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SHORT COMMUNICATION

Assessing the impact of oil palm husk-derived biochar on soil characteristics and tomato yield in Okitipupa, coastal agroecosystems

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ABSTRACT

In coastal ecological agriculture, soil and fertility conditions limit tomato growth and productivity. Organic synthetic biochar can boost soil production. At Olusegun Agagu University of Science and Technology Teaching and Research Farm, biochar application rates (10 t ha^{-1}, 7.5 t ha^{-1}, 5 t ha^{-1}, and 0 t ha^{-1}) were tested on soil physical and chemical properties, phenological parameters, and tomato variety fruit number and yield. The trials were performed three times in an RCBD. Application of 10 t ha^{-1} considerably enhanced soil pH, organic carbon, total nitrogen, and accessible phosphorus and potassium. At 7.5 t ha^{-1}, the highest fruit output (686.2 kg ha^{-1}) and harvest weight (3452 kg) were reached, whereas 10 t ha^{-1} had the highest biomass and harvest index relative to the control group. The 7.5 t ha^{-1} biochar application rate successfully improved yield, nutrient efficiency, and economic returns in open-field tomato agriculture.

Keywords: biochar, fertilizer management strategies, utilization efficiency, and yield

INTRODUCTION

Reducing soil nutrient leaching, bioavailability of pollutants, carbon sequestration, greenhouse gas emissions, and crop productivity to improve environmental quality are agroecosystem researchers' aims (Ippolito et al., 2016). This underscores the importance of locally available, economically viable, and eco-friendly technologies, such as biochar utilization., Biochar, a soil conditioner that is obtained from the pyrolysis of organic residues such as oil palm wastes common in the study area, under a low oxygen environment emerges as a promising tool for improving the soil physiochemical attributes of most degraded farmlands as a result of continuous cropping and land management. Thus followed their loss of fertility; bolstering soil organic matter and cation exchange capacity, among others (Ippolito et al., 2016; Oladitan and Olamilekan, 2023,). Biochar is rich in organic carbon and boasts active functional groups and unique structures that augment its capacity to interact with toxic metals (Mohamed et al., 2017). While the benefits of biochar application output on cultivated crops are widely acknowledged, its effectiveness hinges on variables like rates of application for soil type, and crop variety, sources of materials for biochar, and prevailing environmental factors that are still understudied for a large-scale utilization (Eissa, 2019).

Tomato (*Solanum lycopersicum* L.) is one of the most widely consumed fruits and vegetables in the world (Dari et al., 2018). Tomatoes are important for food, medicine, nutrition, security, and livelihood worldwide (Kurina et al., 2021). A report from FAOSTAT (2021) ascertained that production record in humid ecological zones is still below the average yield of approximately 7.5 t ha^{-1} recorded for most producing parts of Nigeria, which is lower than the tropical Africa 13.5 t ha^{-1} and the world 22 t ha^{-1} a mean output yield respectively. Forecasting the potential crop achievable yield, and the ensuing yield gap are essential to address the imperative of meeting rising food production needs for a burgeoning global population. Hence, increasing local production is critical for satisfying the needs of both fresh and processed tomatoes (Ugonna et al., 2015). The impacts of environmental factors (soil and weather conditions), genetic factors, and crop management practices have all been reported to account for the low level of tomato production in humid zones (Oladokun et al., 2019). Typically, Soil type and fertility status as a result of weather factors and land management have been identified as major constraints in tomato growing and yield output in coastal agroecology (Oladitan et al., 2020). The application of mineral fertilizer provides a solution to improve the productivity of degraded soils; however, their use has been restricted by the cost of purchasing, availability, and negative contributions to soil properties. Aliyu et al. (2003) found that extended mineral fertiliser use lowers fruit output by delaying fruit set, delaying ripening, and causing massive vegetative growth. Organic fertilizers are environmentally beneficial, readily available, and cheaper. However, bulkiness, mineralization, and improper application rates limit their utilization.

Innovative techniques and technologies for the utilization of biochar, an organic-based soil amendment, have been endorsed as a means of improving the soil to enhance crop yields. Biochar compounds can improve the physicochemical properties and biological activities of agricultural soils for tomato production (Adebajo et al., 2021). Biochar is rich in organic matter, and its addition to soil has the potential to increase carbon in the soil over a long period due to its recalcitrant nature (Lehmann et al., 2006). Studies by Chen et al. (2015) and Liu et al. (2020) have demonstrated that appropriate biochar application rates can bolster fruit weight, increase fruit yield per plant, and elevate overall yield across various vegetable crops, including tomatoes. These findings underscore the positive impact of biochar on enhancing the yield potential of tomato plants. However, there are few or no studies that evaluate the agricultural effect of biochar-based organic materials on the tomato plant. As a result, this investigation was intended to assess the effects of different rates of application of biochar on soil properties and tomato yields. Therefore, the present study aimed to determine the most effective application rate for Okitipupa, located in a coastal agroecology zone.

MATERIALS AND METHODS

Soil fertility conditions and nutrient sources for tomato production in ecologically unfavourable areas were managed under rain-fed conditions at the Olusegun Agagu University of Science and Technology (OAUSTECH) Teaching and Research Farm Okitipupa during the 2021 and 2022 growing seasons. The experimental site is approximately located at 06°25' and 06°25' north latitude and 04°35' and 04°50' east longitude in the rainforest area of southwestern Nigeria. The climatic conditions of the Okitipupa axis are characterized by a pronounced rainy season, which occurs almost exclusively during seven months (April to October). The rainy season pattern has two peak rainfall periods, the first pattern occurs from May to July and the peak rainfall period occurs in June. The other peak pattern commences from September to October, with a short dry period in August between the two patterns (Omotosho et al., 2000). Daily temperatures range from 25 to 28 °C and remain constant for most months of the year, with an average temperature of 27 °C and relatively high humidity (60 to 80%). The average amount of solar radiation during most months of the year is 17 MJ/m2/day. There are two prominent geological formations in the area: the precambium bedrock complex with granite in the northern area, and the near tertiary sandy sediments below 300 m. The oil palm husk-based biochar and soil samples were randomly collected from the experimental site at a depth of 0 to 30 cm. The samples were subjected to a comprehensive laboratory analysis before planting and after the growing season for routine and proximate analysis (pre-planting and post-planting soil analysis) (IITA Handbook, 2011). The effects of biochar application on tomato plant growth and yield were evaluated. The treatments were four biochar application rates (0 kg ha^{-1} (control), 5 t ha^{-1}, 7.5 t ha^{-1}, and 10 t ha^{-1}). The biochar rates were incorporated into soil 10 days before transplanting 28-day-old seedlings of the *Platino* variety of tomato procured from a registered agricultural company to the field.

Tomato seedlings were arranged in a randomized complete block design (RCBD) (Gomez and Gomez, 1984), in a plot area of 1.5 × 2 m2 and a spacing of 1 m, repeated three times. Each seedling was planted individually in holes at a planting distance of 30 cm x 90 cm at a planting density of 55,556 plants per hectare. Standard agronomic practices were implemented, including hand weeding two weeks after transplanting, application of insecticides, and staking of plants during fruiting to prevent lodging.

Data collection began two weeks after transplantation and continued every two weeks until harvest. Data on plant height, stem circumference, number of flowers, number of fruits per plant, and harvested weight were collected weekly from three randomly selected marked plants in each plot. Yields are calculated on fresh weight by summing the total harvestable yield from the net plots and extrapolating to one hectare. Analysis of variance (ANOVA) was performed on the collected parametric data using the SAS statistical software package, with significance set at 5%.

RESULTS AND DISCUSSION

The values of the nutrient status of the soil from the experimental site to a depth of 0-15cm before planting are shown under Control in Table 1. The biochar application rate had a significant effect on the percentage of sand, silt, and clay particles. The soil nutrient status values from the experimental site (0-15 cm depth) before planting are listed under the "Control" item in Table 1. The amount of biochar applied has a significant effect on the proportions of sand, silt, and clay particles. The size and percentage of soil particles vary significantly. For biochar, the sand content increased by 70%, 72.5%, and 68% and decreased by 10.8% at 5 t ha^{-1}, 7.5 t ha^{-1}, and 10 t ha^{-1}, respectively. A decrease ranging from 10.8%–20.0% was recorded in the parentage quantities of clay and silt, respectively. The bulk density of biochar dropped from 1.51 g/dm^{-3} to 1.31, 1.34, and 1.42 g/dm^{-3} ha^{-1} at 5 t, 7.5 t, and 10 t ha^{-1}. Able et al. (2013) found that biochar treatment on poor soil decreased soil density and increased total pore volume and water-holding capacity. Oguntunde et al. (2004) found that biochar reduced soil bulk density by 9% compared to surrounding field soils at a charcoal site.

Biochar demonstrates the potential to enhance soil chemical properties. Initial Soil pH was initially slightly acidic (pH 5) (without biochar application, control). A significant difference was observed for biochar treatment rates, rising from pH 5 to 6.09 for 10 t ha^{-1} and pH 6.06 for 5 t ha^{-1}. The cation exchange capacity (CEC) increased significantly with increasing soil biochar content, but no significant differences were observed between treatments. Similar trends were observed for soil copper and aluminium concentrations but with significant differences. These results suggest that biochar treatment can act as a pH buffer (Khan et al., 2017). This is consistent with previous reports showing that biochar amendments can reduce the bioavailability of toxic metals due to their high pH, CEC, and soil organic carbon content (Mohamed et al., 2016; Khan et al., 2017).

Phosphorus and potassium values differed significantly between treatments. The application rate of 5 t ha^{-1} increased available phosphorus by 8.05%, whereas 10 t ha^{-1} increased it by 7.95%. The 5 t ha^{-1} biochar treatment had more phosphorus than the control, followed by the 10 t ha^{-1} treatment. Biochar may improve phosphorus availability due to its adsorption and desorption capacities. Using 10 t ha^{-1} of biochar enhanced the potassium concentration in cotrol from 0.16 cmol kg^{-1} to 1.85 cmol kg^{-1}. The application of 7.5 t ha^{-1} yielded 1.88 cmol kg^{-1}. When applying 5 t ha^{-1}biochar, the concentration was 1.21 cmol kg^{-1}. Although there were no significant differences between treatments, charcoal feedstock potassium components increased soil-available potassium (Pandit et al., 2021). The lowest total organic carbon content (1.04) was at 5 t ha^{-1}, while 10 t ha^{-1} biochar application increased it substantially. Total calcium at 0 t ha^{-1} was 1.20 cmol kg^{-1}. Biochar application rates of 10 t ha^{-1} enhanced concentration.

Table 1. Pre (control) and post-soil analysis (soils amended with different amounts of biochar)

Parameters	10 t h^{-1}	7.5 t ha^{-1}	5 t ha^{-1}	Control/Initial soil status
pH	6.09±0.13^{b}	6.04±0.06^{b}	6.06±0.08^{b}	5.00±0.0^{a}
organic carbon	1.47±0.05^{b}	1.13±0.18^{ab}	1.04±0.06^{a}	1.12±0.1^{ab}.
organic matter	-	-	-	2.15
(EAL) SATURATION	-	-	-	2.8
K (mg kg^{-1})	1.85±0.22^{b}	1.74±0.37^{b}	1.21±0.29^{b}	0.16±0.04^{a}
P (mg kg^{-1})	7.95±0.08^{b}	7.73±0.39^{b}	8.05±0.07^{b}	5.26±0.37^{a}
Na (mg kg^{-1})	0.69±0.44^{a}	0.72±0.40^{a}	0.79±0.30^{a}	0.61±0.55^{a}
Ca (mg kg^{-1})	2.92±0.12^{b}	2.78±0.32^{b}	3.01±0.01^{b}	1.20±0.28^{a}
Mg (mg kg^{-1})	3.77±0.33^{b}	3.69±0.44^{b}	3.08±0.11^{b}	0.80±0.28^{a}
CEC (meg 100 g^{-1})	7.98±0.04^{a}	8.58±0.60^{a}	8.12±0.17^{a}	8.15±0.21^{a}
% sand	67.95±0.08^{a}	72.68±0.45^{d}	70.06±0.08^{c}	41.00±0.0^{a}
% clay	12.16±0.18^{b}	10.84±0.23^{a}	14.68±0.46^{c}	39.00±0.0^{d}
% silt	19.93±0.10^{c}	16.98±0.03^{b}	15.77±0.33^{a}	20.00±0.0^{c}
Bulk Density (gm)	1.31	1.34	1.42	1.51
Texture	SL	SCL	SCL	CL

Note: SL-Sandy-loam; SCL-Sandy-clay-loam; CL- Clay-loam.

A summary of the yield and yield component data is shown in Table 2. The biochar application rates on the anthesis day were significantly different but ranged from 21.61-21.50 among the treatment effects. The control plot attained the earliest anthesis day (approximately 21 days), which was statistically similar to that of the other application rates but significantly different from each other application rates. These corroborate the findings of Oladitan and Akinseye (2014) that anthesis is a genetically based process, but it could also be influenced by environmental factors. The richness of available exchangeable cations in biochar could also play a significant role.

The mean comparisons revealed a significant difference in fruit weight concerning the biochar application rate. The highest mean fruit weight was recorded at 10 t ha^{-1} (85.95 g), followed closely by that at 7.5 t ha^{-1}, for which a weight of 78.7 g was recorded, while the control plot (41.48 g) had the lowest fruit weight. It could be inferred that the number of fruits produced is a result of nutrient availability in the soil and environmental interactions. (Zhang et al., 2022). The total harvested weight (kg ha^{-1}) significantly differed among the treatment groups. The 7.5 t ha^{-1} application rate had the maximum harvested weight (3452.8 kg) closely followed by the 10 t ha^{-1} application (3446.5 kg) and was significantly different from that of the 5 t ha^{-1} and control treatments, which had the lowest values (2197.8 kg and 1953.2 kg, respectively). The shoot dry weight and harvest indices were influenced by biochar application in the same pattern. There was a significant difference among the treatments in the decreasing order of 7.5t/ha>10t/ha>5t/ha > control because of the response of the test crop to nutrient availability. Table 2 summarizes data on yield and yield components. The application amount of biochar during the flowering period varied significantly, but the treatment effect ranged from 21.61 to 21.50. The control plot reached the earliest day of flowering (approximately 21 days), which was statistically equivalent to, but significantly different from, other application rates. These results corroborate the findings of Oladitan and Akinseye (2014) that flowering is a genetic process but may be influenced by environmental factors. The abundance of exchangeable cations in biochar can also play an important role.

The average comparison showed significant differences in fruit weight for biochar dosage. Average fruit weight was highest at 10 t ha^{-1} (85.95

g), followed by 7.5 t ha^{-1} at 78.7 g, while the control plot (41.48 g) had the lowest fruit weight. This suggests that the amount of fruit produced is a result of nutrient availability in the soil and interaction with the environment (Zhang et al., 2022). There were significant differences in total harvest weight (kg/ha) between treatment groups. The application rate of 7.5 t ha^{-1} produced the highest harvest weight (3452.8 kg), closely followed by the 10 t ha^{-1} application rate (3446.5 kg), which was significantly different from the 5 t/ha application rate and the control treatment values (2197.8 kg and 1953.2 kg respectively). Biochar affected shoot dry weight and harvest indicators similarly. There were substantial differences in test plant response to nutrient availability across treatments, 7.5 t ha^{-1}> 10 t ha^{-1}> 5 t ha^{-1}> control. Plants treated with greater biochar rates had better nutritional characteristics. When put in the soil, biochar increases fertility since it contains plant nutrients. Carbon from the treatment may also help soil nitrogen-fixing bacteria develop (Zhang et al., 2021).

Table 2. Effects of biochar application rate on the yield and yield components of tomato plants

Treatment	Anthesis day	Fruit wt.(g) (wet)	Fruit no./m2	Harvested wt.(kg/ha)	Shoot (dry wt.(g)	Harvest index
10t ha^{-1}	21.61^{a}	85.95^{a}	635.8^{b}	3446.5^{b}	24.86^{b}	0.050^{b}
7.5t ha^{-1}	21.36^{b}	78.72^{b}	686.2^{a}	3452.8^{a}	25.37^{a}	0.073^{a}
5t ha^{-1}	21.53^{ab}	76.42^{b}	567.6^{c}	2197.8^{c}	18.63^{d}	0.048^{cb}
Control	21.50^{ab}	41.48^{c}	426.5^{d}	1953.2^{d}	19.24^{c}	0.036^{dc}
L.S. D	0.163	0.066	8.58	7.070	0.033	0.0026

Means with similar weights in the same treatment are not significantly different ($p< 0.05$; DMRT).

CONCLUSION

Biochar treatment at various rates increased crop growth and yield, possibly via improving soil physicochemical qualities and root development. Biochar can improve soil chemical qualities like pH, organic carbon, N, P, and K, increasing tomato fruit output in sandy clay loam soil. Biochar treatment, especially at greater rates, increased soil nutrients including N, P, and K, improving tomato yield. This controlled study on the agronomic effects of biochar made from oil palm bunch solid waste in tomato production demands additional study across varied crops/vegetables, soil types, and agroecological zones in Okitipupa. Due to fertiliser scarcity among subsistence farmers, considerable research and outreach by relevant authorities is needed to promote biochar-based organic fertilisers. These efforts may help farmers adopt biochar.

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AUTHOR CONTRIBUTION

All authors made equal contributions to the conception, design, and execution of the research, as well as to the analysis of the results and the drafting of the manuscript.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

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