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Optimizing the Use of Biochar in Okra (*Abelmoschus esculentus* L.) Production in Nigeria

Optimizando el uso del Biocarbón en la producción de Okra (*Abelmoschus esculentus* L.) en Nigeria

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Abstract

Soil fertility has been a challenge worldwide and increasing crop productivity is essential for food security. Consequently, to ameliorate this problem of low soil fertility, biochar is used. However, farmers are unaware of the optimal amount of Okra biochar dosage required, especially in Nigeria. This study, therefore, looked at the amount of biochar required to increase production and examined the effect of biochar on okra growth in a completely randomized design (CRD) experiment. Treatments used were biochar at two different levels: 50 $g.kg^{-1}$ and 100 $g.kg^{-1}$ of soil (treatment 1 and treatment 2), - NPK at the rate of 0.08929 $g.kg^{-1}$ of soil (treatment 3) and a control. The result showed that Okra planted with biochar grew significantly in height, weight, and number of fruits compared to those treated with NPK and Control with treatment 2 giving the best yield. We conclude that biochar contributes significantly to Okra growth and that the optimal amount required is 50 $g \cdot kg^{-1}$ of soil, we recommend that farmers use this dose to maximize the benefit of biochar.
Key word: *biochar, okra, production, soil fertility, Nigeria*

Resumen

La fertilidad del suelo ha sido un reto en todo el mundo y el aumento de la productividad de los cultivos es esencial para la seguridad alimentaria. En consecuencia, para mejorar este problema de baja fertilidad del suelo, se utiliza el biocarbón. Sin embargo, los agricultores desconocen la cantidad óptima de dosis de biocarbón de Okra necesaria, especialmente en Nigeria. Este estudio, por lo tanto, analizó la cantidad de biocarbón necesaria para aumentar la producción y examinó el efecto del biocarbón en el crecimiento de okra en un experimento de diseño completamente aleatorizado (DCA). Los tratamientos utilizados fueron biochar en dos niveles diferentes: 50 $g \cdot kg^{-1}$ y 100 $g \cdot kg^{-1}$ de suelo (tratamiento 1 y tratamiento 2), - NPK a razón de 0,08929 $g \cdot kg^{-1}$ de suelo (tratamiento 3) y un control. El resultado mostró que la Okra sembrada en biocarbón creció significativamente en altura, peso y número de frutos en comparación con las tratadas con NPK y Control, siendo el tratamiento 2 el que dio el mejor rendimiento. Concluimos que el biocarbón contribuye significativamente al crecimiento de Okra y que la cantidad óptima requerida es de 50 $g \cdot kg^{-1}$ de suelo, recomendamos que los agricultores utilicen esta dosis para maximizar el beneficio del biocarbón.
Palabra clave: *biocarbón, okra, producción, fertilidad del suelo, Nigeria*

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Introduction

Given that nearly all the world's arable land is presently cultivated, future food and fiber demand will have to be satisfied by increasing plant yield per unit of land area. Anthropogenic land degradation challenges our ability to meet food and fiber demand in the twenty-first century, with over 50 % of global soils deteriorating and certain locations approaching 70 % (Gomiero, 2016; Willet et al., 2019). Only roughly 11 % of the world's land area is classified as Class I-III arable land, which needs support a 50 % increase in agricultural production to feed 9.5 billion people by 2050 (Zilberman et al., 2013). Both onsite (e.g., erosion) and offsite (sediment deposition) factors contribute to land deterioration. Physical (crusting, compaction, erosion, desertification), chemical (acidification, leaching, salinization, fertility depletion), and biological (carbon oxidation/loss, microbial biodiversity) activities all have an impact on agricultural output on-site (European Comision [EC], 2020). Surface water eutrophication, groundwater contamination, and trace gas emissions (CO_2, CH_4, N_2O,) to the atmosphere are all offsite impacts. Many of the same biological, chemical, and physical soil qualities that are changed by onsite soil degrading processes also have an impact on soil fertility and plant nutrient availability.

Soil fertility has been improved, primarily through the application of fertilizers, the most important of which are inorganic fertilizers. However, inorganic fertilizer use is frowned upon since it poses a number of health and environmental risks (Cui et al., 2018). Inorganic fertilizers pollute groundwater are not environmentally beneficial (Shukla & Saxena, 2018; Zhang et al., 2013; Savci, 2012). Plant tissues absorb heavy metals more frequently as a result of continuous and consistent use of inorganic fertilizers, lowering crop nutritional and grain quality (Lenart-Boro & Boro, 2014; Abdiani et al., 2019; Maqbool et al., 2020). Overuse of inorganic fertilizers, as a result of nutrient leaching, deterioration of soil physical properties, the buildup of harmful compounds in water bodies, and other factors, has resulted in soil, air, and water pollution, as well as serious health, environmental problems and biodiversity loss (Cui et al., 2018; Sharma & Singhvi, 2017).

Organic fertilizer, particularly biochar, is a better eco-friendly choice (Abukari et al., 2021). Biochar is a carbon-rich, highly porous substance made from organic biomass after it has been pyrolyzed (Tomczyk et al., 2020). Biochar production is a long-term solution for trash and disease management (Oni et al., 2019). It retains 50 % of the original carbon, which is extremely recalcitrant in nature; as a result, its synthesis aids in carbon sequestration by trapping carbon in plant biomass (Tomczyk et al., 2020). The temperature, heating rate, and residence time maintained during biochar formation have a strong correlation with the elemental makeup and structural structure of the material (Zhao et al. 2018). In addition to biochar, some bio-oil and gases are created, which can be used to generate energy and various compounds (Zhao et al., 2018).

Jeffery et al. (2011) provided a general estimate of a 10 % increase in crop yield with biochar soil amendment in a meta-analysis of data from 16 articles that were accessible up to March 2010. Additionally, it was found that adding biochar to soil increased crop productivity significantly, with an 8.4 % increase in crop production and a 12.5 % increase in aboveground biomass, in 103 research published before April 1st 2013 (Liu et al., 2013). Additionally, a considerable rise in crop output and aboveground biomass was noted by Biederman & Harpole (2013) after adding biochar to the soil.

Recent studies have revealed that the reactions of soil and plants to the application of biochar can be either positive or negative (Gravel et al., 2013), or neutral (Ali Jaaf et al., 2022), depending on the type of feedstock, the temperature at which it is pyrolyzed, the application rate and method, the type of crop and soil, and the environmental circumstances (Joseph et. al., 2021; Rivelli et al., 2022).

The lack of understanding about the proper proportion of biochar to use, particularly in Africa, is a challenge. Furthermore, because there is less research on the ideal amount of biochar necessary, we undertook an experiment to determine the best quantity. As a result, the specific objectives of the study were to: 1) examine the effect of biochar on the physical features (plant height, number of fruit, fruit weight, and fruit length) of okra; 2) examine the effect of biochar on the yield of Okra; and 3) determine the optimum biochar dose required per kg of soil.

Material and Methods

The study area

The experiment was carried out at the Faculty of Agriculture screen house which is part of the University of Ilorin Teaching and Research Farm, University of Ilorin, Ilorin, Kwara State. The University of Ilorin is located in the Southern Guinea Savanna Ecological Zone of Nigeria, which lies on latitude and longitude (N 8^0 28' 53.3" E 4^0 40' 28.9"). It is categorized under the bimodal rainfall pattern, with high rainfall in June and September, and a break between mid-July and August. This city has a tropical climate. The annual rainfall in the area is about 1200 mm, and the least amount of rainfall occurs in January. The average in this month is 10 mm. Most of the precipitation here falls in September, averaging 232 mm and temperature varies between 33 ^{0}C and 34 ^{0}C during the year, with an average temperature of 24.5 ^{0}C. The temperature is the highest on average in March, at around 29 ^{0}C. August is the coldest month, with the temperature averaging 24.5 ^{0}C with a distinct dry season from December to March. Throughout the year, the temperature varies by 4.5 ^{0}C.

Collection and preparation of materials

The biochar was gotten from Hill crest agro-allied industry, Offa, Kwara State. The biochar was produced with rice husk. Viable seeds of okra were obtained from a store at the fate junction, Ilorin. The NPK (15:15:15) was bought from an agrochemicals store at Fate junction, Ilorin. The soil was collected from the Faculty of Agriculture nursery area. The soil collected was sterilized by heating in a drum to minimize the incidence of spores and disease-causing organisms and then allowed to cool before use. The sterilized soil was measured at the rate of 5 kg/bucket. The soil has a definite sandy-loamy textural characteristic and a pH of 6.5, which is mildly acidic.

Field experimental layout, land preparation, and crop

In this study, the experiment was carried out using a Completely Randomised Design (CRD). Treatments used were biochar at two different levels, and NPK was applied at the rate of 0.08929 g.kg^{-1} of soil. Biochar was hand applied into the soil using two rates: 50 g.kg^{-1} and 100 g.kg^{-1} of soil; NPK 15:15:15 and a control (soil that received no treatment). Each treatment was replicated seven times as well as the control making a total of 28 treatments. the treatments were labeled thus:

Treatment 1: Biochar application rates at 50 g.Kg^{-1} of soil; B_1R_1, B_1R_2, B_1R_3, B_1R_4, B_1R_5, B_1R_6 and B_1R_7

Treatment 2: Biochar application rates at 100 g.kg^{-1} of soil ; B_2R_1, B_2R_2, B_2R_3, B_2R_4, B_2R_5, B_2R_6, B_2R_7

Treatment 3: NPK treatment; NR_1, NR_2, NR_3, NR_4, NR_5, NR_6, NR_7

Treatment 4: Control; CR_1, CR_2, CR_3, CR_4, CR_5, CR_6, CR_7

Weed control, manual thinning, and watering of the plants

Manual thinning that is, removal of excess vegetable was carried out to avoid overcrowding and competition for photosynthesis, water and nutrient and this help the viable plant to grow perfectly. Weeding was done manually by hand-pulling occasionally till harvesting time. Watering can was used to irrigate the plants very early in the morning on daily basis.

Data collection

Data collection commenced one week after planting and was done weekly. The following parameters was collected.

Plant Height

Plant height was recorded for each plant in the bucket of okra using a ruler. The measurements were taken from the soil level to the highest point of the stem apex and the mean recorded.

Number of fruit

Total number of fruits on each selected plant of okra of each bucket was counted and recorded.

Yield of the plants

After harvesting, the yield was measured using a weighing balance.

Data analysis

Data collected, such as plant height, number of fruits and fruit length collected, were subjected to Analysis of Variance (ANOVA) using GenSat 17th Edition. The mean was separated using Least Significant Difference (LSD) at 5 % probability level. Also, profitability ratios i.e gross margin, operating ratio and rate of returns to investment was used.

Analysis of variance

Analysis of variance (ANOVA) was used to analyze objectives 1 and 2 which are: To know the effects of biochar usage on the physical characteristics of okra and to examine the effect of biochar on the yield of okra using the mean average of the sampled plant.

Results and discussion

Effect of biochar and NPK fertilizer on the height of okra plant

The effects of Biochar and NPK fertilizer on the growth of okra plant height are shown in Table 1. The treatments significantly affect the growth of the plant height. Throughout the weeks of data collection, there was no significant difference between the two applications rate of Biochar. This is due to the fact that the micro- and macronutrients found in biochar are slowly released into the soil and taken up by plants, increasing plant productivity and yield (Thomas et al., 2013; Hammer et al., 2014; Drake et al., 2016; Kim et al., 2016). As a result, the beneficial and actual effect of biochar could be clearly observed in long-term experiments. Nevertheless, their effects significantly differ from the effects of NPK fertilizer and the control except at the fifth and eighth week after planting, where their effects were significantly the same with the control. Plants treated with NPK fertilizer had the shortest plant height throughout the weeks while Biochar had the highest effect in increasing the height of the okra plant. This result is in tandem with the works of Williams & Qureshi (2015), who reported a significant effect of Biochar in increasing the plant height growth of the okra plant.

Effect of Biochar and NPK fertilizer on the yield performance of okra plant

Table 2 shows the effects of Biochar and NPK fertilizer on the number of fruit, the fruit's weight, and the average fruit length of the okra plant. The treatments significantly affect the number of fruits, the fruit's weight, and the fruit length. Plants treated with 50 g of Biochar per kilogram of soil had the highest number of fruits with the highest fruit weight, while plants treated with 100 g of Biochar per kilogram of soil and those treated with NPK fertilizer significantly had the same number of fruit and fruit weight. The least number of fruit and smallest fruit weight were obtained from the control plants. Fruits harvested from a plant treated with biochar at 50 $g.kg^{-1}$ of soil had the same length as those treated with biochar at 50 $g.kg^{-1}$ of soil this is probably due to the duration of the experiment

Table 1. Effect of Biochar and NPK fertilizer on the growth of okra plant height (cm).

TRTS	1WAP	2WAP	3WAP	4WAP	5WAP	6WAP	7WAP	8WAP
B1	8.15^{a}	13.11^{a}	18.61^{a}	23.07^{a}	24.82^{a}	25.68^{a}	25.96^{a}	26.03^{a}
B2	8.38^{a}	13.04^{a}	18.89^{a}	22.86^{a}	24.86^{a}	25.71^{a}	26.00^{a}	26.07^{a}
NPK	5.36^{c}	8.32^{c}	12.10^{c}	15.33^{c}	16.64^{b}	17.14^{c}	17.36^{c}	17.62^{b}
CON	7.48^{b}	10.93^{b}	16.75^{b}	21.07^{b}	23.11^{a}	23.75^{b}	23.79^{b}	23.84^{a}
$LSD_{(0.05)}$	0.42	0.53	0.60	0.89	3.53	0.92	0.91	2.96

Key notes: Mean with same letter in a column are significantly the same, B1 = 50g of Biochar/kg of soil, B2 = 100g of Biochar/kg of soil, CON = Control, WAP = Week after planting, $LSD_{(0.05)}$ = Least significant difference at 5 % of significance, NS = Not significant and it is consistent with observation of Glaser et al., 2002 that Biochar performs better in the second and third years of use than it does in the first. However, the length of fruits harvested from biochar-treated pots significantly differs from the fruit length of the control plants and plants treated with NPK fertilizer. This finding is in tandem with the report of Farias et al., 2020, who reported a significant effect of biochar in increasing the yield of okra plants.

Table 2. Effect of Biochar and NPK fertilizer on the yield of okra plant (kg).

TRTS	NUMBER OF FRUIT	FRUIT WEIGHT (g)	AVERAGE FRUIT LENGTH (cm)
B1	5.00[a]	26.37[a]	5.06[a]
B2	3.71[b]	21.09[b]	4.99[ab]
NPK	3.86[b]	17.37[b]	4.13[bc]
CONTROL	2.43[c]	12.16[c]	4.49[c]
$LSD_{(0.05)}$	0.59	4.12	0.54

Key notes: Mean with same letter in a column are significantly the same, B1 = 50 g of Biochar/kg of soil, B2 = 100 g of Biochar/kg of soil, WAP = Week after planting, $LSD_{(0.05)}$ = Least significant difference at 5 % of significance, NS = Not significant

Conclusion

This study shows that the use of Biochar as a soil fertility improver was able to increase both the vegetative growth and reproductive performance of the okra plant. The two application rates of Biochar significantly increased the height of the okra plant throughout the weeks of data collection except for the fifth and eighth weeks, where their effect was not manifested.

The effects of both application rates on plant height and average fruit length were the same however, their effects on the number of fruit and fruit's weight differs. 50 g of Biochar per kilogram of soil significantly had the highest number of fruit and the highest fruit weight. Its yield significantly differs from the yield of 100 g of Biochar per kilogram of soil, NPK fertilizer, and control.

NPK fertilizer and 100 g of Biochar per kilogram of soil had the same effects on yield, but their effects significantly differ from the control, which had the least performance. 50 g of Biochar per kilogram of soil having the least operational ratio to produce okra had the highest return on investment and is therefore recommended as the optimum required for farmers.

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Author contributions

MF-S: Conceptualization of the work, experimental design, review of statistical analysis of results, discussion of results, drafting of the manuscript, revision of the manuscript, and supervision of the study

M-M: Revision of the manuscript, support, Logistics management

O-I: Support, Logistics management

KK-O: Revision of the manuscript, support, Logistics management

V-A: Experimental design, execution of fieldwork, statistical analysis of results, discussion of results

S-S: Experimental design, execution of fieldwork, statistical analysis of results, discussion of results

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Conflicts of interest

The signing authors of this research work declare that they have no potential conflict of personal or economic interest with other people or organizations that could unduly influence this manuscript

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