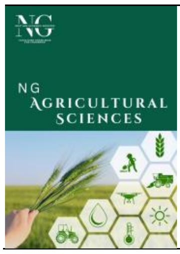

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Effects of Biochar and Compost on Soil Nutrient Dynamics and pH in Alfisols across Two Cropping Cycles at Ibadan, Nigeria

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ABSTRACT

This study evaluated the residual effects of biochar and compost on soil nutrient dynamics and pH in an Alfisol over two tomato cropping cycles under screen house conditions at the University of Ibadan, Nigeria. Biochar and compost were produced from maize stover, cow dung and moringa leaves and applied at 0, 15, 30, 45 and 60 kg/ha in a completely randomized design with three replications. Soil samples collected after each cropping cycle were analyzed for pH, total nitrogen (N), available phosphorus (P) and exchangeable potassium (K). Biochar contained higher K (3.20 mg/kg) but slightly lower N and P than compost, which was richer in P (1.44 mg/kg), indicating contrasting short against long term nutrient availability. Across two cropping cycles, biochar-amended soils retained more N than the control, although N declined by 36–84.9% depending on rate, reflecting high N mobility. In contrast, biochar significantly increased soil P and K storage, with average increments of 112.98% and 405.9%, respectively, over one cropping cycle. Compost significantly enhanced N at 15 and 30 kg/ha (up to 12% increase) and sequestered P and K by 173.4% and 123.68% on average over two cycles. Both amendments increased soil pH from slightly acidic (~5.2) to near neutral–alkaline levels (7.6–7.8), demonstrating strong liming effects. Overall, biochar and compost proved complementary organic amendments for sustaining N, P and K availability and ameliorating soil acidity in Alfisols, supporting their use as climate-smart, low-input options for smallholder tomato production.

1. INTRODUCTION

Soil fertility degradation is a persistent challenge in Sub-Saharan Africa (SSA), significantly limiting agricultural productivity and food security (Tefara et al., 2024; Dimkpa et al., 2023). To address this, sustainable soil management strategies are essential to improve soil health, enhance crop yields, and mitigate adverse environmental impacts. One promising approach involves the application of organic soil amendments such as biochar and compost. These materials are increasingly recognized for their potential to improve soil structure, enhance nutrient availability in soils and improve soil health

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for sustainable crop production (Pandian et al., 2024; Fornes et al., 2024).

Conventional farming systems in many parts of Nigeria and other developing countries still rely heavily on synthetic fertilizers, which, although effective in the short term, contribute to soil acidification, nutrient imbalances, and ecological damage when used excessively (Akanmu et al., 2023; Abebe et al., 2022; Reda et al., 2017). This justifies the call for the use of organic amendments, which are eco-friendly and have been reported to sustainably improve soil health (Singh et al., 2024). Despite the benefits, the widespread adoption of these organic amendments faces several limitations. Farmers often lack access to quality biochar and compost or the technical know-how to apply them effectively (Mahmoud et al., 2021; Rogers et al., 2021). Additionally, there is variability in the composition of organic materials based on their source, which affects their consistency and predictability in field conditions (Kebede et al., 2023; Adunga, 2016). Nutrient leaching, especially of nitrogen, remains a concern, as organic materials may not hold nitrogen as effectively as desired, which affects the overall performance of crops (Valenzuela, 2024; Noulas et al., 2023).

There is an urgent need for sustainable nutrient management solutions that align with climate-smart agricultural practices (Kottegoda et al., 2023; Zerssa, 2022). This study is therefore justified by the necessity to explore affordable and environmentally friendly alternatives to chemical fertilizers. It seeks to provide evidence-based recommendations for the practical application of biochar and compost as viable soil amendments. These findings will be particularly relevant for smallholder farmers who aim to increase crop productivity with minimum nutrient inputs.

The objectives of this study are to:

i. Evaluate the effects of varying application levels of biochar and compost on the concentrations of nitrogen (N), available phosphorus (P), and potassium (K) in alfisols over two cropping cycles.

ii. Assess the impact of these soil amendments on soil pH levels, and determine their potential to correct soil acidity.

iii. Compare the nutrient retention efficiency of biochar and compost, with a focus on their suitability as sustainable soil fertility enhancement tools.

2. MATERIALS AND METHODS

The research work was carried out in the screen house at the Department of Agronomy, University of Ibadan, Ibadan, Nigeria. Tomato variety (UC 82B) was obtained from Agritropic Nigeria Limited, Bodija Market, Ibadan, Oyo State. The compost studied for the residual study was made from the combination of maize stovers, cow dung and moringa leaves in a ratio of 1: 1.7: 2.3 (w/w) with C: N ratio of 25:1 as recommended by Rynk (1992). The feedstock used for the biochar was also a combination of maize stovers, cow dung and moringa leaves. Maize stover and moringa were collected from crop fields, while cow dung was obtained from the dairy unit both at the Teaching and Research farm, University of Ibadan. The biochar feedstock was mixed to a ratio of 3: 1.5: 1 (w/w) (maize stover, cow dung and moringa leaves) to enhance nitrogen and phosphorus enrichment while maintaining sufficient plant materials for stable biochar production

The biochar used in the initial experiment was produced with a pyrolyzer consisting of three main sections: an insulated outer metal chamber fitted with a lid, an inner cylindrical chamber with a separate cover, and a lower compartment through which the charred material was removed. The dried feedstock materials were loaded into the inner cylinder and sealed properly. Burning charcoal was then introduced into the space surrounding the inner chamber, after which the reactor was covered to initiate the pyrolysis process. The duration of heating was monitored with a timer, and carbonization was completed after approximately five hours at about 600°C. At the end of the process, the partially combusted biomass remaining inside the chamber was recovered as biochar. The hot char was discharged through the lower outlet, removed from the base of the unit, and lightly quenched with water to stop further combustion. It was subsequently air-dried for one week before application.

For compost preparation, the feedstock mixture comprising maize stover, cow dung, and moringa leaves was first cut into smaller pieces to accelerate decomposition by increasing the exposed surface area. The materials were then heaped, moistened adequately, and mixed thoroughly to ensure uniformity. Composting was carried out under aerobic conditions, with the heap turned at weekly intervals and watered when necessary to maintain suitable moisture for microbial activity. After about three months, the material had decomposed into a dark, stabilized, humified compost. The compost was then allowed to cure for an additional three weeks before being bagged for use.

The residual study was carried out in a screen house using a completely randomized design with three replications. Tomato seedlings were first established in nursery trays and maintained for three weeks. Thereafter, two healthy seedlings were transplanted into each of the 30 experimental pots. Two weeks after transplanting, the seedlings were thinned to one vigorous plant per pot to maintain uniformity across treatments.

Biochar were previously applied at rates of 0, 4.2, 8.4, 12.6 and 16.8 g/pot (0, 1.68, 3.36, 5.04, 6.72t/ha) and Compost at the rate of 0, 4, 8, 12 and 16 g/pot (0, 1.6, 3.2, 4.8, 6.4 t/ha). The treatments were replicated three times in a completely randomized design. Biochar and compost were applied at rates of 15kgha-1, 30kgha-1, 45kgha-1 and 60 kgha-1 for the initial study and which formed the basis for this residual study.

The following analyses were carried out on each soil sample using standard methods: Soil pH (Thomas, 1996), total nitrogen (Bremner, 1996), available phosphorus (Kuo, 1996) and Potassium (Summer and Miller, 1996). Soil samples collected after each cropping cycle were air-dried, sieved through a 2 mm mesh, and analyzed using standard procedures. Soil pH was measured in a 1:2.5 soil–water suspension using a glass electrode pH meter. Total nitrogen was determined by the Kjeldahl digestion, distillation, and titration method. Available phosphorus was extracted by the Bray-1 method and determined colorimetrically using the molybdenum blue procedure at 882 nm. Exchangeable potassium was extracted with 1 N neutral ammonium acetate and measured with a flame photometer. Data were subjected to analysis of variance using GENSTAT, and treatment means were separated with Duncan's Multiple Range Test at the 5% level.

3. RESULTS

Table 1 shows that biochar contained more potassium (3.20 mg/kg) and slightly less nitrogen and phosphorus than compost, which had higher phosphorus (1.44 mg/kg).

Table 1. Chemical Properties of Biochar and Compost for the Study

Properties	Biochar	Compost
OC(g/kg)	22.21	20.11
N(g/kg)	0.89	0.95
P(mg/kg)	0.19	1.44
K (mg/kg)	3.20	0.60

Note: N: Nitrogen, P: Phosphorus, K: Potassium, OC: Organic Carbon

The application of biochar (nitrogen rates) to the soil at the rates of 15kgha-1, 30kgha-1, 45kgha-1 and 60 kgha-1 significantly retained more nitrogen in the soil compared to the control after the second cropping cycle with 15kgha-1 being the best. At the end of the second cropping cycle, biochar nitrogen levels showed a 36%, 84.45%, 84.96% and 56.2% decrease at 15, 30, 45 and 60 kgha-1 rates of application, respectively, while the control showed 95.04% reduction (Table 2).

Table 2. Effects of Biochar on soil pH, Nitrogen, Phosphorus and Potassium levels on an Alfisol over one cropping cycle

Biochar											
	N			P			K			pH	
AL (kg/ha)	C1	C2	% Δ	C1	C2	% Δ	C1	C2	% Δ	C1	C2
0	1.21	0.06	-95.04 d	11	19.4	+76.36 d	0.19	0.41	+115.7 d	5.2	5.87
15	1.25	0.8	-36 a	11.01	19.7	+78.9 d	0.22	0.9	+309.1 b	5.26	7.6
30	1.29	0.2	-84.49 c	11.02	25.25	+129.1 b	0.25	1.9	+660 a	5.22	7.72
45	1.33	0.2	-84.96 c	11.03	21.64	+96.19 c	0.28	1.21	+332.1 b	5.27	7.7
60	1.37	0.6	-56.2 b	11.04	27.35	+147.73 a	0.31	1.31	+322.5 b	5.25	7.65
AvgR			**-65.41**			**+112.98**			**+405.9**		

Note: N; Nitrogen (g/kg), P; Phosphorus (mg/kg), K; Potassium (mg/kg), C1; Cycle 1, C2; Cycle 2, %Δ; Percentage difference, pH; Soil pH level, AvgR: Average percentage application levels of 15,30,45 and 60 kg/ha, AL; Application level. Means with different alphabets in the column are significantly different from each other at P≤0.001

From Table 3, compost nitrogen content significantly increased over two cropping cycle for application levels of 15 and 30 Kg N/ha. Nitrogen content loss was recorded in the 0 Kg/ha, 60kg/ha and 45kg/ha application rate at 93.4 %, 56.2 % and 54.9 %, respectively over two cropping cycle. Application rates of 15kg/ha and 30kg/ha significantly increased nitrogen levels by 12% and 8.5%, respectively over two cropping cycles.

Table 3. Effects of Compost on Soil pH, Nitrogen, Phosphorus and Potassium Levels on an Alfisol over One Cropping Cycle

Compost	N			P			K			pH	
AL (kg/ha)	C1	C 2	% Δ	C 1	C 2	% Δ	C 1	C 2	% Δ	C 1	C 2
0	1.21	0.08	-93.4 c	11	19.95	+81.36 c	0.19	0.7	+268.4 a	5.2	5.67
15	1.25	1.4	+12 a	11.06	21.56	+94.93 c	0.32	0.94	+193.8 b	5.27	7.70
30	1.29	1.4	+8.5 a	11.12	19.55	+75.8 c	0.45	0.95	+111 c	5.28	7.78
45	1.33	0.6	-54.9 b	11.18	45.21	+304.4 a	0.58	1.29	+122 c	5.28	7.87
60	2.37	0.6	-74.7 b	11.24	35.81	+218.5 b	0.72	1.21	+68 d	5.28	7.83
AvgR			**-27.3**			**+173.4**			**+123.68**		

Note: N; Nitrogen (g/kg), P; Phosphorus (mg/kg), K; Potassium (mg/kg), C1; Cycle 1, C2; Cycle 2, %Δ; Percentage difference, pH; Soil pH level, AvgR: Average percentage application levels of 15,30,45 and 60 kg/ha, AL; Application level. Means with different alphabets in the same column are significantly different from each other at $P < 0.001$

4. DISCUSSION

Potassium is highly soluble and is not bound in organic molecule complexes (Sardans and Peñuelas, 2021). Therefore, it is easily lost (via leaching) during composting, which explains the low potassium content of the compost. Furthermore, during the process of pyrolysis, the gaseous form of hydrogen, carbon and oxygen are usually released to the atmosphere while elements such as calcium, magnesium and potassium are retained in the charred material (Giudicianni et al., 2021). This further explained why potassium content of the biochar was higher than that of the compost. Both amendments had high organic carbon contents, supporting soil enrichment. These figures suggest compost enriches short-term fertility while biochar improves long-term nutrient holding.

The result from Table 2 showed that biochar as a soil amendment lost significant amount of nitrogen over the period of this study. This could be attributed to the fast rate and diverse ways through which nitrogen is lost in the soil. Nitrogen is consumed by plants at a very high rate compared to other nutrients. Due to its high mobility, the pathways through which nitrogen could be lost in the soil include but are not limited to leaching down the soil profile, runoff through overland flow, and volatilization through vapour (Ibitoye et al., 2024; Olakayode et al., 2020; Oguike and Mbagwu, 2009).. Nevertheless, biochar-amended plots performed better than the control plot over the two cropping cycles. This could be linked to the ability of biochar to conserve plant nutrients, thereby showing potential to help retain nutrients in the soil. This result is consistent with the previous studies by Kugedera, et al., (2025) and Zubairu et al., (2023).

Phosphorus content of the biochar application across the rates of 15kgha-1, 30kgha-1, 45kgha-1 and 60kgha-1 showed significant increase in its store potential for the second cropping cycle as it averaged a 112.98% increase in the phosphorus content in the soil which is available for plant use. This significantly agrees with the findings of Luo et al. (2024) and Zhao et al. (2023) which reported the potential of biochar to store nutrients in the soil acting as an amendment which supports sustainable nutrient availability for crop production over one cropping cycle. The increase in phosphorus content over one cropping is also attributed to the parent material used in producing the bochar as reported by Wali et al (2022). This significantly helps reduce dependency on inorganic source of phosphorus in climate smart and sustainable agriculture. Pan et al (2021) reports that biochar as a soil amendment could improve the CO2 sequestration potential, enhance mineralization, and increase the retention of nitrogen and phosphorus nutrients in soils. The potassium content of biochar in this study showed a significant increase in its storage potential over one cropping cycle. Biochar in this study sequestrated potassium to 405.9% over one cropping showing its potential to help retain soil nutrients beyond one cycle and prevent nutrient loss in the same cropping cycle due to various agronomic practices. This result is in agreement with Luo et al., (2024) who also reported that biochar acts as a store of nutrients that is mineralized and released slowly for crop production. Its ability to bind nutrients together to avoid loss is significantly supported in this study. The soil pH level was influenced by the application of biochar and compost over one cropping cycle (Table 1 & 2). The soil pH rose from slightly acidic in the first year of planting to alkaline in the second cropping cycle. This shows the potential of biochar and compost to influence soil pH over one cropping cycle. This is in agreement with the findings of Zhang et al., (2023) and Goldan et al., (2023) who reported that soil amendments such as biochar and compost have the potential to amend soil pH levels for crop production.

Application of compost significantly increased Phosphorus content over two cropping cycles with 45 Kg Pha-1 performing best in retaining phosphorus in the soil. This shows the potential of compost to store nutrients and act as a sustainability tool for crop production (Bremaghani, 2024; Paradelo et al., 2023; Ranjan et al., 2023). Compost sequestered phosphorus at 173.4% over two cropping cycle which makes it available to crops within the two cropping cycles to support sustainable crop production. Similar result was observed for potassium content over two cropping cycles in the soil with an average of 123.68% increase for all the application levels. This signifies the importance of compost to store nutrients such as nitrogen, which is easily lost in the soil (Mi et al., 2025; Ndubo, 2023).

The efficiency of compost and biochar to store nutrients over one cropping has also been reported by Sanchez-Monedero et al., 2019 who reported that compost was more efficient in storing nutrients while biochar had negligible fertilizer effect over one cropping except for compost enriched biochar that stored more than sole biochar in their study in Spain. This study reports that biochar used as a soil amendment in an alfisol in Nigeria, stored more nutrients over one cropping and this differences may be attributed to the rate of mineralization in both soils as higher temperature in sub-Saharan Africa affects rate of mineralization. You et al (2025) reported that temperature differences affects mineralization in different soil regions and areas.

5. CONCLUSIONS

Compost and biochar will significantly help store nutrients such as Nitrogen (N), Phosphorus (P) and Potassium (K) beyond one cropping cycle, ensuring their suitability for sustainable soil fertility enhancement tools. The Nitrogen (N) content of the soil amendment (Biochar) will require additional application after one cropping cycle to enable optimum crop production and performance. Compost best performed in sequestering nitrogen at 15 and 30 Kg N ha-1 and potassium at 45 Kg K ha-1 while Biochar best performed in sequestering nitrogen at 15kg/ha, phosphorus at 60 kgha-1 and potassium at 30 kgha-1 over two cropping cycles. Compost and biochar also increased the soil pH levels over a cropping cycle, thereby adjusting acidic soil pH levels for sustainable crop production.

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