Research Article

Edward Yeboah*, Gideon Asamoah, Patrick Ofori, Ben Amoah, Kwaku Osei Adu Agyeman

Method of biochar application affects growth, yield and nutrient uptake of cowpea

https://doi.org/10.1515/opag-2020-0040
received May 7, 2020; accepted June 20, 2020

Abstract: Biochar produced from pyrolysis of organic materials has been found to improve plant growth by improving the physical and chemical characteristics of the soil as well as enhancing the sequestration of carbon that would have been released as carbon dioxide into the atmosphere through the decomposition of organic residues. However, there is scanty information on the methods used to apply biochar in order to optimize the benefits of biochar use for agricultural production. In view of this, a field study was carried out at the experimental field of CSIR – Soil Research Institute, Kumasi, to assess the effect of method of biochar application on the growth, yield and nutrient uptake of cowpea (*Vigna unguiculata*) in a moderately acidic sandy *Ferric Acrisol*. The experiment was set up using a Randomized Complete Block Design with three replications. The treatments imposed were as follows: control, broadcast, spot and ring methods of application. The parameters assessed included growth and yield data as well as nitrogen and phosphorus uptake in shoots and grains. The data collected were subjected to analysis of variance using Genstat 12th edition. The results showed that the spot and ring methods of application significantly enhanced height, girth, nodule number and dry weight, shoot biomass and grain yield as well as nitrogen and phosphorus contents in shoots and grains when compared with the broadcast method and control. This study therefore recommends the spot and ring methods of biochar application for adoption in cowpea production for enhanced growth, yield and nitrogen and phosphorus uptake.

Keywords: biochar, soil fertility, nutrient uptake, productivity

*** Corresponding author: Edward Yeboah,** Soil Microbiology Division, CSIR-Soil Research Institute, Academy Post Office, Kwadaso, Kumasi, Ghana, e-mail: eyeboah5@hotmail.com
Gideon Asamoah, Patrick Ofori, Ben Amoah, Kwaku Osei Adu Agyeman: Soil Microbiology Division, CSIR-Soil Research Institute, Academy Post Office, Kwadaso, Kumasi, Ghana

1 Introduction

Cowpea (*Vigna unguiculata* L. Walp) is an important crop that is one of the most extensively produced pulse crops in Sub-Saharan Africa (Walker et al. 2016). It constitutes a major component of farming systems in a variety of agro-ecological zones because of its ability to improve soil fertility through nitrogen fixation. It is a source of human food, livestock feed, green manure and income for smallholder farmers (Timko and Singh 2008; Walker et al. 2016). In spite of the considerable economic and health importance of cowpea, optimum yields have not been realized in Ghana due to constraints such as inadequate rainfall (due to frequent and erratic droughts), use of poor yielding varieties, pest, diseases and parasitic weeds (Onduru et al. 2008; Afutu et al. 2017). Coupled with these challenges, smallholder farmers are faced with the problem of declining soil productivity particularly due to low soil fertility, availability of limited resources to farmers and nutrient mining (McCann 2005). The declining soil productivity is a result of continuous cropping with little or no use of external inputs to replenish removed nutrients coupled with the already inherent low soil fertility of soils in the sub-humid zones (Gruhn et al. 2000). In addition to the problem of low soil fertility, there is a global issue of climate change (Lehmann and Joseph 2009). It has been predicted that climate change will severely affect the arid and semi-arid regions where yields of crops will decrease considerably (Chan and Xu 2009). Over the years, improving soil fertility for crop production has been limited to the use of mineral fertilizers, which when not managed will cause a decline in soil organic matter, soil acidification and physical degradation of the soil. Also, due to their high cost, most smallholder farmers are unable to afford them.

Biochar has been proposed as an effective option to minimize the effect of climate change on agricultural soils, enhance crop productivity and improve the retention of nutrients and moisture in the soil, Laird (2008).

Biochar produced from pyrolysis of organic materials is a fine-grained charcoal, which is high in organic carbon and resistant to decomposition. It creates a recalcitrant soil carbon pool that is carbon-negative, serving as a net withdrawal of atmospheric carbon dioxide that is stored in highly recalcitrant soil carbon stocks. According to Behera et al. (2007), it improves plant growth by improving the physical and chemical characteristics of the soil, i.e. cation exchange capacity (CEC), bulk density, water holding capacity and permeability as well as biological properties, all contributing to an increased crop productivity. Moreover, due to the ability of biochar to persist in the soil over a long period of time as it is recalcitrant to decomposition, it can provide desirable benefits to crops over several seasons (Steiner et al. 2007; Major et al. 2010) and hence does not need to be applied seasonally with each crop. Despite the numerous benefits derived from biochar use, research into the effectiveness of various methods of biochar application to soils has rarely been investigated (Cook and Sohi 2010; Solaiman et al. 2010). Several methods of biochar application including broadcast and incorporation, banding, spot and ring have been recommended. However, most biochar field trials reported to date have used the broadcast and incorporation method of application (Steiner et al. 2007; Major et al. 2010). Also, the effectiveness of biochar use could be influenced by the method used for application. In view of this, the current study was undertaken to assess the effect of biochar application method on growth, yield and nutrient uptake in cowpea in a moderately acidic sandy *Ferric Acrisol*.

2 Materials and methods

2.1 Study location

The study was carried out at the experimental field of the CSIR-Soil Research Institute (N06°40′34.5″, W001°40′ 21.4″) in the Kwadaso Municipal Assembly of the Ashanti Region of Ghana (Figure 1). The study location is within the semi-deciduous forest agro-ecological zone of Ghana and is characterized by two rainy seasons and two dry seasons in a year. This zone has a bimodal rainfall pattern with the major rainy season spanning from March to July and the minor season from September to November with a short dry spell in August. The mean

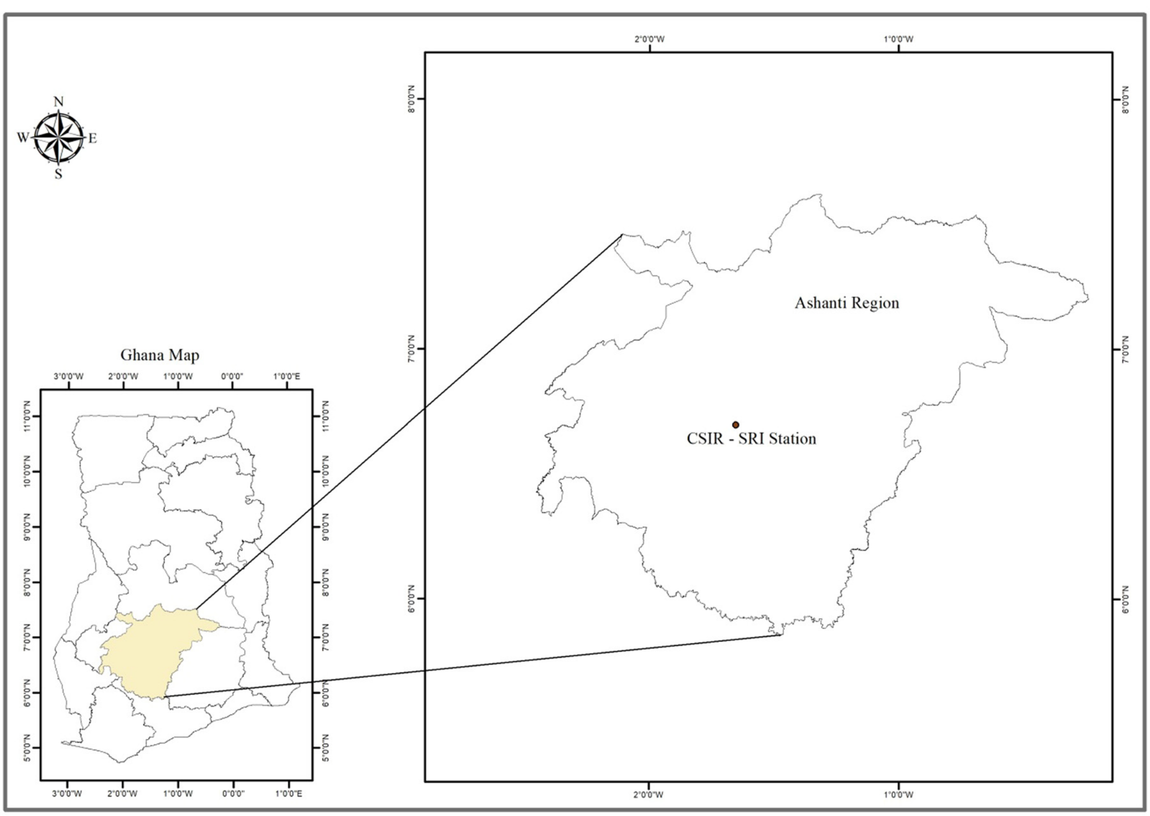

Figure 1: Map of the study area.

Table 1: Some chemical characteristics of the top 20 cm of the experimental field

Parameter	Value	Classification
pH (1:25 H_2O)	5.81	Moderately acidic
Organic carbon (%)	0.91	Very low
Nitrogen (%)	0.10	Low
Available P (ppm)	19.23	Moderate
Potassium (me/100 g)	0.24	Medium
Calcium (me/100 g)	2.13	Low
Magnesium (me/100 g)	0.75	High

annual precipitation is about 1,500 mm. Temperatures within the zone is generally high and uniform throughout the year. Soils at the experimental site belong to the Kumasi series and classified by Adu (1992) as Ferric Acrisol based on the guidelines of FAO (1990) The chemical and physical characteristics of the top 20 cm of the soil of the experimental site are summarized in Table 1.

2.2 Biochar used for study

The biochar used for the study was obtained from corn cob feedstock, which was pyrolyzed in a batch kiln at a temperature of 550°C. The production efficiency and duration was 28% and 48 h, respectively. After the production, the biochar was ground and sieved through a 2 mm sieve and packaged in a plastic bag until ready for use. The chemical characteristics of the corn cob biochar used in this study are shown in Table 2.

2.3 Land preparation, experimental design, application of treatments and planting

The experimental field was cleared off weeds by manually weeding with a cutlass after which the land was ploughed and harrowed using a farm tractor. The experimental design used for the study was Randomized Complete Block Design with three replications. The treatments were assigned to plots measuring 3.2 × 4.2 m with an alley of 1 and 2 m between the plots and blocks, respectively. The treatments imposed were three methods of biochar application i.e. broadcast and incorporation, spot and ring application. In the case of the broadcast and incorporation method of application, the amount of biochar needed per plot was uniformly spread on the surface of the field and worked into the soil using a hoe.

Table 2: Chemical properties of the corn cob biochar used for the study

Property	Value
pH H_2O (1:5)	10.18
Organic carbon (%)	14.20
Nitrogen (%)	0.79
Carbon/nitrogen ratio	18.00
Calcium (cmol/kg)	2.72
Magnesium (cmol/kg)	6.52
Potassium (cmol/kg)	7.02
Sodium (cmol/kg)	1.24
Available phosphorus (ppm)	314.03
Available K (ppm)	3124.19

For the spot method of application, a small hole of about 10 cm diameter and a depth of 10–15 cm was dug and the needed quantity of biochar per stand was put into the hole after which the biochar was covered with soil. The ring method was applied by making a ring of about 5 cm from where the cowpea would be planted, following which the amount of biochar per stand required was put into the ring and covered with soil. An application rate of 5 t/ha biochar was used for all the different methods of application. A basal amount of 30 kg/ha P_2O_5 was applied to all the plots using triple super phosphate (TSP) as the phosphorus source. The biochar was applied during planting, while the TSP was applied a week after planting. An improved cowpea variety "*pad-tuya*" was used as the test crop. Three seeds were planted per stand and were later thinned to two seedlings a week after planting. Throughout the growth of the crop, it was ensured that the field was free of weeds and pest by weeding and spraying with recommended pesticides as and when necessary.

2.4 Data collection

Cowpea height and girth were measured at 2, 4 and 6 weeks after planting using a meter rule and a digital Vernier calliper, respectively. At 50% flowering, five plants were carefully uprooted from the second and seventh rows for the determination of shoot biomass yield, nodule number and nodule weight. After uprooting the plants, the shoots were separated from the roots, and the nodules were detached and counted. The detached nodules and shoots were placed in different envelopes and dried in an oven at a temperature of 60°C for a period of 48 h, after which their dry weights were measured and recorded. At physiological maturity, the cowpea was harvested from the four middle rows by plucking the dry pods and sun drying them afterwards. The pods were then shelled and winnowed to separate the chaff from the grains. The grains were then weighed for the determination of the grain yield. N and P uptake in grains and shoots were determined by multiplying the grain and shoot dry weights by their respective N and P concentrations.

2.5 Data analysis

The collected data were analysed using the GenStat statistical package 12th edition for the analysis of variance procedure (Payne et al. 2006). Significant differences were assessed at the 5% (p = 0.05) level of significance and the treatment means separated using Duncan's Multiple Range Test (DMRT).

3 Results and discussion

3.1 Effects of methods of biochar application on cowpea stem girth and height

Figures 2 and 3 show the effects of methods of biochar application on cowpea stem girth and height, respectively, at 2, 4 and 6 weeks after planting. The results show that significant differences were observed for both stem girth and height among the treatments for week 4 and 6 after planting but not for week 2. Cowpea stem girth ranged from 1.21 to 1.25 cm for week 2 with the control recording the minimum, whereas the ring application method gave the maximum. At 4 weeks after planting, the ring method gave the highest (2.38 cm) girth, which was not significantly different from that of the spot and broadcast methods; however, it differed significantly from that of the control, which recorded the least girth of 2.30 cm. Similarly at 6 weeks after planting, the control produced the minimum (2.56 cm) girth, while the ring method gave the maximum (3.03 cm), which did not differ significantly from that of the spot method of application.

Cowpea height at week 2 ranged from 11.1 to 12.12 cm, with the control producing the lowest height, whereas the spot method of application gave the highest. At week 4, the ring method recorded a maximum height of 41.80 cm, which was not statistically different from that of the spot method, while the control recorded the minimum (38.11 cm). At week 6, the highest (124.0 cm) and minimum (106.3 cm) heights were produced by the spot and control methods, respectively. Reports by Zhang et al. (2012); Khan et al. (2013) and Van Zwieten et al. (2010) have demonstrated a significant positive impact of biochar through the provision of necessary nutrients for plant growth and development. The observed increases in the girth and height of cowpea from the spot and ring methods of application could be attributed to the relatively high concentrations of the biochar around the root zone of the plant, which invariably results in higher nutrient and moisture availability for use by the plants. This finding agrees with the study of Tariku et al. (2017), who reported increases in growth parameters following the application of biochar on garden peas.

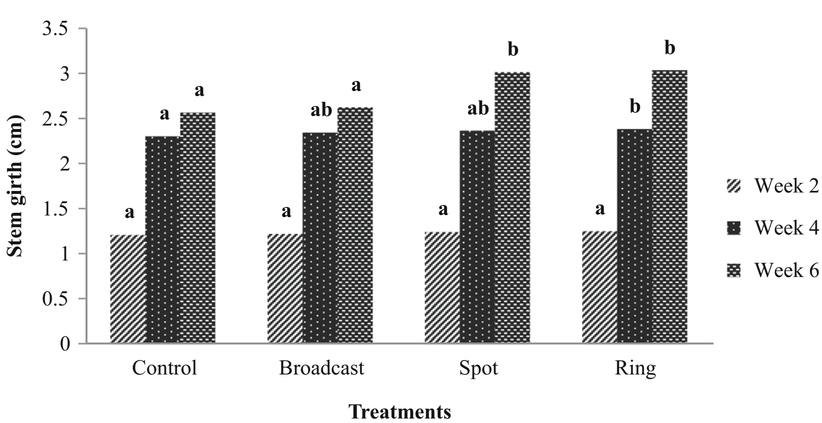

Figure 2: Treatment effects on stem girth of cowpea. *Bars with the same letters for a particular week are not statistically different at $P < 0.05$ LSD.

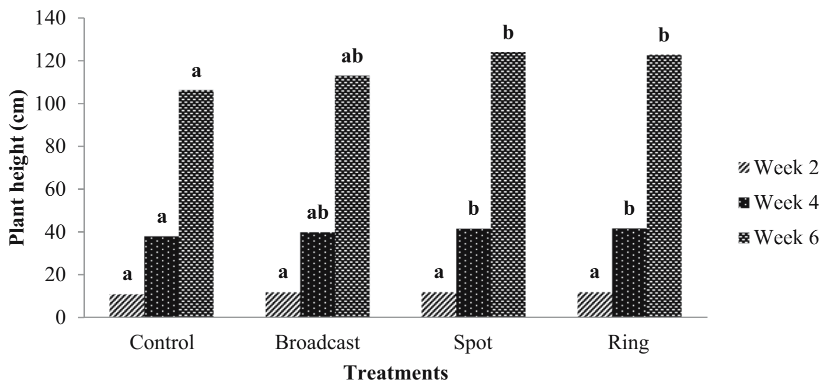

Figure 3: Treatment effects on plant height of cowpea. *Bars with the same letters for a particular week are not statistically different at $P < 0.05$ LSD.

3.2 Effects of methods of biochar application on cowpea nodule number and dry weight

Treatment effects on the number and dry weight of nodules are presented in Table 3. The results indicate that the nodule number was not significantly ($p > 0.05$) influenced by the methods of biochar application. However, the nodule dry weight was significantly ($p < 0.05$) increased by the various biochar application methods. The nodule number per plant ranged between 16.17 and 27.06, with the control producing the least number of nodules while the broadcast method of application the highest. Nodule dry weight was maximum (27.03 kg/ha) for the spot method of application, whereas the control produced the minimum nodule dry weight of 15.53 kg/ha. The results further showed that the nodule dry weights for all three methods of biochar application differed significantly in relation to the control but did not differ among themselves. The enhanced nodulation from the three methods of biochar application particularly by the spot and ring methods could be due to the retention of the applied phosphorus. Phosphorus plays an important role in stimulating root growth and initiating nodule formation (Asuming-Brempong et al. 2013). Also, since the soil of the experimental field was sandy, it was possible that the soil could not hold the applied P in the control plots due to its low CEC. Moreover, the applied biochar could harbour essential micro nutrients such as molybdenum required by the rhizobia for nodule formation. Other studies where the application of biochar has enhanced nodulation have been reported by Rillig et al. (2010) in white clover, Mia et al. (2014) in red clover and Tagoe et al. (2008) in soybean.

Table 3: Treatment effects on cowpea nodule number per plant and nodule dry weight at 50% flowering

Treatment	Nodule number/ plant	Nodule dry weight (kg/ha)
Control	16.17[a]	15.53[a]
Broadcast	27.06[a]	26.48[b]
Spot	23.33[a]	27.03[b]
Ring	21.67[a]	26.62[b]
CV (%)	25.00	20.40

Mean values with the same letters are not significantly different according to DMRT at $P < 0.05$.

3.3 Effects of methods of biochar application on cowpea pod number

The effects of methods of biochar application on the number of pods of cowpea are presented in Figure 4. The results show that the number of pods of cowpea was not significantly influenced by the various methods of application except the spot application method. The highest (17.5) number of pods

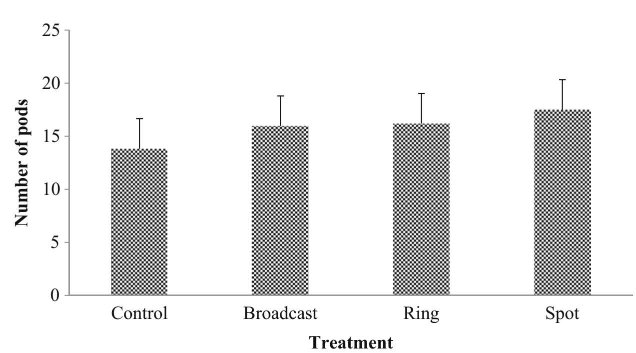

Figure 4: Effects of biochar methods of application on the pod number of cowpea.

was produced by the spot method of biochar application while the lowest number of 13.83 was by the control. The observed significant increase in the number of pods of cowpea from the spot application method could be a result of the provision of adequate nutrients, which leads to more vegetative growth, longer linear growth rate and the accumulation of more dry matter, which has a direct relationship with pod number increment. This observation is in agreement with the findings of Agboola and Moses (2015), who found a significant enhancement of the number of pods of pea in response to the application of rice husk biochar. The results also confirm the findings of Ahmed et al. (2005), who reported that biochar application on acidic soil can increase the number of pods and seed yield of the crop.

3.4 Effects of methods of biochar application on shoot biomass and seed yield of cowpea

Shoot biomass and seed yield response to the treatments is shown in Figure 5. It could be observed from the results that both the shoot biomass and seed yields were significantly ($p < 0.05$) affected by the treatments. The maximum (3,784 kg/ha) and minimum (2,605 kg/ha) shoot biomass yields were produced by the spot methods of application and control, respectively. The shoot biomass yield produced by the spot method of application did not differ from that of the ring and broadcast methods but differed significantly from the that of the control. Similarly with respect to seed yield, the spot method produced the maximum (1,570 kg/ha) seed yield, which did not differ significantly from that of the ring method but was significantly different from that of the control, which produced the minimum seed yield of 1,152 kg/ha. The yields from the spot and ring methods of biochar application were significantly higher because those methods ensured a higher concentration of biochar at the root zones of the plant thereby improving the benefits derived from biochar such as nutrient and moisture retention, increase in soil pH and the provision of nutrients for uptake and use by plants. Also, the increases in the shoot biomass and seed yields could be attributed to the improved growth characteristics such as height and girth as well as nodulation and number of pods from the biochar-treated plots as biochar contains some amounts of both major and minor nutrients, which could have been taken up by the plants for an enhanced partitioning of photosynthates. As indicated by Steiner et al. (2007), the application of biochar improves nitrogen availability in soil, which enhances photosynthesis. This increases fertilizer use efficiency leading to increased plant biomass yield as observed from the results of this study.

Increases in shoot biomass production and seed yield as a result of biochar application have been reported by Liang et al. (2014) and Tammeorg et al. (2014). Chan et al. (2008a, 2008b) has also reported significant increases in radish yield as a result of application of biochar.

3.5 Effects of methods of biochar application on cowpea nitrogen and phosphorus uptake

Effects of the treatments on nitrogen and phosphorus uptake in cowpea shoots and grains are presented in Table 4. From the results, it is observed that the shoot

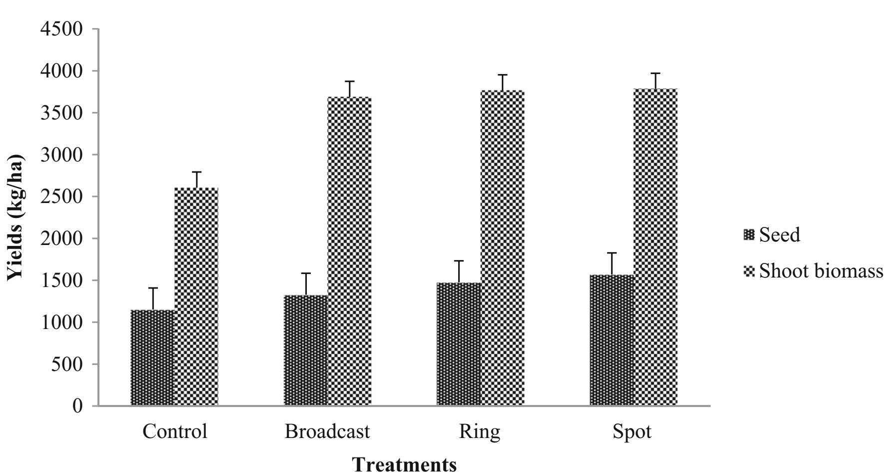

Figure 5: Treatment effects on shoot biomass and seed yield of cowpea.

Table 4: Treatment effects on cowpea shoot and grain nitrogen and phosphorus uptake

Treatment	Nitrogen uptake		Phosphorus uptake	
	Shoot kg/ha	Grain	Shoot	Grain
Control	7.89[a]	35.98[a]	1.56[a]	1.67[a]
Broadcast	9.75[ab]	39.45[ab]	1.84[a]	1.96[ab]
Spot	10.61[b]	42.60[b]	2.22[b]	2.39[bc]
Ring	11.52[b]	41.22[b]	2.03[b]	2.47[c]
CV (%)	9.50	5.90	5.60	11.60

Mean values with the same letters are not significantly different according to DMRT at $P < 0.05$.

and grain nitrogen and phosphorus uptake amounts were significantly ($P < 0.05$) affected by the treatments. The highest shoot (11.52 kg/ha) and grain (42.60 kg/ha) nitrogen uptake amounts were shown by the ring and spot methods of biochar application, respectively, whereas the least shoot nitrogen (7.89 kg/ha) and grain nitrogen (35.98 kg/ha) uptake amounts were shown by the control. It is further evident from the results that both the spot and ring methods of application significantly ($P < 0.05$) increased both the shoot and grain nitrogen uptake in relation to the control.

Shoot phosphorus uptake ranged between 1.56 and 2.22 kg/ha, with the control recording the least, whereas the spot method of application gave the highest. The maximum (2.47 kg/ha) grain phosphorus uptake was obtained by the ring method, while the minimum uptake of 1.67 kg/ha was by the control. The ring and spot methods of application led to significant increases in both shoot and grain phosphorus uptake. This observation is in agreement with the findings of Van Zwieten et al. (2010) and Chan et al. (2007, 2008a, 2008b), who found significant increases in nutrient uptake following the application of biochar in lettuce and radish plants, respectively. According to Liang et al. (2006), the large surface area, higher negative surface charge and greater charge density of biochar result in a higher capacity to absorb nutrients per unit carbon than other kinds of soil organic matter. This could be the reason why the spot and ring methods of application, which lead to relatively large concentrations of biochar around the root zone, significantly increased the nitrogen and phosphorus uptake in shoots and grains. Also, Masto et al. (2013) related the several nutrients in plant tissues following the application of biochar to the production variables of biochar and complex physiochemical properties, which may be involved in the biochar–soil–plant interaction system. Another reason for the significant increases in nitrogen and phosphorus uptake in shoots and grains could be the ability of biochar amendments to reduce soil bulk density leading to increased root penetration that allows the uptake of nutrients from the soil solution (Glaser et al. 2002, Lehmann and Joseph 2015). Moreover, Asai et al. (2009) asserted that biochar induces water permeability and holding capacity and raises the amount of available water to plants and thus poses direct impacts on plant nutrient uptake.

4 Conclusion

This study has shown that the growth, yield and nutrient uptake of cowpea are influenced by the method of biochar application. The increased growth, yield and nutrient uptake of cowpea are a result of the improvement of the physical and chemical characteristics of the soil such as improved pH; improved water holding capacity, which raises the available water to the plant, and improved nutritional contents of biochar in the moderately acidic soil, which inter-relate to ensure that the necessary conditions are met for the growth of cowpea. The methods of biochar application enhanced parameters such as plant height and girth, nodule number and weight, pod number, shoot and seed yield as well as nitrogen and phosphorus uptake. Among the three different methods of biochar application, the spot and ring methods were the most effective in significantly enhancing the measured parameters in comparison with the control. The spot method was the most effective followed by the ring and then by the broadcasting method. Therefore, in order to increase the agronomic performance of cowpea in a moderately acidic sandy soil by using biochar, the choice of method of application is very important for obtaining benefits such as enhanced growth and yield as well as soil fertility. Hence, we recommend the spot or ring method of biochar application for adoption in cowpea production for improved yields and sustained soil fertility. We also recommend that future studies be carried out to investigate the methods of biochar application on other commodities such as maize, cassava and vegetables.

Conflict of interest: The authors have declared that there exist no competing interests.

References

[1] Adu SV. Soils of the Kumasi Region, Ashanti Region, Ghana. Soil Research Institute (Council for Scientific and Industrial Research). Memoir No. 8. 1992.

[2] Afutu E, Agoyi EE, Amayo R, Biruma M, Rubaihayo PR. Cowpea scab disease (*Sphaceloma* sp.) in Uganda. Crop Protect. 2017;9:213–20. doi: 10.1016/j.cropro.2016.06.024
[3] Agboola K, Moses SA. Effect of biochar and cowdung on nodulation, growth and yield of soybean (Glycine max L. Merrill). Anyigba, Kogi State, Nigeria: Department of Soil and Environmental Management, Kogi State University; 2015.
[4] Ahmed M, Islam MM, Paul SK. Effect of nitrogen on yield and other plant characters of local T. Aman rice, Var. Jatai. Res J Agric Biol Sci. 2005;1:158–61.
[5] Asai H, Samson BK, Stephan HM, Songyikhangsuthor K, Homma K, Kiyono Y. Biochar amendment techniques for upland rice production in Northern Laos. 1. Soil physical properties, leaf SPAD and grain yield. Field Crop Res. 2009;111:81–4. doi: 10.1016/j.fcr.2008.10.008
[6] Asuming-Brempong S, Wiafe Y, Aggrey-Martin K. Nodulation of cowpea (*Vigna unguiculata* [L.] walp) at different levels of phosphorus in a Typic Kandiustalf. Agric Sci Res J. 2013;3(12):387–94.
[7] Behera UK, Sharma AR, Mahapatra IC. Crop diversification for efficient resource management in India: problems, prospects and policy. J Sustainable Agric. 2007;30(3):97–217. doi: 10.1300/j064v30n03_08
[8] Chan KY, Xu Z. Biochar: nutrient properties and their enhancement. In: Lehmann J, Joseph S, editors. Biochar for environmental management: science and technology. London, UK: Earthscan; 2009. p. 85–106. doi: 10.4324/9781849770552.
[9] Chan KY, Van Zwieten L, Meszaros I, Downie A, Joseph S. Agronomic values of green waste biochar as a soil amendment. Aust J Soil Res. 2007;45:629–34. doi: 10.1071/sr07109.
[10] Chan KY, Van Zwieten L, Meszaros I, Downie A, Joseph S. Using poultry litter biochars as soil amendments. Australian J Soil Res. 2008a;46:437–44.
[11] Chan KY, Van Zwieten L, Meszaros I, Downie A, Joseph S. Using poultry litter biochars as soil amendments. Soil Res. 2008b;46(5):437–44. doi: 10.1071/sr08036.
[12] Cook J, Sohi S. Application to soil, chapter 5. In: Shackley S, Sohi S, editors. An assessment of the benefits and issues associated with the application of biochar to soil. Edinburgh: UK Biochar Research Centre; 2010. p. 57–63.
[13] FAO. Soil map of the world. Revised Legend. World Soil Resource Report No. 60. Rome: FAO; 1990. doi: 10.1201/9781420040364-12.
[14] Glaser B, Lehmann J, Zech W. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal – a review. Biol Fertil Soil. 2002;35:219–30. doi: 10.1007/s00374-002-0466-4.
[15] Gruhn P, Golleti F, Yudelman M. Integrated Nutrient Management, Soil Fertility and Sustainable Agriculture: Current Issues and Future Challenges. Washington D.C. International Food Policy Research Institute. Food, Agriculture and Environment Discussion Paper 32; 2000.
[16] Khan S, Chao C, Waqas M, Arp HPH, Zhu YG. Sewage sludge biochar influence upon rice (*Oryza sativa* L.) yield, metal bioaccumulation and greenhouse gas emissions from acidic paddy soil. Environ Sci Technol. 2013;47(15):8624–32. doi: 10.1021/es400554x.
[17] Laird DA. The charcoal vision: a win–win–win scenario for simultaneously producing bioenergy, permanently sequestering carbon, while improving soil and water quality. Agron J. 2008;100:178–81. doi: 10.2134/agronj2007.0161.
[18] Lehmann J, Joseph S. Biochar for environmental management. Science and technology. London: Earthscan; 2009. doi: 10.4324/9781849770552.
[19] Lehmann J, Joseph S. Biochar for environmental management: an introduction. In: Lehmann J, Joseph S, editors. Biochar for environmental management: science, technology and implementation. London: Taylor and Francis; 2015. p. 1–13. doi: 10.4324/9780203762264-8.
[20] Liang B, Lehmann J, Solomon D, Kinyangi J, Grossman J, O'Neill B, et al. Black carbon increases cation exchange capacity insoils. Soil Sci Soc Am J. 2006;70:1719–30. doi: 10.2136/sssaj2005.0383.
[21] Liang F, Li G, Lin Q, Zhao X. Crop yield and soil properties in the first 3 years after biochar application to a calcareous soil. J Integr Agric. 2014;13(3):525–32. doi: 10.1016/s2095-3119(13)60708-x.
[22] Major J, Rondon M, Molina D, Riha SJ, Lehmann J. Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. Plant and Soil. 2010;333:117–28. doi: 10.1007/s11104-010-0327-0.
[23] Masto RE, Ansari MA, George J, Selvi V, Ram L. Co-application of biochar and lignite fly ash on soil nutrients and biological parameters at different crop growth stages of Zea mays. Ecol Eng. 2013;58:314–22. doi: 10.1016/j.ecoleng.2013.07.011.
[24] McCann J. Maize and grace: Africa's encounter with a new crop, 1500–2000. New York: Harvard University Press; 2005. doi: 10.2307/20031766.
[25] Mia S, van Groenigen JW, van de Voorde TFJ, Oram NJ, Bezemer TM, Mommer L, Jeffery S. Biochar application rate affects biological nitrogen fixation in red clover conditional on potassium availability. Agr Ecosyst Environ. 2014;191:83–91. doi: 10.1016/j.agee.2014.03.011.
[26] Onduru D, De Jager A, Muchena F, Gachini G, Gachimbi L. Exploring potentials of rhizobium inoculation in enhancing soil fertility and agroeconomic performance of cowpeas in sub-Saharan Africa: a case study in semi-arid Mbeere, Eastern Kenya. Am Eurasian J Sustainable Agric. 2008;2:185–97.
[27] Rillig MC, Mardatin NF, Leifheit EF, Antunes PM. Mycelium of arbuscular mycorrhizal fungi increases soil water repellency and is sufficient to maintain water-stable soil aggregates. Soil Biol Biochem. 2010;42:1189–91. doi: 10.1016/j.soilbio.2010.03.027.
[28] Solaiman ZM, Blackwell P, Abbott LK, Storer P. Direct and residual effect of biochar application on mycorrhizal root colonisation, growth and nutrition of wheat. Aust J Soil Res. 2010;48:546–54. doi: 10.1071/sr10002.
[29] Steiner C, Teixeira WG, Lehmann J, Nehls T, Macedo JLV, Blum WEH, et al. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil'. Plant and Soil. 2007;291:275–90. doi: 10.1007/s11104-007-9193-9.
[30] Tagoe SO, Horiuchi T, Matsui T. Effects of carbonized and dried chicken manures on the growth, yield, and N content of soybean. Plant and Soil. 2008;306(1–2):211–20. doi: 10.1007/s11104-008-9573-9.
[31] Tammeorg P, Simojoki A, Mäkelä P, Stoddard FL, Alakukku L, Helenius J. Short-term effects of biochar on soil properties and wheat yield formation with meat bone meal and inorganic

fertiliser on a boreal loamy sand. Agric Ecosyst Environ. 2014;191:108–16. doi: 10.1016/j.agee.2014.01.007.

[32] Tariku B, Shiferaw T, Muluken T, Firew K. Effect of Biochar application on growth of garden pea (*Pisum sativum* L.) in acidic soil of Bule Woreda Gedeo Zone Southern Ethiopia. Int J Agron. 2017;2017:8. doi: 10.1155/2017/6827323.

[33] Timko MP, Singh BB. Cowpea, a multifunctional legume. In: Moore PH, Ming R, editors. Genomics of tropical crop plants. New York: Springer; 2008. p. 227–57. doi: 10.1007/978-0-387-71219-2_10.

[34] Van Zwieten L, Kimber S, Morris S, Chan K, Downie A, Rust J, et al. Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility. Plant and Soil. 2010;327(1):235–46. doi: 10.1007/s11104-009-0050-x.

[35] Walker T, Cunguara B, Donovan C. Assessing directions for cowpea R&D in USAID's feed the future program in Mozambique. Washington, DC: MEAS and USAID; 2016.

[36] Zhang A, Liu Y, Pan G, Hussain Q, Li L, Zheng J, et al. Effect of biochar amendment on maize yield and greenhouse gas emissions from a soil organic carbon poor calcareous loamy soil from Central China Plain. Plant and Soil. 2012;351(1–2):263–75. doi: 10.1007/s11104-011-0957-x.