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IMPACT OF BIOCHAR FERTILIZER ON SOIL AMENDMENT, CROP PERFORMANCE AND SOME NUTRITIONAL QUALITIES IN CUCUMBER (*Cucumis sativus* L) PRODUCTION

ODUNTAN, A. O.[1*], ABDULRASAK, Y. L.[2], SANNI, K. O.[2, 3]

[1]Department of Horticulture and Landscape Management, Lagos State University of Science and Technology, Ikorodu, Lagos State
[2]Department of Crop Science, Lagos State University of Science and Technology, Ikorodu, Lagos State
[3]Rector Office, Gateway ICT Polytechnic, Saapade, Ogun State

***Corresponding Author:** oduntan.ao@lasustech.edu.ng

Abstract

Cucumber production continues to gain attention because of its economic and nutritional values, thus its high consumption rate. However, one of the reasons for low yield in production is the soil fertility status of its area of cultivation. A field experiment on the impact of biochar fertilizer on soil amendment, crop performance and some nutritional qualities in cucumber (Cucumis sativus L) production was conducted at the Teaching and Research Farm of the Department of Horticulture and Landscape management, Lagos State University of Science and Technology, Ikorodu. Treatments used were two different biochars and their combination at different rates and a control (T1 = 10 tons/ha Bamboo biochar; T2 = 10 tons/ha Neem biochar; T3 = 5 tons/ha Bamboo + 5 tons/ha Neem biochar T4 = Control (no fertilizer application) and was laid out using a Randomized Complete Block Design (RCBD) with three replications. Parameters taken were vine length, number of leaves, stem girth, fruit yield, yield attributes and some nutritional contents of cucumber. All the vegetative parameters were significantly ($P \leq 0.05$) influenced by the application of the biochar fertilizers when compared with those without biochar application. Similarly, fruit weight, fruit length and fruit diameter of cucumber were significantly ($P \leq 0.05$) enhanced by the application of biochar. Moisture content, fat and ash content of the fruits were also considerably affected by the biochar fertilizers. Postharvest, the application of biochar resulted in an increase organic carbon, nitrogen, phosphorus, potassium, calcium and magensium of the soil.

Keywords: Cucumber, Biochar, Soil nutrients, Soil amendment

INTRODUCTION

Cucumber (*Cucumis sativus* L) is an important vegetable crop that belongs to the gourd family Cucurbitaceae and it is a commonly cultivated crawling plant with vine that bears tube shaped fruit. It is widely grown because of its delicious, crunchy, high in nutrient content and low calorie fruits. Additionally, the fruit has hydrating properties and provide a good source of vitamin K with small amounts of minerals (USDA, 2017). Because of their high water content, the fruit is also used for deep cleansing because it contains natural chemical constituents. (Ene *et al*., 2016). The Vitamin K in cucumbers aids in blood clotting in the body, which is essential for wound healing. According to Szalay (2017), it also aids the body build healthy bones. Cucumbers contain some mineral elements including potassium, magnesium, and manganese (Chakraborty and Rayalu, 2021). The minerals contained in cucumber fruits make the water in the vegetable easily absorbed by human body.

Plants need a good amount of soil nutrients for their growth but the soil nutrient levels may decline over-time after harvesting of crops due to the fact that they are not returned to the soil. Both inorganic and organic fertilizers are known to provide nutrients that are essential for plant growth as they contain macro- and micro-nutrients and beneficial microorganisms (Sreenivasa, *et al*., 2010). However, a change in structural diversity and dominant bacterial groups in agricultural soils has been discovered due to long-term treatment with either of these fertilizers (Wu *et al*., 2012). Soil amendments must have properties such as high binding capacity and environmental safety without having any negative effect on the soil structure, soil fertility, or the ecosystem on the whole (Rawat *et al*., 2019). Thus, bio fertilizers are believed to reenergize soil by improving the soil fertility and can be used as a powerful tool for sustainable agriculture that can render agro-ecosystems more stress-free (Kumar *et al*., 2021).

Biochar has been accepted as a sustainable approach and a promising way to improve soil quality and remove heavy-metal pollutants from the soil. It may serve as a better choice for soil amendment because its source is biological and it may be directly applied to soils with little pre-treatment. It is produced through a process called pyrolysis, which basically involves heating of biomass (such as wood, manure, or leaves) in complete or almost complete absence of oxygen, with oil and gas as co-products. It is a combination of charcoal and ash debris with the significant section (70-95%) carbon (C) (Brandstaka *et al*., 2010; Luostarinen *et al*., 2010) which can be used to improve soil properties for growing plants, nutrient management and carbon sequestration (Luostarinen *et al*., 2010). The effect of biochar expansion on yield of crops is more pronounced in barren soils compared with fruitful soils (El-Naggar *et al*., 2019). Also, its impact on plant nourishment and crop yield varies, and it is not usually successful when supplemented with mineral manures (Alburquerque *et al*., 2014).

As a result of the characteristic low fertility condition of most tropical soils, cucumber growers embrace and use diverse soil nutrient management approaches to improve their production. Some of these strategies adopted are sometimes not environmentally friendly and also possibly degrade agricultural soils. In view of this, there is need to focus on achieving sustainable production practices that can commendably increase the soil fertility, improve crop performance and quality of the crop.
This research work was carried out to determine effect of biochar fertilizer on soil fertilituy, crop performance and some nutritional qualities of cucumber.

MATERIALS AND METHODS

Field experiment was conducted at the Teaching and Research Farm of the Department of Horticulture and Landscape management, Lagos State University of Science and Technology, Ikorodu., which lies between latitude 5° 10' N and longitude 3° 16' E of the Greenwich meridian with an elevation of 50 m above sea level. It has a mean average temperature of 25° C and 29° C with an annual rainfall range between 1670 mm and 2200 mm and relative humidity between 65 % and 68 %.

The treatments used were two different biochars and their combination at different rates and a control (T1 = 10 tons/ha Bamboo biochar; T2 = 10 tons/ha Neem biochar; T3 = 5 tons/ha Bamboo + 5 tons/ha Neem biochar, T4 = Control (no fertilizer application). The experiment was laid out using a Randomized Complete Block Design (RCBD) with three replications.

A composite soil sample was collected from 0 - 30 cm depth prior to planting of cucumber before the incorporation of the biochars to determine the pH and the nutrient position of the soil. Soil pH was analyzed by 1:2 in H2O, total N content was determined by Kjeldahl method (Bremner and Mulvaney, 1982); available phosphorus was analyzed using the modified Walkley and Black (Nelson and Sommers, 1996). Neem and bamboo plant materials were sourced and biochar obtained by pyrolysis under high-temperature and low – oxygen conditions. Chemical analysis of the soil and biochars used were done and are presented in Table 1. Application of biochars was done on the experimental plots two weeks before planting to allow for mineralization.
Two seeds of "Ashley" variety of cucumber where sown at a spacing of 50 by 50 cm and later thinned after two weeks to one seedling per stand. Manual weeding was carried out at 3 and 5 weeks after planting. Insect pests were controlled with lamdacyahalothrin as Karate (2 L/ha.) at biweekly intervals for effective insect control.
Growth parameters were assessed at 4, 5, 6, 7 and 8 weeks after planting. Cucumber vine length was measured by using a flexible tape rule. Number of leaves was assessed by visual count of the green leaves. Stem girth was also determined by using venier caliper. At every harvest, the fruit diameter was measured using a Vernier caliper and the fruit length was measured using a flexible tape before the fruits were weighed using a scale. The cumulative weights of the harvests were summed up.

The proximate analysis was done using standard laboratory technique as described by Association of Analytical Communities (AOAC, 2005). Mineral analysis was also done using the Atomic Absorption spectrophotometer technique. Data collected was subjected to analysis of variance (ANOVA) using PROC GLM in SAS version 9.3. Treatment means were separated using a Least Significant Difference (LSD).

RESULTS

Organic Amendments Characteristics

The chemical characteristics of the biochar sources are stated in Table 1. The pH of the neem biochar was slighltly acidic, while that of the bamboo biochar was moderately alkaline. The chemical properties of biochar fertilizers obtained from neem and bamboo used for the experiment showed that Neem biochar had Organic matter content of 19.75 % and Organic carbon content of 11.46 % while Bamboo biochar had Organic matter content of 11.31 % and Organic carbon content of 6.56 %. The result revealed that the biochar fertilizers were comparatively high in both organic matter and organic carbon. The results also showed that both biochars were quite high in Total nitrogen, Potassium, Sodium, magnesium, calcium and phosphorus.

Soil Properties

The results presented in table 2 highlighted the chemical characteristics of the soil before planting, the result indicated that the soil had neutral pH with a value of 6.7. It had lower organic matter content and was also low in exchangeable cations (Ca2+, Mg2+, and K+) and total nitrogen.

Effect of Treatments on Soil Physical and Chemical Properties

The result in Table 3 revealed that biochar had a significant effect ($p < 0.05$) on selected soil properties. The highest soil pH was recorded in Neem-Bamboo combination (5t/ha + 5t/ha) (6.23), which was significantly higher than Bamboo at 10t/ha) (5.96) as well as the Control (5.95). The results showed that there was a significant difference ($p<0.05$) in the concentration of organic carbon content of amended soils compared to the control.

Table 1: Nutrient composition of Neem and Bamboo biochars

Properties	**Neem biochar**	**Bamboo biochar**
pH	6.20	7.90
N (%)	3.65	1.99
P ($mgkg^{-1}$)	8.44	4.83
Org. C (%)	11.46	6.55
Org. M (%)	19.71	11.26
Ex.A (mEq/100g)	2.30	1.40
Na (%)	2.32	2.52
K (%)	2.12	1.82
Ca (%)	6.05	7.12

N = Nitrogen, P = Phosphorus, Org. C= Organic Carbon, Org M= Organic Matter, Ex. A = Exchangeable Acidity, Na =Sodium, K = Potassium, Ca = Calcium

Table 2: Chemical properties of the soil before planting

Properties	Sample
pH (H_2O)	6.9
OM (%)	2.62
Avail. Phosphorus (mg kg^{-1})	5.28
K (cmol/kg)	0.17
Ca (cmol/kg)	2.45
Mg (cmol/kg)	1.96
Total Nitrogen (%)	0.18

Avail. Phosphorus =Avaialable Phosphorus, OM= Organic Matter, K = Potassium, Ca = Calcium, Mg = Magnesium

Table 3: Effect of Biochar application on selected soil chemical properties

		OC	Total N	Potassium	Av. P	Mg	Calcium
Treatment	pH	%	g/kg	cmol/kg	mg/kg	cmol/kg	cmol/kg
Neem (10t/ha)	6.22a	9.31b	115.7d	0.353a	258.0b	3.26a	2.57a
Bamboo (10t/ha)	5.96b	9.43ab	141.8a	0.263b	310.1a	2.71b	2.14b
Neem-Bamboo combination	6.23a	9.52a	128.8b	0.210c	244.1b	2.48c	1.96bc
Control	5.95b	8.18c	119.6c	0.197c	184.0c	2.25d	1.78c
LSD (P≤ 0.05)	0.114	0.1754	2.986	0.031	28.08	0.191	0.212

Means followed by the same alphabet in the same column are not significantly different at 5% probability level; OC= Organic carbon, Total N = Total Nitrogen, Av. P = Available Phosphorus

The highest value was observed in Neem- Bamboo combination (5t/ha + 5t/ha) (9.52), followed by Bamboo (10t/ha) and Neem (10t/ha), with Control (8.18) having the lowest organic matter content. This indicated that the combination of both Neem (5t/ha) and Bamboo (5t/ha) led to the highest increase in organic matter content in the soil. The application of biochar had a significant effect ($p<0.05$) on the total nitrogen (TN) content of the soil. The highest amount of TN was observed at Bamboo (10t/ha) (141.8 k/kg), followed by Control (119.6 g/kg) and Neem-Bamboo combination (5t/ha + 5t/ha) (128.8 g/kg), with the lowest value being observed in Neem (10t/ha) (115.7 g/kg).

The available phosphorus concentration in soils with Bamboo (10t/ha) (258.00 mg/kg) application was significantly ($p<0.05$) higher than that of Neem (10t/ha) and Neem-Bamboo combination (5t/ha + 5t/ha), with control having the lowest (184 mg/kg) concentration. The potassium, magnesium, and calcium content follow a similar trend with the application of Neem (10t/ha) (0.35, 3.26, and 2.57 cmol/kg) for all three properties, respectively, being significantly ($p<0.05$) higher than all other soil amendments and control, with control possessing the lowest values across the properties.

Effects of Biochar fertilizer application on the vegetative growth of cucumber

Cucumber vine length increased significantly ($P < 0.05$) with the application of Bamboo biochar (10t/ha) at 5weeks after planting (WAP) as shown in Table 4. The application of neem biochar only or its combination with bamboo biochar treatments were not significantly different from each other, showing that the additional application of fertilizer was not needed to obtain similar total vine length; however, both treatments were significantly different from the control treatment. The application of bamboo biochar at the rate of 10 t/ha gave the longest vine of (20.03cm) and the control produced the shortest vine length (10.77 cm). At 8WAP, the longest vine of 42.24 cm was observed in the plot treated with only bamboo biochar at the rate of 10 10t/ha, with the control having the shortest (34.06cm).

At the early stage of the vegetative growth, the number of leaves was not significantly influenced by the application of biochar. The mean number of leaves per plant was significantly influenced by biochar application ($P < 0.05$) at 5th, 7th and 8th WAP. The highest number of leaves (14.18) was observed in neem biochar at 10 t/ha while the least number of leaves (10.13) was observed in the untreated plots (Table 5).

The mean stem girth was significantly influenced by biochar application ($P < 0.05$) towards the end of the vegetative growth of the crop. Plots treated with bamboo biochar (10 t/ha) statistically produced the thickest mean stem of 4.71 mm, followed by those treated with neem biochar (10 t/ha) which also produced thicker stems of 4.10mm, while the control showed the thinnest stem of 3.56mm (Table 6).

Table 4: Effect of biochar on vine length (cm) of cucumber at 4-8 WAP

Treatments	Weeks after planting				
	4	5	6	7	8
Neem (10t/ha)	7.29	16.05ab	25.85	35.52	40.96ab
Bamboo (10t/ha)	5.75	20.03a	26.74	32.83	42.24a
Neem-Bamboo combination	7.15	12.24ab	18.03	29.16	39.37ab
Control	5.58	10.77b	19.05	25.43	34.06b
Level of significance	ns	*	ns	ns	*

Means followed by the same alphabet in the same column are not significantly different at 5% probability level. ns- Non significant *- 5% probability

Table 5: Effect of biochar on number of leaves of cucumber at 4-8 WAP

	Weeks after planting				
Treatments	**4**	**5**	**6**	**7**	**8**
Neem (10t/ha)	6.22	6.75ab	9.43	11.47a	14.18a
Bamboo (10t/ha)	5.78	7.74a	9.6	11.13ab	13.67ab
Neem-Bamboo combination	5.67	8.80a	11.55	10.93ab	13.05ab
Control	5.65	6.42ab	7.47	8.27b	10.13b
Level of significance	ns	*	ns	*	*

Means followed by the same alphabet in the same column are not significantly different at 5% probability level. ns- Non significant *- 5% probability

Effect on yield and yield components of cucumber

The application of biochar significantly affected yield and yield components of cucumber. The fruit weight, fruit length and fruit diameter of cucumber were significantly ($P \leq 0.05$) enhanced by the application of biochar as fertilizers but not significant for the number of fruit produced (Table 7). Cucumber fruit weight per hectare was significantly influenced by the application of biochar with the highest fruit weight per hectare of 1.50 ton/ha observed for combined application of 5 t/ha Neem and 5t/ha bamboo biochar and the least yield of 1.15/ha was observed in the control.

Effect of biochar application on proximate and mineral contents of cucumber fruits

The results of the proximate analysis of cucumber are shown in table 8. The results showed that some of the proximate contents of the cucumber fruits were significantly influenced (P≤ 0.05) by the application of biochar as fertilizer. Moisture content, fat and ash contents of the fruits were considerably affected the biochar fertilizers.

Table 6: Effect of biochar on stem girth of cucumber at 4-8 WAP

	Weeks after planting				
Treatments	4	5	6	7	8
Neem (10t/ha)	3.26	3.40	3.59	3.80	4.10ab
Bamboo (10t/ha)	3.35	3.43	3.65	3.92	4.71a
Neem-Bamboo combination	3.40	3.44	3.50	3.71	3.98ab
Control	3.18	3.27	3.33	3.42	3.56b
Level of significance	ns	ns	ns	ns	*

Means followed by the same alphabet in the same column are not significantly different at 5% probability level. ns- Non significant *- 5% probability

Table 7: Effect of biochar fertilizers on yield traits of cucumber

Treatments	Number of fruit	Fruit weight (ton/ha)	Fruit length (cm)	Fruit diameter(mm)
Neem (10t/ha)	3.08	1.38ab	12.70b	29.20a
Bamboo (10t/ha)	2.83	1.34ab	15.32ab	17.35ab
Neem-Bamboo combination	2.5	1.50a	17.00a	15.12b
Control	2.5	1.15b	12.80b	15.63b
Level of significance	ns	*	*	*

Means followed by the same alphabet in the same column are not significantly different at 5% probability level. ns- Non significant *- 5% probability

Table 8: Effect of biochar on proximate contents of cucumber fruit

Treatments	MOIST (%)	DM (%)	FAT (%)	ASH (g/100g)	CDF (g/100g)	CDP (g/100g)	CHO (g/100g)
Neem (10t/ha)	98.73	2.27	0.08	0.25	0.69	0.48	0.94
Bamboo (10t/ha)	97.73	2.27	0.10	0.29	0.66	0.46	0.86
Neem-Bamboo combination	97.5	2.5	0.09	0.21	0.73	0.52	0.94
Control	96.81	2.09	0.11	0.12	0.54	0.35	0.80
Level of significance	ns	ns	ns	ns	ns	ns	ns

MOIS-Moisture. DM- Dry Matter, CDF- Crude Fibre, CDP- Crude Protein, CHO- Carbohydrate; ns- Non significant *- 5% probability

Table 9 showed the result of the mineral content of the cucumber fruits. The study demonstrated that cucumbers grown with the combination application of Neem (5t/ha) and Bamboo (5t/ha) biochar had the greatest concentrations of potassium, phosphorus, and iron, measuring 147.95 mg/100 g, 25.04 mg/100 g, and 0.27 mg/100 g, respectively. Which are significantly higher at $p<0.05$ when compared with the sole application of Bamboo (10t/ha) and Neem (10t/ha). The calcium content ranged from 15.63mg/100 g to 16.69 mg/100 g, with control having the least value and Bamboo (10t/ha) biochar had the highest value. The result on magnesium showed that cucumber cultivated with Bamboo (10t/ha) biochar had the highest value of 24.96mg/100 g when compared with other applications.

Table 9: Effect of biochar on mineral contents of cucumber fruit

Treatments	K (mg/100g)	Ca (mg/100g)	Mg (mg/100g)	P (mg/100g)	Fe (mg/100g)
Neem (10t/ha)	146.54c	15.96b	12.10d	24.03c	0.19d
Bamboo (10t/ha)	146.98b	16.69a	13.77a	24.96a	0.22c
Neem-Bamboo combination	147.95a	16.12b	12.08b	25.04a	0.27a
Control	147.46ab	15.63c	12.66c	24.68b	0.24b
LSD (P≤ 0.05)	*	*	*	*	*

K- Potassium, Ca- Calcium, Mg- Magnesium, P- Phosphorus, Fe- Iron.
Means followed by the same alphabet in the same column are not significantly different at 5% probability level. ns- Non significant *- 5% probability

DISCUSSION

The physical and chemical properties of biochar are key to understanding the performances and mechanisms of biochar in the improvement of soil's fertility. The textural class of the experimental site was sandy loam and soils in this textural class are identified with susceptibility to leaching and erosion by run-off as reported by Amalu and Isong (2015). The soil was also observed to be neutral in pH, having low exchangeable cations (Ca^{2+}, Mg^{2+}, and K^{+}), OC, and total nitrogen. Essential nutrients such as total N, organic C, and exchangeable cations in coastal plain soils are mostly low as reported by Uko *et al.*, (2019) and Akpan *et al.*, (2022), the low status of these nutrients suggested low fertility in the experimental soil. As a result, a supplementary supply of nutrients through biochar to improve the growth and yield of cucumber was necessary.

Variations were observed from the effect of treatments on the soil pH. This difference in pH can be as a result of the inorganic elements and characteristics of individual biochar source. Jatav *et al*. (2021) noted that the temperature during pyrolysis, the length of production, and the non-pyrolyzed inorganic components in feed stocks all affect pH variations of applied biochar. The acidic pH observed across all treatments might be due to biochar oxidation during the process of pyrolysyis leading to formation of acids. According to Liu *et al*. (2020), the pH of alkaline soils can be lowered by the conversion of $NaHCO_3$ and Na_2CO_3 contents to $Ca(HCO_3)_2$ and $CaCO_3$.

The positive increase in organic matter content of biochar treated soils compared to soils with no application could be the direct result of an external organic matter input of biochar directly increasing the organic matter content of the soil. According to Gong *et al*. (2021), the addition of biochar was thought to have the potential to increase the organic carbon content and reserve in aggregates at all levels due to the high carbon content of biochar and its ability to promote the production and accumulation of soil organic matter. This is similar to the findings of (Tian *et al*., 2024) who observed an increase in soil organic matter content with application of biochar.

The effect of nitrogen content was inconsistent, with soils without amendment possessing a higher value. This difference observed in nitrogen content might be due to the characteristics of the biochar source, with neem biochar containing a higher level of nitrogen compared to bamboo biochar. Martí *et al*. (2021) observed that when different types of biochar were applied to different types of soil, the results on the nitrogen forms in the soil varied greatly. The majority of the impacts were primarily attributed to the properties of the soils under investigation, and then to the source of the biochar.

The amendments showed higher available phosphorus, calcium, magnesium and potassium content compared to control. This might be due to the inherent release of basic cations present in the biochar. According to Abewa *et al*. (2014), applying biochar increased the amount of calcium and magnesium that was available. This could be because biochar dissolves basic cations and has a high surface positive charge that prevents positively charged ions from leaching (Alkharabsheh *et al*., 2021). This is similar to the findings of Devika *et al*. (2018) who highlighted that application of biochar led to an increase in available phosphorus, potassium, calcium and magnesium over control.

Cucumber growth and yield responded positively to the amendments applied either singly or their combination. The growth traits of cucumber significantly increased with the application of biochar compared to the control, which is an indication that high levels of essential nutrients that promoted the vegetative growth of cucumber were present in the biochar, which could be subsequently released and absorbed by the plants. The application either with Neem biochar, Bamboo biochar or its combination reasonably gave better vegetative parameters compared to control plots at all sampling periods. Such enhanced growth with applied biochar has been established recurrently in a number of studies (Njoku *et al*., 2017; Adekiya *et al*., 2019). The increased vegetative growth may be attributed to enhanced nutrient availability and improved soil properties as reported by Adekiya *et al*. (2019). Also, the significant increase in growth parameters in response to biochar application could be attributed to the decomposition of organic matter components of these biochar sources to release nutrients to the soil and thus, cucumber plants.

Further results indicated that using biochar as fertilizer considerably enhanced fruit yield relative to control plots. From the study, the use of biochar as fertilizer either singly or its combination resulted in higher yield in terms of more number of fruits harvested, bigger fruits and higher fruit weight. The observed higher yield compared to the control may be a result of the significant increase in the vegetative attributes (e.g. vine length, No of leaves and stem girth) of the cucumber. The results obtained from this study thus agree with similar study by Agegnehu *et al*. (2015) who stated that improvement in soil properties following application of biochar led to an increase in the number of fruits, fruit length, vine length, and yield of cucumber relative to control. In addition, similar studies by Njoku *et al*. (2017); Adekiya *et al*. (2019) and Solaiman *et al*. (2020) attributed the effect of biochar on crop yield to be associated with nutrients retention, increased pH, base saturation available phosphorus, and increased plant available water.

Except for the crude protein, crude fibre, fat, and carbohydrate, the higher dry matter in cucumber grown with application of biochar as fertilizer is consistent with the result of Oyedeji *et al*. (2014). Also, ash content in cucumber fruits produced from plots with biochar application (either singly or its combination) was significantly higher possibly because of the balanced nutrient in the manure as suggested by Oyedeji *et al*. (2014). Biochar as fertilizers positively influence the mineral elements in cucumber fruits especially potassium and magnesium, which happened to be a very important mineral element as reported by Kowalewska, (2018). The high mineral contents could be as a result of additional mineral content from the biochar fertilizers being released into the soil as this agrees to the findings of Olatunde and Onisoya, (2017) that the mineral in the soil showed a relationship with the mineral content of the plant grown on it.

CONCLUSION

In the current study, all the vegetative parameters were significantly influenced by the application of the biochar when compared with those without biochar application. Also, the yield and yield components were considerably enhanced by the application of biochar. Mineral contents of the fruits were also considerably affected by the biochar application. Application of biochar as a soil amendment showed an increase in levels of selected soil properties. The study clearly showed that cucumber production can be promoted by the use of biochar which is expected to revitalize soil by improving the fertility and enhancing the crop performance of cucumber production thus, can be adopted as a great tool for sustainable agriculture.

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