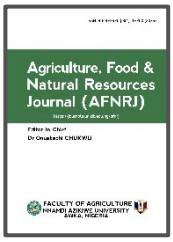
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Original Article

Effects of biochar-urine amendment on soil loss associated with Sweet Potato (*Ipomoea batatas* L.) harvesting

OPEN ACCESS

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ABSTRACT

Biochar with urine has potential to enhance crop productivity and minimize soil loss during harvesting. Hence, a field study was conducted on a sandy loam Alfisol at the Teaching and Research Farm, University of Ibadan, Ibadan, Nigeria, to evaluate the effects of biochar-urine application on soil loss due to harvesting of sweet potato. The experiment was laid out in a randomized complete block design with six treatments replicated three times. The six treatments comprised three sole applications (biochar at 3 t ha^{-1}, cow urine at 3,000 liters ha^{-1}, and NPK 15:15:15 at 400 kg ha^{-1}) and two combined applications (biochar at 1.5 t ha^{-1} with NPK at 200 kg ha^{-1} and biochar at 1.5 t ha^{-1} with cow urine at 1500 l ha^{-1}) and an unamended control (no additive). The response variables measured were aboveground biomass, crop yield, and soil loss due to crop harvesting (SLCH). Soil loss was determined by collecting, air-drying, and weighing the soil adhering to harvested tubers, and SLCH was computed from these measurements. Nutrient loss (C, N, P, K, Ca, Mg, Na) was quantified. Biochar-urine application gave an increased yield by 20.5% and reduced Soil Loss due to Crop Harvesting (SLCH) by 21.6% compared to biochar-NPK. The use of biochar amended with cow urine may be a promising approach to improving crop yield while minimizing soil loss. Also, there was a positive correlation between soil loss and soil nutrient loss, showing the deleterious consequences of soil loss due to crop harvesting on soil productivity.

KEYWORDS: *Cow urine, Crop productivity, Nutrient loss, Soil conservation, Sweet potato tuber yield*

INTRODUCTION

Sweet potato (*Ipomoea batatas*) is an important economic crop and plays a significant role as source of energy and nutrition in many countries such as China, Argentina, Nigeria, Brazil, Philippines, among others (FAO, 2025). They are grown on about 9 million hectares, yielding about 89 million tonnes in global production led by China with 55% of the world's total production. Sweet potato spreads and covers the soil surface, preventing direct raindrop impact, thereby reducing soil loss due to runoff (FAO, 2025). One recognized erosion process contributing to soil degradation is soil loss due to crop harvesting, which has been extensively studied (Mesele *et al*., 2025; Panagos *et al*., 2023). During the harvesting process, soil adhering to these crops, along with soil clods and stones, is transported from the field to various locations such as headlands, farmsteads, and crop-processing factories, leading to soil movement known as soil loss due to crop harvesting (SLCH) (Ruysschaert *et al*., 2004). Increased soil loss from farmland is rapidly causing a decline in soil quality, resulting

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into low crop productivity, which is a major hindrance in achieving food security. Biochar, with its ability to improve soil structure and water retention, and cow urine, as a nitrogen-rich organic input, have complementary roles that can enhances sweet potato yield while mitigating soil loss due to crop harvesting (Zhang *et al.,* 2023). Biochar is a carbon-rich product obtained through the process of pyrolysis of biomass in the absence of oxygen or little oxygen at high temperatures between 300 and 1000 ^{0}C (Pandit *et al*. 2024). Biochar is highly porous, thus its application to soil is considered to improve a range of soil physical properties including total porosity, pore size distribution, soil density, soil moisture content, water holding capacity or plant available water content (PAWC), and infiltration or hydraulic conductivity (Zhang *et al.,* 2023). In contrast, cow urine is a nitrogen-rich source that can complement biochar to increase soil productivity. Cow urine is a rich source of macro, and micronutrients and has disinfectant properties thus purifying the atmosphere and increasing soil nutrients. Cow urine, therefore, could be an effective tool to address multi-nutrient deficiencies in most soils. However, limited have examined the effect of biochar-cow urine on soil loss due to sweet potato harvest. Therefore, the objectives of this study were to compare the effects of biochar-cow urine and biochar-NPK on soil nutrients loss due to harvesting of sweet potato and also to compare the effects of biochar-cow urine and biochar-NPK on growth and yield of sweet potato.

MATERIALS AND METHOD

Experimental site

The experiment was carried out at the Teaching and Research Farm along Parry Road at the University of Ibadan, Ibadan, Oyo state, Nigeria located at 7.4433° N and 3.9003° E. The average annual rainfall of the area is 1,250 mm with a bimodal rainfall pattern. The soil of the area is an Alfisol classified as Typic Kandiustalf and formed from basement complex rock (Soil Survey Staff, 2006).

Experimental design

A randomized complete block design (RCBD) was adopted, consisting of six treatments replicated three times, with each plot measuring 2 m by 3 m (6 m²). The land was cleared and tilled manually using traditional hoe and cutlass The total experimental plot size was 180 m^2 with a spacing of 0.6 m by 0.4 m. The vines were cut into 20 cm lengths with two-thirds of the cuttings buried in the soil. The use of 20 cm vine cuttings follows established sweet potato agronomic practice.

Cow urine collection and curing

Cow urine was collected at the University of Ibadan Teaching and Research Farm using a clean 25-liters plastic gallon placed directly under monitored cattle during urination. After collection, the containers were tightly sealed and the urine was stored for three months before laboratory analysis and field application. Cow urine is a valuable organic resource containing water, urea, mineral salts, hormones, and enzymes, and it has been reported to have potential as a biofertiliser and soil nutrient source. Its agricultural application has been associated with improvements in soil fertility, crop growth, and productivity. Therefore, the collected cow urine was subsequently analyzed to determine its nutrient composition before use in the experiment (Pradhan *et al*., 2018).

Preparation of biochar

Biochar was produced from maize residues (cobs and husks) using a controlled pyrolysis unit at the Department of Mechanical Engineering, University of Ibadan. The pyrolyzer consists of an insulated outer chamber, an inner sealed cylinder, and a lower collection compartment. Feedstock was loaded into the inner cylinder, surrounded by burning charcoal, and pyrolyzed for approximately 3 hours. After pyrolysis, the charred material was quenched with water to prevent complete combustion and air-dried before use.

Pre-soil sampling

Soil samples were taken from 12 randomly selected points at a depth of 0-10 cm and mixed thoroughly to form a composite sample. Sub-samples were taken, air-dried, sieved, and stored for laboratory analysis.

Planting material

Sweet potato vines (Ex-Igbariam) were sourced from the National Root Crop Research Institute (NRCRI), Umudike, ensuring varietal purity and adherence to national germplasm standards.

Treatments, rates, and application

Six treatments were applied: T1: Control, T2: Biochar (3 t ha^{-1}), T3: Cow urine (3000 L ha^{-1}), T4: NPK 15:15:15 (400 kg ha^{-1}), T5: Biochar (1.5 t ha^{-1}) + NPK (200 kg ha^{-1}) and T6: Biochar (1.5 t ha^{-1}) + Cow urine (1500 L ha^{-1})

Biochar was incorporated into the soil two weeks before planting to facilitate soil-biochar interactions and enhance nutrient retention and stabilization. Cow urine was applied in split doses at 2, 4, and 6 weeks after planting (WAP) to reduce leaching and synchronize nutrient release with crop demand. NPK fertilizer was similarly applied at 2 and 4 WAP following standard sweet potato fertilizer application schedules.

Data collection

Growth parameters were measured at 4, 8, 12 and 14 weeks after planting (WAP):

- *Vine length (cm):* The vine length was measured using a flexible tape from the base to the tip of the main shoot.
- *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 were taken at 20 weeks after planting (WAP):
• *Number of tubers:* The number of tubers per plant was counted.
• *Weight of tubers:* This was done by weighing each plot yield using weighing scale.
• *Above-ground biomass:* The weights of crop residues of each plot were taken with the use of a weighing scale.
• *Soil loss and nutrient loss:* The soils adhered to harvested sweet potato tubers on each experimental plot were rubbed off and weighed. The soils were analysed to estimate the nutrient loss.

Soil loss determination

The soils attached to the surface of the freshly harvested tubers were rubbed off with bare hands, weighed, and bagged separately for each experimental unit. The tubers were placed on the measuring scale and weighed and taken to the laboratory. This was followed by brushing the tubers to remove the remaining fine soil attached to the tubers. The soil was air-dried and weighed. Nutrients (C, N, P, k, Ca, Mg, Na,) were determined.

Soil loss value per unit of crop mass ($SLCH_{spec}$), and soil loss due to crop harvest ($SLCH_{crop}$) were determined using the equation after Ruysschaert *et al.* (2007).

Soil loss value per unit crop mass (SLCH spec) was calculated using Eq. 1

$$SLCH_{spec}\ (kg\ kg^{-1}) = \frac{Mass\ of\ exported\ dry\ soil\ (kg)}{Mass\ of\ crop\ (kg)} \quad (1)$$

Soil loss due to crop harvest (SLCH crop) was calculated using Eq. 2

$$SLCH_{crop}\ (kg\ ha^{-1}\ harvest^{-1}) = SLCH\ spec\ (kg\ kg^{-1}) \times crop\ yield\ (kg\ ha^{-1}) \quad (2)$$

Soil nutrient loss determination

Nutrient loss (expressed on an elemental basis) through crop harvesting was estimated using Eq. 3

$$Nutrient\ loss\ (kg\ ha^{-1} harvest^{-1}) = \frac{nutrient\ (g)}{soil\ (100\ g)} \times 0.01 \times SLCH\ crop\ (kg\ ha^{-1}) \quad (3)$$

Determination of biochar, urine, and soil chemical properties

Biochar and urine were subjected to digestion to determine the concentrations of key metals. The biochar was digested using a mixture of nitrate and perchloric acid in a 2:1 ratio, followed by dilution with distilled water. The resulting digest was then read using a bulb scientific atomic spectrophotometer for Mg, Fe, Cu, and Zn concentrations, while Na and K concentrations were determined using a flame photometer.

Statistical data analysis

Data obtained were subjected to Analysis of variance (ANOVA) using General Statistics Package (GENSTAT) 4th edition, 2015, while significant means were separated using Duncan multiple range test (DMRT) at $P < 0.05$.

RESULTS

Table 1 presents the soil chemical and physical properties. The soil had a pH of 6.8. The organic carbon content of 15.2 g kg^{-1} was low. The total nitrogen content (0.28 g kg^{-1}) of the soil was relatively low, which indicated that there may be a need for nitrogen fertilizer application. The available phosphorus content (4.0 mg kg^{-1}) of the soil was low, indicating that it may be necessary to apply phosphorus fertilizer to improve crop productivity. The exchangeable cations (Ca, Mg, K and Na) were low in concentration. The bulk density of the soil was 1.3 Mg m^{-3} with a sandy loam texture. The saturated hydraulic conductivity of the soil was 10.76 cm hr^{-1}.

Table 1: Pre-planting soil physical and chemical properties of the experimental site

Soil Parameter	Values n = 6
pH (H_2O) 1:1	6.8
Organic carbon (g kg^{-1})	15.2
Total nitrogen (g kg^{-1})	0.3
Available phosphorus (mg kg^{-1})	4
Exchangeable cations (cmol kg^{-1})	
Ca	3.5
Mg	1.1
K	0.2
Na	0.7
Exchangeable Acidity (cmol kg^{-1})	0.5
Particle size distribution (g kg^{-1})	
Sand	838
Silt	46
Clay	116
Textural class	Sandy loam
Bulk density (Mg m^{-3})	1.3
Saturated hydraulic conductivity (cm hr^{-1})	10.8

K= Potassium, Ca= Calcium, Mg= Magnesium, Na= Sodium

As shown on Table 2, the chemical analysis of maize residue biochar had a high amount of carbon (205.0 g kg^{-1}), low levels of nitrogen (0.28 g kg^{-1}) and phosphorus (176.0 mg kg^{-1}), and a relatively high concentration of potassium (24.80 cmol kg^{-1}). Also, the chemical composition of the cow urine used for the experiment contained high levels of total nitrogen (10.93 g l^{-1}) and total phosphorus (343.72 mg l^{-1}), while calcium (46.0 mg l^{-1}) and potassium (0.59 mg l^{-1}) are low.

Table 2: Chemical properties of the maize residue biochar and cow urine

Parameter	Maize residue biochar n = 2	Cow urine
Total C (g kg^{-1})	205.00	-
Total N (g kg^{-1})	0.28	10.93
Total P (mg kg^{-1})	176.00	343.72
Ca (g kg^{-1})	7.61	46.63
Mg (g kg^{-1})	3.47	1478.75
K (g kg^{-1})	24.80	0.59
Na (g kg^{-1})	6.50	0.24

N= Nitrogen, P= Phosphorus, K= Potassium, Ca= Calcium, Mg= Magnesium, Na= Sodium, C= Carbon

Growth performance of sweet potato as affected by amended biochar application

Figures 1–4 show the effects of amended biochar application on vine length, number of leaves, number of branches, and stem girth of sweet potato at 30 and 60 days after planting (DAP). Treatment effects were generally more pronounced at 60 DAP than at 30 DAP. At 30 DAP, treatment did not significantly affect vine length (P = 0.192), number of leaves (P = 0.063), number of branches (P = 0.706), or stem girth (P = 0.412). Although NPK produced the numerically longest vines (74.1 cm), followed by cow urine (62.5 cm), biochar (57.5 cm), biochar + NPK (54.9 cm), biochar + cow urine (54.8 cm), and the control (54.5 cm), these means were statistically similar. Similarly, NPK recorded the highest numerical number of leaves (66.4), followed by cow urine (53.2), control (46.9), biochar + NPK (44.7), biochar (42.4), and biochar + cow urine (41.9), but the differences were not statistically significant. The number of branches ranged from 1.6 under biochar to 2.0 under NPK, while stem girth ranged from 0.45 cm under biochar + NPK to 0.61 cm under biochar; however, treatments did not differ significantly for either parameter at this stage. At 60 DAP, treatment significantly affected vine length (P < 0.001). NPK produced the longest vines (124.2 cm) and was significantly higher than all other treatments. Biochar, cow urine, biochar + NPK, and biochar + cow urine had statistically similar vine lengths (107.1, 104.9, 107.7, and 103.2 cm, respectively), whereas the control recorded the shortest vines (95.7 cm). The number of leaves was also significantly affected by treatment at 60 DAP (P = 0.014). NPK (131.6) and cow urine (128.8) recorded the highest number of leaves and were statistically similar. Biochar + cow urine (109.3) was intermediate and did not differ significantly from either the higher or lower treatment groups, while the control (90.3), biochar (99.7), and biochar + NPK (100.7) formed the lower statistical group. Similarly, treatment significantly affected the number of branches at 60 DAP (P = 0.036). NPK produced the highest number of branches (5.3), although it was statistically similar to cow urine (4.8). Biochar (4.1), biochar + NPK (3.3), and biochar + cow urine (3.4) were intermediate, while the control recorded the lowest number of branches (2.9). Stem girth was significantly affected by treatment at 60 DAP (P = 0.003). NPK produced the highest stem girth (1.65 cm) and was significantly greater than the control (1.31 cm) and biochar (1.50 cm). Cow urine (1.64 cm) and biochar + cow urine (1.59 cm) were statistically similar to NPK, while biochar + NPK (1.41 cm) was intermediate.

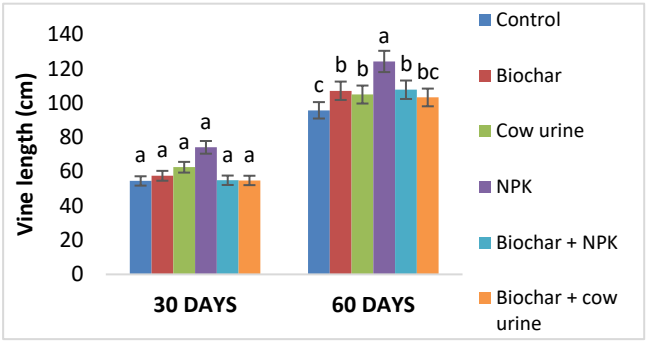


Figure 1: Effect of amended biochar application on vine length of sweet potato

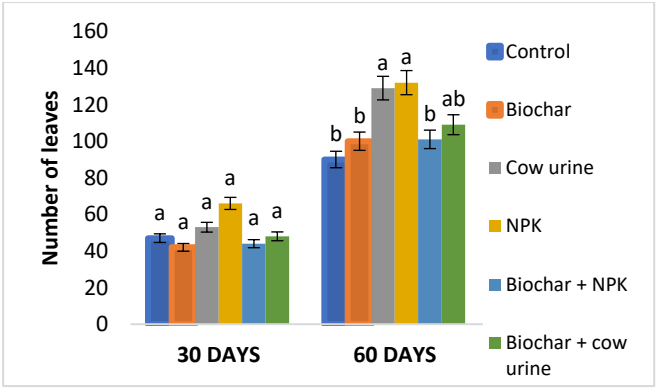


Figure 2: Effect of amended biochar application on number of leaves of sweet potato

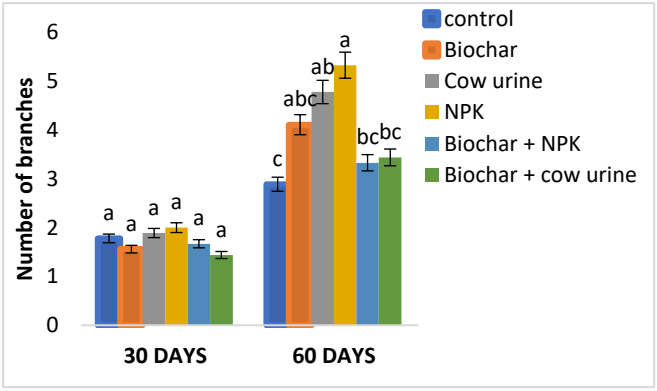


Figure 3: Effect of amended biochar application on number of branches of sweet potato

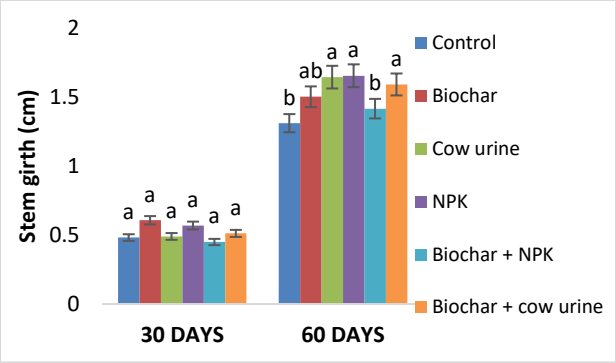


Figure 4: Effect of amended biochar application on stem girth of sweet potato

Table 3 presented below shows the SLCHspec amount of soil loss per unit weight of sweet potato harvested. Biochar alone, NPK, and biochar + cow urine had SLCHspec of 3.97 g kg^{-1}, 4.07 g kg^{-1}, and 4.08 g kg^{-1} respectively, which are not significantly different from each other. Biochar + NPK had a 21.6 % SLCHspec increase compared to biochar + cow urine. Biochar alone had 8.5 % SLCHspec increase compared to the control. SLCHcrop measured the amount of soil loss per hectare of land used for growing sweet potato. The control had the lowest SLCHcrop of 13.85 kg ha^{-1}, while NPK had the highest SLCHcrop of 29.53 kg/ha. Biochar + cow urine had a 0.17 kg ha^{-1} decrease in SLCHcrop when compared with biochar + NPK. Cow urine had a 3.29 kg ha^{-1} decrease in SLCHcrop when compared to biochar + NPK and when cow urine was compared with biochar + cow urine, there was a 3.12 kg ha^{-1} decrease in SLCHcrop. Biochar alone had a 7.42 decrease in SLCHcrop compared to cow urine. Means in the same column followed by different superscript letters are significantly different by DMRT at (P<0.005)

Table 4 presents the analysis of soil nutrient loss due to harvesting of sweet potatoes as affected by amended biochar applications showing variations in the amount of nutrient loss for each treatment. The nutrients considered include OC, TN, P, K, Ca, and Mg.

Soil organic carbon: Biochar + cow urine had more OC loss of 4.62 kg ha^{-1} when compared to biochar + NPK. Cow urine had more OC loss of 3.49 kg ha^{-1} compared to NPK. Biochar alone had more OC loss of 2.14 kg ha^{-1} compared to the control that had the least OC loss of 14.97 kg ha^{-1}.

Total nitrogen: NPK had the highest TN loss of 28.76 kg ha^{-1} while the control had the lowest TN loss of 0.52 kg ha^{-1}. Biochar + NPK had more TN loss of 2.82 kg ha^{-1} than biochar + cow urine. Cow urine had less TN loss of 2.45 kg ha^{-1} when compared to biochar + NPK, but when compared to biochar + cow urine, cow urine had more TN loss of 0.37 kg ha^{-1}.

Phosphorus: NPK and biochar + cow urine had the same P loss of 0.17 kg ha^{-1}, while biochar had the least P loss of 0.04 kg ha^{-1}. Biochar + cow urine had more P loss of 0.08 kg ha^{-1} compared to biochar + NPK.

Potassium: NPK had the highest K loss of 3.33 kg ha^{-1} while the control had the lowest K loss of 0.88 kg ha^{-1}. Biochar + NPK had 35.7 % more K loss compared to biochar + cow urine. Biochar had 49.5 % less K loss compared to cow urine.

Calcium: NPK had the highest Ca loss of 2.42 kg ha^{-1} while the control had the lowest Ca loss of 1.08 kg ha^{-1}. Biochar + cow urine had 0.18 kg ha^{-1} more Ca loss compared to biochar + NPK. Cow urine had 0.39 kg ha^{-1} Ca loss compared to biochar.

Magnesium: NPK had the highest Mg loss of 0.91 kg ha-1, while the control had the lowest Mg loss of 0.48 kg ha-1. Biochar + cow urine had 6.3 % more Mg loss than biochar + NPK. Cow urine had 7 % more Mg loss compared to biochar + NPK.

Relationship between soil loss parameters and soil nutrient loss

Table 5 presents the relationship among SLCHcrop, SLCHspec, OC, TN, P, K, Ca and Mg. SLCHspec positively correlated with OC (0.56), K (0.37), Ca (0.30), and Mg (0.34). However, the correlation between SLCHspec and TN (0.07), and the correlation between SLCHspec and P (-0.03) were very weak. SLCHcrop strongly and positively correlated with OC (0.69), TN (0.59), P (0.69), K (0.79), Ca (0.90), and Mg (0.89). OC positively correlated with P (0.47), Ca (0.38), and Mg (0.34). However, the correlation between OC and TN was negative and very weak. OC and K had a weakly positive correlation. TN had low and positive correlation with K (0.44), Ca (0.35), and Mg (0.40). However, the correlation between TN and P was moderately positive (0.62). P had strong and positive correlation with K (0.65), Ca (0.80), and Mg (0.71). K had strong and positive correlation with Ca (0.63) and Mg (0.89).

Table 3: Sweet potato yield, SLCH spec, and SLCH crop as affected by amended biochar application

Treatments	Sweet potato yield (t ha^{-1})	SLCH spec (g kg^{-1})	SLCH crop (kg ha^{-1})
Control	3.81 ± 0.75^{d}	3.66 ± 0.33^{c}	13.85 ± 2.32^{b}
Biochar	4.39 ± 0.25^{cd}	3.97 ± 0.20^{bc}	17.40 ± 0.85^{b}
Cow urine	5.83 ± 0.50^{b}	4.25 ± 0.10^{b}	24.82 ± 2.68^{a}
NPK	7.28 ± 0.67^{a}	4.07 ± 0.18^{b}	29.53 ± 1.80^{a}
Biochar + NPK	5.67 ± 1.15^{bc}	4.96 ± 0.05^{a}	28.11 ± 5.59^{a}
Biochar + cow urine	6.83 ± 0.60^{ab}	4.08 ± 0.14^{b}	27.94 ± 3.43^{a}
p-value	0.001	<0.001	<0.001

Means ± Standard deviation in the same column followed by different superscript letters are significantly different by DMRT at (P<0.005)

Table 4: Estimate of soil nutrients loss (kg ha^{-1}) due to sweet potato harvesting as affected by amended biochar application

Treatments	OC	TN	P	K	Ca	Mg
			kg ha^{-1}			
Control	14.97 ± 2.75^{d}	0.52 ± 0.10^{d}	0.09 ± 0.02^{b}	0.88 ± 0.16^{d}	1.08 ± 0.20^{d}	0.48 ± 0.09^{d}
Biochar	17.11± 0.53^{cd}	0.56 ± 0.02^{d}	0.04 ± 0.00^{c}	1.01 ± 0,03^{d}	1.27 ± 0.04^{cd}	0.56 ± 0.02^{cd}
Cow urine	21.72± 2.45^{bc}	3.38 ± 0.38^{c}	0.10 ± 0.01^{b}	1.51 ± 0.17^{c}	1.66 ± 0.19^{bc}	0.76 ± 0.09^{bc}
NPK	18.23 ± 1.06^{cd}	28.76 ± 1.67^{a}	0.17 ± 0.01^{a}	3.33 ± 0.19^{a}	2.42 ± 0.14^{a}	0.91 ± 0.05^{a}
Biochar + NPK	25.52 ± 5.32^{ab}	5.83 ± 1.22^{b}	0.09 ± 0.02^{b}	2.13 ± 0.44^{b}	1.70 ± 0.36^{b}	0.69 ± 0.14^{bc}
biochar + cow urine	30.14 ± 3.44^{a}	3.01 ± 0.34^{c}	0.17 ± 0.02^{a}	1.57 ± 0.18^{c}	1.88 ± 0.21^{b}	0.72 ± 0.08^{bc}
p-value	0.002	<0.001	<0.001	<0.001	<0.001	0.003

Means ± standard deviations in the same column followed by different superscript letters are significantly different by DMRT at (P<0.005). OC: Organic carbon, TN: Total Nitrogen, P: Phosphorus, K: Potassium, Ca: Calcium,

Table 5: Correlation matrix showing the relationship between soil loss parameters and soil nutrients loss

	SLCH spec	SLCH crop	OC	TN	P	K	Ca
SLCH crop	0.63*						
OC	0.56*	0.69*					
TN	0.07	0.59*	-0.13				
P	-0.03	0.69*	0.47*	0.62*			
K	0.57*	0.79*	0.14*	0.44	0.65*		
Ca	0.30	0.90**	0.48*	0.35	0.80*	0.63*	
Mg	0.34	0.89**	0.34	0.40	0.71*	0.89*	0.97**

** = P < 0.05, correlation is significant at 5%, ** correlation is significant at 0.01 level. SLC= soil loss due to crop harvesting, OC= Organic carbon, TN= Total Nitrogen, P= Phosphorus, K= Potassium, Ca= Calcium, Mg= Magnesium,*

Figure 5 shows the effects of amended biochar application on post-harvest soil physical properties. Treatment did not significantly affect field capacity (FC; P ≈ 0.170), bulk density (BD; P = 0.681), or soil moisture content (SMC; P = 0.832). Numerically, FC ranged from 11.53% under cow urine to 16.40% under biochar, while BD ranged from 1.24 Mg m^{-3} under biochar to 1.39 Mg m^{-3} in the control. Soil moisture content ranged from 23.26% in the control to 27.07% under biochar. In contrast, treatment significantly affected soil hydraulic conductivity (SHC; P < 0.001). Biochar recorded the highest SHC (8.81 cm h^{-1}), which was significantly higher than all other treatments. Biochar + cow urine recorded 5.03 cm h^{-1} and was significantly higher than cow urine (3.14 cm h^{-1}), but was statistically similar to the control (3.35 cm h^{-1}), NPK (4.38 cm h^{-1}), and biochar + NPK (3.43 cm h^{-1}).

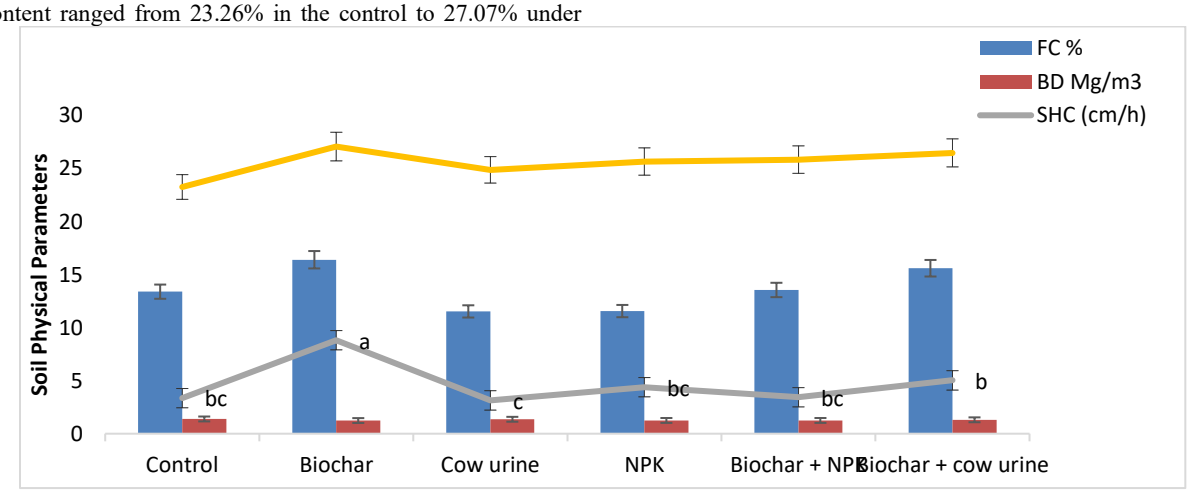


Figure 5. Effects of amended biochar application on post-harvest soil physical properties under sweet potato.
FC: field capacity; BD: bulk density; SHC: soil hydraulic conductivity; SMC: soil moisture content. For SHC, treatment means followed by different superscript letters are significantly different at P < 0.05.

Relationship between soil loss parameters and post-harvest soil physical parameters

Table 6 presents the relationship between the soil loss parameters and post-soil physical parameters. FC had weak negative correlation with BD (-0.29), SLCHspec (-0.14), and SLCHcrop (-0.33). However, the correlation between FC and SHC (0.76), and FC and SMC (0.57) were moderately positive. BD negatively and moderately correlated with SHC (-0.55). The correlation between BD and SMC was high and negative, while SLCHspec (-0.46) and SLCHcrop (-0.44) had low and negative correlation with BD. SHC correlated positively and moderately with SMC (0.72), while SLCHspec (-0.27) and SLCHcrop (-0.29) had low and negative correlation with SHC. The correlation between SMC and SLCHspec (0.32), and SLCHcrop (0.42) were positively low.

Table 6: Correlation matrix showing the relationship between soil loss parameters and some soil physical parameters

	FC	BD	SHC	SMC	SLCH spec
			n=18		
BD	-0.29				
SHC	0.76*	-0.55*			
SMC	0.57*	-0.82*	0.72*		
SLCH spec	-0.14	-0.46	-0.27	0.32	
SLCH crop	-0.33	-0.44	-0.29	0.42	0.63*

** = P < 0.05, correlation is significant at 5%, ** correlation is significant at 0.01 level. SLCH: soil loss due to crop harvesting, FC: Field Capacity, BD: Bulk Density, SHC: Soil Hydraulic Conductivity, SMC: Soil Moisture Content*

DISCUSSION

The pre-planting soil analysis indicated that the soil was near neutral, had low organic carbon content, low total nitrogen, and available phosphorus content, and low levels of potassium, and the soil is generally suitable for sweet potato production as reported by Adekiya (2022). Sweet potato yield found that the application of NPK fertiliser had the highest impact on increasing the yield of sweet potato, followed by the combination of biochar and cow urine. Cow urine alone and biochar + NPK also had a positive effect on sweet potato yield but to a lesser extent. Biochar alone had a negligible effect on sweet potato yield, as its yield was not significantly different from the control. This was consistent with the findings of a study conducted by Alori *et al*. (2017) which showed that the combination of organic and inorganic fertilizers had a significant positive effect on the growth and yield of sweet potato. The findings of this research indicated that all treatments used, including NPK fertiliser, biochar, cow urine, and their combinations, have a significant effect on sweet potato yield and soil loss. Specifically, the application of NPK resulted in the highest sweet potato yield but also led to the highest soil loss per hectare of land. In contrast, the application of biochar or biochar in combination with cow urine resulted in higher sweet potato yield and relatively lower soil loss per unit weight of sweet potato harvested (SLCHspec) and per hectare of land used (SLCHcrop).

The correlation indicated that there was a positive relationship between sweet potato yield and soil loss parameters, particularly SLCHcrop and SLCHspec. Additionally, as above-ground biomass increases, crop yield also tends to increase. However, there was a weak negative correlation between SLCH spec and above-ground biomass, indicating that an increase in SLCHspec may lead to a decrease in above-ground biomass. The relationship between SLCHcrop and above-ground biomass was moderate and positive, suggesting that an increase in SLCHcrop may also lead to an increase in above-ground biomass. This aligns will the study of Balogun *et al*., (2024) who found that SLCH was a significant predictor of yield in sweet potato, while a study by Famba *et al*. (2018) found that SLCHcrop was positively correlated with yield in cassava. The soil nutrient loss findings indicated that the addition of biochar, cow urine, and NPK fertilizer can significantly increase soil nutrient levels during the harvesting of sweet potatoes. Specifically, the use of NPK fertilizer can increase Total Nitrogen and Potassium, while the use of biochar and cow urine can increase Soil Organic Carbon, Phosphorus, and Calcium. These results align with the study reported by Zhang *et al.* (2023) that biochar amendment could enhance soil nutrient availability, water retention, and crop yields in different soil types and climates. Similarly, other studies have demonstrated the benefits of cow urine and manure as a source of nutrients and organic matter for soil improvement (Mekonnen *et al.*, 2017). Based on the correlation coefficients, there was a positive correlation between soil loss parameters and soil nutrient loss. Specifically, SLCHspec was positively correlated with soil organic carbon, Potassium, Calcium, and Magnesium, while SLCHcrop was strongly positively correlated with all the soil nutrients mentioned above. Additionally, there was a positive correlation between soil organic carbon and Phosphorus, Calcium, and Magnesium, while Total Nitrogen was positively correlated with Potassium, Calcium, and Magnesium, and Phosphorus was positively correlated with Potassium, Calcium, and Magnesium. This finding aligns with Wang *et al*. (2019) who reported that soil erosion significantly decreased soil organic carbon and nutrient content. Another study by Feng *et al*. (2016) showed that soil erosion led to a decline in soil nutrients, including nitrogen, phosphorus, potassium, and organic matter. Also, the addition of biochar had positive effects on the soil's physical properties, including an increase in field capacity, soil moisture content, and soil hydraulic conductivity, as well as a decrease in bulk density. The addition of cow urine did not have a significant effect on these properties. The combination of biochar and cow urine resulted in intermediate values for these properties. The findings were consistent Wang *et al*. (2019) who found that biochar amendment improved soil hydraulic conductivity and reduced bulk density. Additionally, a study by Zhang *et al.*

(2023) reported that biochar amendment improved soil water retention and reduced soil bulk density.

CONCLUSION AND RECOMMENDATIONS

The application of NPK fertiliser had the highest impact on increasing the yield of sweet potato, followed by biochar amended with cow urine. The application of biochar, cow urine, and their combinations significantly increase soil nutrient levels. The positive correlations found between soil loss parameters and soil nutrient loss indicated that harvesting of sweet potato from the farm if not properly handled can cause soil nutrient loss. Overall, the study suggests the importance of adopting sustainable practices that promote soil health and productivity in agriculture.

However, further research needs to be carried out to determine the long-term effects of biochar and organic amendments on soil health and productivity.

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Authors' Contributions

GPA conceptualized the study. AAO & TSO designed the experiment, GPA & JJM collected data, performed data analysis, and wrote the first draft of the manuscript. GPA, AAO & TSO performed literature searches and reviewed the first draft of the manuscript. All authors read and approved the final draft of the manuscript. Ethical Statement

Ethical Statement

Not applicable

AI Declaration Statement

The authors declare that no Artificial Intelligence (AI) tools were used in the generation, analysis, interpretation, or writing of this manuscript.

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