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Influence of Enriched Cassava Peel Biochar and Other Soil Amendments on Growth, Yield and Proximate Composition of Sweet Potato

Abiodun Abass Otun[1]*, Ezekiel Akinkunmi Akinrinde[2], Ojo David[3], Adediwura Ifeoluwa Ajibola-Akanbi[2], Yejide Kafayat Fafiyebi[2], Jimoh Jamiu Muhammed[4], Aisha Motunrayo Soladoye[2]

[1]National Biotechnology Research and Development Agency, FCT, Abuja, Nigeria
[2]Department of Crop and Horticultural Sciences, University of Ibadan, Nigeria
[3]Department of Fruit and Spices, National Horticultural Research Institute, Ibadan, Oyo State, Nigeria
[4]Bioscience Unit, International Institute of Tropical Agriculture, Ibadan, Oyo State, Nigeria

*Corresponding author email ID: otunabbey@yahoo.com

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ABSTRACT

Sweet potato (*Ipomoea batatas* L.) is a vital food security crop in Nigeria and sub Saharan Africa, yet its productivity is constrained by acidic soils and declining fertility due to continuous cultivation without fertilizer inputs. Biochar has emerged as a sustainable amendment for improving soil fertility, but its slow nutrient release limits effectiveness unless combined with other inputs. This study evaluated the effects of enriched cassava peel biochar, applied alone and in combination with lime, compost, and NPK fertilizer, on the growth, yield, nutrient use efficiency, and proximate composition of sweet potato under acidic Alfisol conditions in Ibadan, Nigeria. Ten treatments were arranged in a randomized complete block design with three replicates. Growth parameters were not significantly affected ($p > 0.05$), but yield responses differed significantly ($p < 0.05$). The integrated treatment of lime + compost + biochar (T9) produced the highest tuber yield (10 t/ha), while lime + biochar (T8) yielded the greatest number of storage roots per hectare. Nutrient use efficiency indices (NUE, PUE, KUE) were markedly improved under integrated treatments, particularly T9, confirming synergistic effects of soil pH correction, organic matter enrichment, and nutrient retention. Proximate composition of tubers remained largely stable across treatments. Profitability Index analysis revealed that integrated treatments provided higher returns, with T9 achieving a profitability index of 3.51 compared to 1.63 for sole NPK (T5). These findings highlight the potential of enriched biochar, when combined with lime and compost, to sustainably improve sweet potato yield, nutrient efficiency, and farmer profitability under acidic soil conditions.

1. INTRODUCTION

Sweet potato (*Ipomoea batatas* L.) is a globally important root and tuber crop, contributing significantly to food security and nutrition. Nigeria ranks as the second largest producer worldwide after China and the leading producer in Africa, with an annual output of about 3.46 million metric tons (Tewe et al., 2003; FAOSTAT, 2020). Beyond its nutritional role, sweet potato provides income opportunities for resource-poor farmers, making it a strategic crop for livelihood improvement in sub-Saharan Africa (Rees et al., 2001). Despite these advantages, productivity is increasingly constrained by declining soil fertility due to continuous cultivation and limited fertilizer use.

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Soil acidity is a major challenge in sweet potato production. Lime ($CaCO_3$) application is widely adopted to mitigate acidity, enhancing microbial activity and nutrient uptake (Xuan et al., 2016). However, prolonged reliance on lime alone can lead to re-acidification, soil compaction, and nutrient leaching (Wang & Jiang, 2017). Organic amendments such as biochar have therefore gained attention. Biochar, a pyrogenic carbon material produced through biomass pyrolysis, is recognized for its persistence in soil, ability to enhance nutrient availability, and role in improving soil physical properties such as aeration, moisture retention, and bulk density (Adekiya et al., 2020; Syuhada et al., 2016; Ullah et al., 2018). It also contributes to soil organic carbon build-up and acts as a carbon sink due to its slow mineralization (Joseph et al., 2020). Nevertheless, biochar slow nutrient release often limits immediate crop response, necessitating enrichment to accelerate nutrient availability. Integrating biochar with compost, lime, and inorganic fertilizers has been reported to improve nutrient use efficiency and provide balanced macro- and micronutrients for plant growth. Such combinations not only enhance yield but also improve soil quality and microbial activity, particularly in acidic soils where aluminum toxicity restricts productivity (Ryan et al., 2018). However, limited studies have examined the enriched application of cassava peel biochar in sweet potato production in Nigeria.

The objectives of this study are to:

1. Evaluate the effect of enriched cassava peel biochar on the growth performance of sweet potato.
2. Assess the influence of enriched biochar and its combinations with lime, compost and NPK 15:15:15 fertilizer on the yield of sweet potato.
3. Determine the proximate composition of sweet potato tubers under different soil fertility treatments.

2. MATERIALS AND METHODS

2.1 Experimental location

The experiment was carried out at the field plot of National Horticultural Research Institute (NIHORT), Idi-Ishin Jericho GRA Ibadan, Oyo State in the Southern Guinea Savannah ecological zone of Nigeria. The farm is situated at Longitude (3° 50' E) and Latitude (3° 23' N) and altitude of approximately 144m above sea level and a uniform slope 7%. The soil of the study site belongs to Alfisols, classified as Typic Kanhaplustalf according to USDA classification and locally classified as Iwo series. The soil is characterized by loamy sand texture and strongly acidic pH (4.56). Baseline soil physiochemical properties were analysed before treatment application to established fertility status.

2.2 Experimental Materials

Sweet potato variety, Ex-Igbariam was obtained from National Root Crops Research Institute (NRCRI), Nigeria. The feedstock used for the biochar production was dried cassava peel and biochar which was produced at the screen house of Crop and Horticultural Sciences Department, University of Ibadan, using locally fabricated pyrolysis unit, while compost was prepared from poultry waste and mango leaves. NPK 15:15:15 fertilizer and Lime ($CaCO_3$) were sourced from certified agro-input suppliers to ensure consistency.

2.3 Plot Justification, Layout and Procedure

Each plot measured 2 m x 3 m (6m²), with 1 m spacing between plots and blocks to minimize edge effects and nutrient leaching. This plot size was chosen to balance resource availability with adequate replication for statistical reliability. The total experimental land area was 319 m², accommodating 30 plots. Planting density was 16 stands per plot (75 cm x 50 cm 50 cm spacing), giving a total of 480 plants. Lime was applied into the soil three weeks before planting so as to allow enough time for it to react with the soil and adjust the pH effectively, enhance nutrient uptake and promote better tuber growth while compost and biochar were worked into the soil two weeks before planting. Planting was done September, 2025 while harvesting was carried out December, 2025.

2.4 Experimental Design and Randomization

This study employed a Randomized Complete Block Design (RCBD) with three replicates to account for spatial variability across the field. Treatment were randomly assigned within each block sing a random number generator to eliminate bias. Each treatment was coded (T1 – T10) for clarity in data presentation.

Treatments included:

- T1: Control (no amendment)
- T2: Biochar (333.33 kg/ha)
- T3: Compost (3000 kg/ha)
- T4: Lime (112.5 kg/ha)
- T5: NPK 15:15:15 (400 kg/ha)
- T6: Lime + Compost

- T7: Lime + NPK
- T8: Lime + Biochar
- T9: Lime + Compost + Biochar
- T10: Lime + Compost + Biochar + NPK

2.5 Data Collection

The following growth and yield data were collected on sweet potato at 4, 8 and 12 Weeks After

Planting (WAP):

Growth parameters which include:

- Vine length (cm): The vine length was measured using a flexible tape from the base to the tip of the main shoot at 4 weeks intervals.

- Vine girth (mm): Vernier caliper was used to measure the stem diameter.

- Number of leaves: The number of leaves was obtained by counting at 4 weeks intervals.

- Number of branches: The number of branches was obtained by counting the branches of selected plant stands.

Yield parameters which include:

- Number of storage roots: The number of tubers per plant was counted.
- Weight of storage roots: This was done by weighing each plot yield using weighing scale.

2.6 Pyrolysis of Biochar

The biochar used in this study was produced using a locally fabricated pyrolysis unit consisting of three main compartments: an insulated outer metal box with a cover, an inner cylindrical chamber with its own lid and a lower outlet for collecting the charred material. Dried cassava peel feedstock was loaded into the inner chamber and securely sealed. Pre-heated charcoal was then introduced into the space surrounding the inner cylinder to initiate the pyrolysis process, after which the entire reactor was covered. A timer was set to monitor the duration of the charring process, which lasted approximately five hours. Upon completion, the residual material inside the inner chamber, which was fully charred was identified as biochar. This biochar was discharged through the lower outlet and water was immediately sprinkled over the hot char to prevent further combustion. The resulting biochar was then air-dried for one week before being applied in the experimental treatments.

2.7 Proximate Analysis Procedures

Chemical analyses of sweet potato tuber samples were conducted in duplicate using standard protocols outlined by the Association of Official Analytical Chemists (AOAC, 2005). The parameters assessed included crude protein, crude fat, moisture content, dry matter, ash, and crude fiber.

Crude Protein: This was determined using the semi-micro Kjeldahl method, which involves three sequential steps: digestion, distillation, and titration. This technique quantifies nitrogen content, which is then converted to protein percentage using a standard conversion factor.

Crude Fat: It was analyzed using the Soxhlet extraction method. One gram of dried sweet potato leaf sample was placed into a fat-free extraction thimble and lightly packed with cotton wool. The thimble was inserted into the extractor, which was connected to a reflux condenser and a pre-weighed 250 ml Soxhlet flask. The flask was filled to three-quarters capacity with petroleum ether (boiling point: 40–60°C) and heated for six hours with continuous water flow to condense ether vapors. After extraction, the flask containing the extracted fat was dried to a constant weight in an oven. Crude fat content was calculated using the formula:

$$\frac{W_1 - W_0}{Weight\ of\ Sample} \times 100$$

Moisture Content and Dry Matter: They were determined by oven-drying two grams of fresh tuber sample in a pre-weighed crucible at 100°C for 24 hours. After drying, the crucible was cooled in a desiccator and reweighed. Dry matter percentage was calculated as:

$$Dry\ Matter\ (\%) = \frac{W_1 - W_0}{W_2 - W_0} \times 100$$

$$Moisture\ (\%) = 100 - DM\ (\%)$$

where (W_0) is the weight of the empty crucible, (W_1) is the weight of crucible plus fresh sample, and (W_1) is the weight after drying.

Ash Content: This was determined by incinerating two grams of tuber sample in a porcelain crucible at 550°C for four hours in a muffle furnace. The resulting white ash was cooled first in air, then in a desiccator, and weighed. Ash percentage was calculated as:

$$Ash\ Content\ (\%) = \frac{Weight\ of\ Ash}{Original\ Weight\ of\ Sample} \times 100$$

Fiber: It was analyzed by refluxing two grams of tuber sample with 100 ml of 0.255N sulfuric acid for one hour. The mixture was filtered through a fiber sieve cloth, and the residue was then refluxed with 100 ml of 0.313N sodium hydroxide for another hour. After filtration, 10 ml of acetone was added to dissolve organic residues, followed by washing with hot water. The residue was transferred to a crucible, dried in an oven, cooled in a desiccator, and weighed (W_1). The crucible was then ashed at 550°C for four hours, cooled, and reweighed (W_2). Crude fiber was calculated as:

$$\%\, Fiber = \frac{W_1 - W_2}{Weight\ of\ Sample} \times 100$$

2.8 Nutrient Use Efficiency

Sweet potato leaf samples were collected, oven dried and weighed. The dried samples were further processed into powder form by milling after which they were analyzed for their nutrient contents.

Nitrogen use efficiency (NUE) was determined using the formula (Rahimizadeh et al., 2010):

$$NUE = \frac{Yield}{N\text{-}supply\ (kg)}$$

Phosphorus use efficiency (PUE) was determined using the formula:

$$PUE = \frac{Yield}{P\text{-}supply\ (kg)}$$

Potassium use efficiency (KUE) was determined using the formula:

$$KUE = \frac{Yield}{K\text{-}supply\ (kg)}$$

Statistical Analysis

Data collected were subjected to Analysis of Variance (ANOVA) using General Statistical Package (GENSTAT) 4th edition, 2015 while significant means were separated using Duncan multiple range test (DMRT) at $P < 0.05$. The RCBD model applied was:

$$Y_{ij} = \mu + T_i + B_j + \varepsilon_{ij}$$

Where Y_{ij} = observation, μ = overall mean, Ti = treatment effects, B_j = block effect, and ε_{ij} = random error.

3. RESULTS

The baseline properties of the experimental soil are presented in Table 1 below. The soil analysis revealed that the experimental soil possessed a loamy sand texture, characterized by high sand content and relatively low proportions of silt and clay, indicative of moderate water retention and aeration potential.

Table 1. Soil Physicochemical Properties of the Experimental Site

Properties	Values	Critical levels *(Chude et al., 2012)*	Remark
pH (1:1, H_2O)	4.56	6–7.2	Strongly acidic
Organic carbon (g/kg)	4.51	10–14	Low
Total nitrogen (g/kg)	0.49	1.6–2.0	Low
Available phosphorus (mg/kg)	3.36	7–20	Low
Exchangeable cations (cmol/kg)			
Ca	4.79		
Mg	1.06		
K	0.17	0.3–0.6	Very low
Na	0.87		
Exchangeable acidity	0.40		
Extractable micronutrient (mg/kg)			
Fe	81.00	30–35	High
Mn	78.50		High
Cu	1.03		Low
Zn	1.14		Low
Particle size distribution (g/kg)			
Sand	81.00		
Silt	13.00		
Clay	6.00		
Textural class			Loamy sand

The values in Table 2 represent Pearson correlation coefficients (r), indicating the strength and direction of linear relationships among parameters. The correlation analysis reveals strong and positive associations among nutrient level, vegetative growth traits and tuber yield in sweet potato.

Table 2. Pearson correlation coefficient relating leaf nutrient content with growth and yield parameters

	Number of leaves	Nutrient level	Plant height	Yield
Number of leaves	1			
Nutrient level	0.9035	1		
Plant height	0.7501	0.6667	1	
Yield	0.9129	0.9471	0.8246	1

Table 3 presented below, show the morpho-agronomic properties of sweet potato growth as influenced by lime, compost, NPK fertilizer, biochar and their combinations. The number of branches ranged from 2.10 in lime treatment to 3.67 in control. However, sweet potato leaves number ranged from 51.17 in NPK 15:15:15 treatment to 99.87 in lime treatment. The vine diameter of sweet potato ranged from 0.45 cm in biochar and lime + compost + biochar NPK treatments to 0.73 cm in lime + compost + biochar treatment.The least and highest vine length of 67.80 cm and 103.10 cm were observed in NPK 15:15:15 and control, respectively, while

As presented in Table 4, the response of sweet potato to various soil fertility treatments revealed that integrated inputs had more positive significant on storage root development compared to individual amendments. The combined treatment application of lime + compost + biochar produced the highest storage root yield (10.00 t/ha) compared to all other treatments applied.

Table 3. Effect of treatments application on growth parameters of sweet potato

Treatments	No. of branches	No. of leaves	Vine diameter (cm)	Vine length (cm)
Control	3.67	72.93	0.46	103.10
Biochar	2.95	83.39	0.45	92.50
Compost	2.59	62.73	0.52	96.40
Lime	2.10	99.87	0.59	92.20
NPK 15:15:15	2.40	51.17	0.61	67.80
Lime + Biochar	3.33	80.67	0.67	107.90
Lime + Compost	2.40	60.00	0.49	98.00
Lime + NPK 15:15:15	2.67	71.64	0.63	188.80
Lime + Compost + Biochar	2.57	91.37	0.73	107.10
Lime + Compost + Biochar + NPK	3.13	82.39	0.45	92.50
SED	NS	NS	NS	NS

Note: *NS: not significant, No.: Number, cm: centimeter*

Table 4. Effect of treatment applications on yield of sweet potato

Treatments	Storage root weight (t/ha)	No. of storage root/ha
Control	5.33^{d}	$33{,}333^{c}$
Biochar	5.39^{d}	$38{,}300^{bc}$
Compost	6.61^{c}	$46{,}667^{ab}$
Lime	7.72^{b}	$35{,}000^{c}$
NPK 15:15:15	5.83^{cd}	$46{,}667^{ab}$
Lime + Biochar	8.56^{b}	$51{,}667^{a}$
Lime + Compost	5.89^{b}	$40{,}000^{bc}$
Lime + NPK 15:15:15	5.83^{cd}	$46{,}667^{ab}$
Lime + Compost + Biochar	10^{a}	$38{,}333^{bc}$
Lime + Compost + Biochar + NPK	6.28^{cd}	$40{,}000^{bc}$
SED	0.4296	2.188

Note: Means followed by the same letter in a column are not significantly different by DMRT at (p<0.05)

Table 5 below shows that the protein content of sweet potato studied ranged from 3.90 to 4.57% on dry weight. These values are in the same range of 3.28 to 4.16% obtained by (Ukom *et al*., 2009) except for treatment lime + compost + biochar + NPK 15:15:15 and biochar. The ash content varied from 1.07 to 1.80% which is closely around the range of values 0.40 to 2.35% reported by (Eleazu and Eleazu, 2012; Eleazu and Ironua, 2013; Ellong *et al.,* 2014). However, sole application of lime had the lowest fat content while control had the highest fat content. There was significant difference in fat content among the treatment applied. The fat contents were lower than the values reported by (Ishida *et al.,* 2000). Fat is involved in the insulation of the body organs and in the maintenance of the body temperature and cell function. Crude fiber content as presented in the table varied from 1.24 to 1.49% in dry weight basis. The dry matter content was observed that it ranges from 90.80 to 92.50%. This also shows that all the ten treatments had similar dry matter content values. This result supports the findings of Ellong *et al.* (2014). The moisture content values were between 7.50 to 9.20% which were within the range values reported by (Ukom *et al*., 2009). For carbohydrate, lime + compost had the highest carbohydrate content while sole application of biochar had the lowest carbohydrate content. This attributed to improved soil pH, enhanced microbial activity and better moisture and nutrient retention reported by Sika and Hardie (2014).

Table 5. Proximate composition of sweet potato under the influence of treatments application

Treatments	CP %	Ash %	Fat %	CF %	D M%	MC %	CHO %
Control	4.26b	1.80c	0.34	1.49a	91.85	8.15d	84.69d
Biochar	4.57a	1.07a	0.30	1.26e	91.61	8.39c	83.68i
Compost	4.08cd	1.17bc	0.31	1.24e	91.60	8.40c	84.77c
Lime	3.98de	1.40b	0.26	1.46ab	91.75	8.25cd	84.85h
NPK 15:15:15	4.03cde	1.20bc	0.29	1.29de	90.80	9.20a	83.99g
Lime + Biochar	4.05cd	1.10c	0.33	1.35cde	90.80	9.20a	83.97g
Lime + Compost	3.90e	1.16bc	0.28	1.30de	92.50	7.50e	85.86a
Lime + NPK 15:15:15	4.15bc	1.14c	0.29	1.43bc	91.66	8.34cd	84.58a
Lime + Compost + Biochar	4.10cd	1.17bc	0.30	1.40bce	90.82	9.18a	83.85e
Lime + Compost + Biochar + NPK	4.22b	1.14c	0.28	1.34cde	91.25	8.75b	84.27f
SED	0.1403	0.2218	NS	0.1126	0.223	0.2188	0.01377

Note: Means followed by the same letter in a column are not significantly different by DMRT at (p<0.05)
CP = Crude protein, CF = Crude fiber, MC = Moisture content, CHO = Carbohydrate, DM = Dry matter, NS = Not significant

As presented in Table 6, the Nitrogen use efficiency (NUE), Phosphorus use efficiency (PUE) and Potassium use efficiency (KUE). Lime + compost treatment had the lowest NUE of 1.91 while lime + compost + biochar recorded the highest NUE of 6.21 value. It was also observed that, NPK 15:15:15 treatment had the least PUE value while lime + compost + biochar had the highest PUE value of 96.15. NPK 15:15:15 treatment recorded the least KUE value of 4.74 and lime + compost + biochar recorded the highest value of 19.05.

As shown in table 7, the effect of Profitability Index (PI) of sweet potato production using ten treatment applications which was carried out in order to assess the cost and profit implication of each treatment applied. The total cost for each treatment on table 7 was done by adding up all expenses in Nigeria naira (₦) from land acquisition to harvesting of tubers and also transporting of harvested tubers to the farm gate was calculated.

Table 6. Effect of treatments on the Nutrient Use Efficiency of sweet potato leaves

Treatments	NUE	PUE	KUE
Control	2.07fg	41.98a	6.11bc
Biochar	3.21d	43.82a	5.83c
Compost	2.17f	35.73a	5.29c
Lime	3.8d	87.73b	16.25a
NPK 15:15:15	2.72e	35.06a	4.74c
Lime + Biochar	4.89ab	83.11b	10.7b
Lime + Compost	1.91g	37.04a	6.73bc
Lime + NPK 15:15:15	3.2d	35.51a	5.18c
Lime + Compost + Biochar	6.21a	96.15b	19.05a
Lime + Compost + Biochar + NPK	4.49c	57.61b	5.71c
SED	0.0765	NS	1.580

Note: Means followed by the same letter in a column are not significantly different by DMRT at (p<0.05)
NUE: Nutrient Use Efficiency, PUE: Phosphorus Use Efficiency, KUE: Potassium Use Efficiency.

Table 7. Effect of profitability index of sweet potato

Treatments	Yield (t/ha)	Total cost (₦)	Gross profit (₦)	P.I. (₦)
Control	5.5	434,166	760,000	1.7
Biochar	5.39	550,816	1,078,000	1.96
Compost	6.16	626,166	1,232,000	1.97
Lime	7.72	538,406	1,544,000	1.94
NPK 15:15:15	5.33	654,166	1,266,000	1.63
Lime + Biochar	8.56	543,611	1,711,200	3.15
Lime + Compost	5.89	580,286	1,178,000	2.02
Lime + NPK 15:15:15	5.83	595,286	1,166,000	1.96
Lime + Compost + Biochar	10	570,463	2,000,000	3.51
Lime + Compost + Biochar + NPK	6.28	591,389	1,256,000	2.12

Note: *P.I.: Profitability Index*

4. DISCUSSION

The results of this study demonstrate that integrated soil amendments, particularly the combination of lime, compost and biochar, significantly enhanced sweet potato yield compared to sole applications. Although growth parameters such as vine length, girt, and leaf number did not show significant differences across treatments. Yield responses were markedly improved under integrated inputs. This apparent discrepancy highlights the importance of nutrient partitioning and soil chemical improvements rather than vegetative growth alone in determining tuber yield. Similar findings have been reported by Agele et al. (2017), who noted that nutrient enrichment in acidic soils promotes assimilate partitioning into storage organs rather than excessive vegetative expansion.

The superior performance of T9 can be attributed to synergistic effects on soil fertility. Lime corrected soil acidity, thereby improving nutrient availability and reducing aluminum toxicity. Compost contributed organic matter, enhancing microbial activity and soil structure. Biochar, due to its porous structure and high cation exchange capacity, improved nutrient retention and moisture availability. Together, these amendments created a favorable soil environment that supported tuber bulking and nutrient uptake. This aligns with the mechanisms described by Lehmann and Joseph (2015), who emphasized biochar role in reducing nutrient leaching and stabilizing soil organic carbon.

Nutrient use efficiency (NUE, PUE, KUE) was also enhanced under integrated treatments, particularly T9, which recorded the highest values. This suggests that enriched biochar combinations not only improved nutrient supply but also facilitated more efficient utilization by sweet potato plants. Farrar et al. (2019) similarly observed that biochar-based fertilizers increase nutrient uptake efficiency by improving soil chemical balance and microbial interactions. The improved NUE and KUE under lime treatments further confirm lime role in correcting soil acidity and enhancing cation exchange processes.

Despite the application of various soil amendments, including biochar, compost, lime and inorganic fertilizer, the proximate composition of sweet potato tubers remained largely unaffected across treatments applied. Although a slight variation was observed in fat content, the overall differences were minimal and within the normal nutritional ranges reported in literature. This suggests that while these soil enhancement strategies can influence yield, they do not significantly alter the nutritional quality of the tubers. Increase in leaf nutrient concentrations of sweet potato can be related to soil quality improvement, nutrient release into the soil solution, increase in soil chemical properties and balanced nutrition of plants.

T3 (NPK 15:15:15) alone produced moderate yields but the lowest profitability index, reflecting the high cost of inorganic fertilizer relative to its yield benefit. In contrast, integrated treatments provided higher profitability index, with T9 (lime + compost + biochar) yielding a PI of 3.51. I.e., ₦1 spent on treatment combination of lime + compost + biochar gave a profit of ₦3.51 in return, while NPK 15:15:15 gave the lowest profitability index. This demonstrates that integrated nutrient management is not only agronomically effective but also economically viable, offering farmers greater returns on investment. Such findings are consistent with integrated soil fertility management principles, which advocate combining organic and inorganic inputs for sustainable productivity (Paradelo & Barral (2023)).

5. CONCLUSIONS

From the results obtained in this research, it is evident that the applied treatments did not have significant influence on the growth of sweet potato in the study area, also, enriched biochar did not influence proximate compositions of sweet potato storage roots while liming enriched biochar gave better yield of sweet potato than other treatments applied. It is, therefore, concluded that organic fertilizer should be used to increase sweet potato

storage roots quantity and quality. However, further studies need to be carried out to ascertain the residue impact of biochar on sweet potato production.

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