) and nutrients (nitrogen, phosphorus, potassium, zinc, iron, manganese and copper) in plant samples. All the analytical work was carried out in soil chemistry Lab and central Lab of Arid agriculture university Rawalpindi.

Plant Analysis

Digestion for Plant Nitrogen and Phosphorus

After washing and drying when Plant leave samples were ready, 0.2 gram of sample was taken for digestion. The method used was developed by Anderson and Ingram (1993). In which color is developed for total N and total P. Absorbance was measured using a spectrophotometer at 665nm and 880nm for N and P respectively. Plant Potassium and Micronutrients (iron, zinc, copper and manganese). Plant Micronutrients (iron, zinc, copper and manganese) were analyzed by Atomic Absorption

Spectrometer and potassium by flame photometer after dry-ashing and making a solution of the samples (Chapman and Pratt., 1961).

Plant Growth

The crop was harvested from 1m² area from each plot randomly. Plants were oven dried for 48 hours at 65°C. Dry weight of plants were recorded and this total biomass yield was converted to tons ha^{-1}**.** The sample plants collected from 1m² were threshed manually to determined grain yield. Grains obtained from each plot were weighed and the yield was converted to tones ha^{-1}.

Statistical Analysis

The experimental design was two factors factorial. The data collected were analyzed statistically Randomized Complete Block Design and means were compared at 5% level of significance (Steel *et al.,* 1997).

Results and discussion

Biochar effect on nutrients in maize plant

Plant Nitrogen

Different biochar treatments effect on nitrogen concentration is shown in table 2. The maximum nitrogen concentration was observed in treatment soil treated with wheat straw biochar at 10t/ha having 1.013% followed by 1.00% in the treatment soil treated with wheat straw biochar at 10 t/ha. Treatment sugarcane bagasse 10t/ha and wheat straw biochar 10t/ha were significantly different from control. The minimum nitrogen concentration 0.86% was observed in treatment control. The nitrogen uptake from the soils amended with biochar is low and an additional nitrogen fertilizer is needed to fulfill the crop nitrogen needs (Asai *et al.*, 2009). Chan and Xu (2009) observed greater yield response per unit of mineral fertilizer used, while Chan *et al.* (2007) concluded in their experiment a significant nitrogen content with greater biochar rates applied.

Plant Phosphorus

Different biochar treatments effect on phosphorus concentration is shown in table 2. The maximum phosphorus concentration was observed in treatment soil treated with wheat straw biochar at 10t/ha having 0.25% followed by 0.23% in the treatment soil treated with wheat straw biochar at 10 t/ha. Treatment sugarcane bagasse 10 t/ha and wheat straw biochar 10 t/ha were significantly different from control. The minimum phosphorus concentration 0.18 % was observed in treatment control. Plants growing in phosphorus-deficient soils develop thicker rhizosphere because of longer root hair growth, which increases soil volume exploration and thus increases phosphorus uptake (Bruun *et al.*, 2012). As P is retained by biochar when subjected to pyrolysis (Kloss *et al.,* 2012), biochar made from eucalyptus wood showed positive effect on availability of P (Petter *et al.*, 2012).

Plant Potassium

Effect of different biochar treatments on potassium concentration is shown in table 2. The maximum potassium concentration was observed in treatment soil treated with wheat straw biochar at 10 t/ha having 3.10% followed by 3.03% in the treatment soil treated with sugarcane bagasse biochar at 10 t/ha. Treatment wheat straw biochar 10 t/ha and sugarcane bagasse 10 t/ha were significantly higher from control. The minimum potassium concentration 2.33% was observed in treatment control. Biochar are high in plant available potassium, because potassium is not volatile at temperatures up to 700°C (Naeem *et al.*, 2014). All the potassium is retained in biochar, so biochars have a greater amount of K than original source (Ro *et al.,* 2009).

Table 2. Comparative effect of different biochar at different rates on macronutrients concentration in plant.

Treatments	N	P	K
	----------%----------		
Control	0.87b	0.18d	2.33d
Wheat Straw Biochar 5t ha^{-1}	0.98a	0.22bc	2.89b
Wheat Straw Biochar 10t ha^{-1}	1.01a	0.25a	3.10a
Sugarcane Biochar 5t ha^{-1}	0.94ab	0.21c	2.64c
Sugarcane Biochar 10t ha^{-1}	1.00a	0.23b	3.03ab

Zinc content in plant

Effect of different biochar treatments on zinc concentration is shown in table 3. The maximum zinc concentration was observed in treatment control

having 17.6mg /kg followed by 17mg /kg in the treatment soil treated with wheat straw biochar at 10 t/ha. All the treatments were non-significant to each other. The minimum zinc concentration 15.6mg /kg was observed in treatment sugarcane biochar at 10 t/ha. Leaf zinc concentrations in seedlings were not affected by the treatment of biochar application (Dharmakeerthi *et al.,* 2012). Biochar limits the bioavailability of heavy metals (Park *et al.*, 2011).The study conducted by Novak *et al.* (2009) on pecan shell biochar showed that the extractable zinc slightly decreased from 13mg kg^{-1} to 10mg kg^{-1} with a raise in the adding up of the biochar concentration. This demonstrated that biochar had an elevated sorption capacity for the zinc.

Copper content in plant

Effect of different biochar treatments on copper concentration is shown in table 3. The maximum copper concentration was observed in treatment control having 2.36mg /kg followed by 2.23mg /kg in the treatment soil treated with wheat straw biochar at 5t/ha. All the treatments were non-significant to each other. The minimum copper concentration 2.1mg /kg was observed in treatment soil treated with sugarcane biochar at 10t/ha. Biochar limits the bioavailability of heavy metals (Park *et al.*, 2011). This demonstrated that biochar had an elevated sorption capacity for the Cu.

Manganese content in plant

Effect of different biochar treatments on manganese concentration is shown in table 3. The maximum manganese concentration was observed in treatment control having 56.3mg /kg followed by 54mg/kg in the treatment soil treated with sugarcane bagasse biochar at 5t/ha. All the treatments were non-significant to each other. The minimum manganese concentration 50mg/kg was observed in treatment soil treated with sugarcane biochar at 10 t/ha. Biochar limits the bioavailability of heavy metals because of its high sorption capacity (Park *et al.*, 2011).

Iron content in plant

Effect of different biochar treatments on iron concentration is shown in table 3. The maximum iron concentration was observed in treatment control having 41.3mg/kg followed by 54mg /kg in the treatment soil treated with wheat straw biochar at 5 t/ha. All the treatments were non-significant to each other. The minimum iron concentration 35.6mg /kg was observed in treatment soil treated with sugarcane biochar at 5t/ha. Leaf iron concentrations in both seedlings and scions were not affected by the treatment of biochar application (Dharmakeerthi *et al.,* 2012). Biochar limits the bioavailability of heavy metals (Park *et al.*, 2011).

Table 3. Comparative effect of different biochar at different rates on micronutrients in plant

Treatments	Cu	Zn	Fe	Mn
	---------mg/kg---------			
Control	2.367 a	17.67 a	41.33 a	56.33 a
Wheat Straw Biochar 5 t ha^{-1}	2.233 a	16.33 a	38.33 ab	51.33 a
Wheat Straw Biochar 10 t ha^{-1}	2.200 a	17.00 a	36.67 b	51.00 a
Sugarcane Biochar 5 t ha^{-1}	2.233 a	16.33 a	35.67 b	54.00 a
Sugarcane Biochar 10 t ha^{-1}	2.100 a	15.67 a	36.00 b	50.00 a

Effect Of Biochar On Maize Yield And Biomass

Grain Yield

Effect of different biochar treatments on grain yield is shown in table 4. The maximum grain yield was observed in treatment soil treated with sugarcane biochar at 10t/ha having 3.85t/ha followed by 3.82t/ha in the treatment soil treated with wheat straw biochar at 5 t/ha. The minimum grain yield 3.16t/ha was observed in treatment control. If biochar is applied to a soil with characteristics as high sand content, low CEC, as the soil used the pot trial, biochar might enhance these properties (Yuan & Xu., 2011) as well as water holding capacity (Karhu *et al.*, 2011). Hence, the soil will be more suitable for plant growth and yield. Raj kovich (2010) demonstrated a minor increase in yield with biochar from maize Stover's even though a high C/N ratio, which indicates that other factors may have influence on plant growth, e.g. nutrient concentration and production conditions (Lehmann and Joseph., 2009).

Biomass

Different biochar treatments effect on biomass is shown in table 4. The maximum biomass was observed in treatment soil treated with wheat straw

biochar at 5t/ha having 32.6 t/ha followed by 32.3 t/ha in the treatment soil treated with sugarcane biochar at 10t/ha. The minimum biomass 25.3t/ha was observed in treatment control.

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Table 4. Comparative effect of different biochars at different rates on plant biomass and grain yield.

Treatments	Biomass	Grain yield
	----------t ha^{-1}--------	
Control	25.3 b	3.16 c
Wheat Straw Biochar 5 t ha^{-1}	29.3 ab	3.59 ab
Wheat Straw Biochar 10 t ha^{-1}	32.6 a	3.82 a
Sugarcane Biochar 5 t ha^{-1}	29.0 ab	3.41 bc
Sugarcane Biochar 10 t ha^{-1}	32.3 a	3.86 a

Conclusion

In this study Biochar of both types i.e. wheat straw biochar and sugarcane bagasse biochar when applied to soils in rainfed areas of potohar region increased maize grain yield and biomass. Different application rates showed that greater the biochar quantity greater will be the grain yield and biomass of maize crop. All biochar showed significant increase in N, P and K concentration in maize plants. Wheat straw biochar and sugarcane bagasse biochar at 10t ha-1 showed an increase of 28.9% and 27.6% in biomass respectively. While with the same rates of biochar grain yield was increased 20.8% and 22.1% respectively.

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