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Optimising Vine Growth, Marketable Tuber Yield, and Biomass Production of Orange-Fleshed Sweet Potato Through Tillage and Fertilizer Management in FCT-Abuja, Nigeria

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ABSTRACT
Orange-fleshed sweet potatoes (OFSP) are widely promoted in sub-Saharan Africa to improve vitamin A intake. However, production is constrained by poor soil fertility and tillage practices in Nigeria's Federal Capital Territory (FCT). This research determined the combined effects of three tillage practices (mound, ridge and flat-bed) and four fertilizer treatments (NPK 20: 10:10 at 200 kg/ ha; poultry manure at 5 t/ha, urea at 200 kg/ha and unfertilized control) on growth, yield and pest incidence of OFSP cultivar Mother's Delight during the 2024 and 2025 cropping seasons at University of Abuja Teaching and Research Farm on factorial combination of 3 x 4 in randomized complete block design with three replicates. Tillage combined with NPK fertiliser application increased vine length (233.7 cm), leaf number (174.1), and fresh biomass yield (9.4 kg/plot) by 76%, 86%, and 62%, respectively, over the control. Root yield was highest in mound tillage (29.4 t/ha), while the maximum storage root yield of 38.5 t/ha was obtained from the mound–NPK interaction, representing a 92% improvement over the flat-bed control treatment. Application of poultry manure shifted soil pH (4.6–6.7) and increased cation exchange capacity (CEC) to 3.78 cmol/kg, indicating improved soil fertility. However, the incidence of Cylas weevil infection was increased by 84% with the use of NPK fertilizer. Fresh biomass had a positive correlation with marketable roots (r = 0.971, r = 0.900, respectively). Mound tillage coupled with the application of NPK fertilizer would increase OFSP yield significantly.

Keywords: Biofortification, Cylas Infestation, Fertilizer Management, Orange-Fleshed Sweet Potato, Soil Fertility, Tillage Systems, Yield Performance

INTRODUCTION

Orange-fleshed sweet potato (OFSP; *Ipomoea batatas* L.) has become an important biofortified food crop used to address vitamin A deficiency (VAD), which currently affects about 30% of children under 5 years in Nigeria (Low *et al.*, 2019; Tanumihardjo *et al.*, 2020). Owing to its high β-carotene content and wide adaptability across diverse agro-ecological zones, with potential yields reaching about 56.4 t/ha (Andrade *et al*., 2019; Laurie *et al.,* 2020), the "Mother's Delight" variety (UMUSP3/CIP 440293) was officially released by the National Root Crops Research Institute (NRCRI), Umudike, in November 2013 as part of efforts to combat malnutrition in Nigeria. However, Nigeria is currently Africa's second-largest sweet potato producer, growing up to 2.88 million tonnes annually, but OFSP average yields are less than 10 t/ha against attainable yields of 27–35 t/ha achieved by smallholders in neighbouring Mozambique and Malawi (FAO, 2022; Chipungu *et al.,* 2021). This yield gap exists mainly in Nigeria's Federal Capital Territory (FCT) because sweet potato farmers are simultaneously confronted with two major, albeit related limitations: the imposition of tillage practices inconducive to healthy root growth (Agbede and Adekiya, 2022). Farmers grow OFSP on flat beds without ploughing or turning the soil because they are smallholders who till mainly by hand. Evidence from neighbouring countries such as Ghana and Ethiopia suggests that ridge-and-mound tillage decreases bulk density and improves root-zone aeration for increased nutrient uptake from the soil profile (Dumbuya *et al.,* 2022; Tsegaye *et al.,* 2023). Mound tillage particularly enhances the soil macrostructure around developing tubers by concentrating fertile topsoil within the root zone and improving drainage in compact tropical Alfisols (Onwueme, 2021; Parwada *et al.,* 2020).

On the other hand, these same soils are losing fertility because farmers grow sweet potatoes continuously on the same land without replenishing lost nutrients from previous harvests. Organic carbon (OC) and exchangeable cations (particularly K: 0.09 $cmol^{+}/100$ g) were recently reported to be low across farmlands of the FCT (Anyaegbu and Ibrahim, 2022). Synthetic fertilizers such as NPK 20:10:10 and urea release nutrients more rapidly and can have prolonged residual effects that enhance crop productivity. However, their increasing cost and associated environmental pollution have renewed interest in the use of organic amendments, such as poultry manure (Olatunji and Adeyongu, 2022; Egata Shunka *et al.,* 2021). Application of poultry manure is particularly interesting because it not only releases nutrients like N, P, and K slowly over time but can also help ameliorate the low soil pH characteristic of most tropical soils (pH 4.6–5.5), thereby suppressing Al toxicity, another OFSP growth limitation reported in Nigeria (Nedunchezhiyan *et al*., 2022).

Nonetheless, there is limited information regarding how tillage interacts with fertilizer type to affect OFSP growth and yield. In fact, tillage experiments conducted in Abuja failed to report effects on sweet potato crops because only one season was grown due to the outbreak of the COVID-19 pandemic disruptions at the time (Agbede *et al.,* 2023). Multi-season experiments are highly recommended because annual weather variations can drastically impact agronomic performances, which may either negate or reinforce findings from single-season trials (Motsa *et al.,* 2019; Adebayo *et al*., 2023; Ilozobhie *et al.,* 2024). Tillage and fertilizer type have never been tested to see how mound, ridge or flat preparations affect agronomic performance (number and length of vines, biomass partitioning, fresh marketable tuber yield, %Cylas infestation) of OFSP amended with NPK, Urea, or poultry manure fertilizer in two consecutive seasons (Kibrom, 2021; Stathers *et al.,* 2020). This is especially important for 'Mother's Delight' OFSP grown under Abuja's derived savannah ecology because Nigeria loses an estimated 20–80% of harvested storage roots to the sweet potato weevil (*Cylas puncticollis* Fabricius) post-harvest, and rates of infestation may increase with nitrogen fertilisation if producing more lush vegetative tissues (Mbua *et al.,* 2021; Ogunlade *et al.,* 2023). This study, therefore sought to: determine the effect of tillage–fertilizer combinations on vine number, vine length, fresh biomass yield and marketable tuber yield of OFSP variety 'Mother's Delight' across two growing seasons; ascertain the tradeoffs between using inorganic (NPK and Urea) versus organic (poultry manure) fertilizer sources on OC loss, base saturation reduction and % Cylas infestation; evaluate possible interactions between tillage practice, fertilizer source, and season on growth parameters and marketable yield; and lastly make OFSP-specific recommendations for scaling up sweet potato intensification efforts across Nigeria's Federal Capital Territory.

MATERIALS AND METHODS

Study Area

The experiment was conducted across two growing seasons (May–September) in the years 2024 and 2025 at the Teaching and Research Farm of the University of Abuja, Federal Capital Territory, Nigeria (Latitude 9° 4′ 24.45″ N, Longitude 7° 27′ 40.59″ E; elevation 480 m above sea level). The study area falls within the southern Guinea Savannah agroecological zone of Nigeria, with rainfall spread from April to October. Mean annual rainfall ranges from 80 to 180 cm, with rainfall distribution being fairly similar across both cropping seasons – 98.4 cm (2024) and 95.7 cm (2025). Mean temperatures range from 22 °C to 38 °C, with an annual average temperature of about 30 °C. Relative humidity ranges from 60–80% during the cropping season (Barnabas and Nwaka, 2014). The dominant soil type within the study area is sandy loam Alfisol (70% sand, 20% clay, and 10% silt), developed from granite gneiss parent material. The baseline soil properties measured before planting season one (2024) were pH (0.01 M $CaCl_2$): 4.6, organic carbon: 0.67%, total N: 0.35%, available P Bray 2: 8.6 ppm, exchangeable K: 0.09 $cmol^+$/100 g soil, base saturation (BS): 57%, cation exchange capacity (CEC): 1.67 $cmol^+$/100 g soil. Soil properties were determined before planting season two (2025) and were similar to season one – pH 4.7 with no significant difference from pre-planting soil measurements done in 2024, indicating no effects carried over from treatments applied in season (Table 1). Plots were prepared anew before season two started.

Land Preparation and Soil Sampling

The experimental field was cleared, levelled and stumped using a cutlass (machete) and hoes before each season start. Subsequently, the land was ploughed using a semi-rotary plough and then harrowed with a metal ridging implement attached to a tractor until a fine tilth was achieved, making the plots suitable for planting. The same experimental design was replicated for the second season. Pre-planting soil sampling was done by collecting soil from 10 randomly selected points within each plot at a depth of 0–30 cm using a hand auger per plot. Samples were composited in a clean plastic bucket, air-dried and sieved using a 2 mm mesh before laboratory analysis. Soil chemical properties were determined according to procedures described by FAO (2019). Another batch of soil samples was obtained from the 0–15 cm soil layer at the completion of each cropping season.

Experimental Materials

A single sweet potato genotype, UMUSP3 (CIP 440293), which is a biofortified orange-fleshed cultivar approved by Nigeria's National Root Crops Research Institute, was employed in this study. Fresh vine cuttings were obtained one week before planting in each season from the NRCRI outstation located along the Abuja–Nyanya corridor within the FCT–Nasarawa region of Nigeria. UMUSP3 was chosen because of its high β-carotene content and nutritional profile. It has been previously validated as having more provitamin A than standard white-fleshed varieties as well as favourable dietary fibre content, essential minerals and antioxidants desirable for nutritional studies and interventions targeting micronutrient malnutrition (Tumuhimbise *et al.,* 2019; Amagloh *et al.,* 2021). Its sensory qualities are also well documented. UMUSP3 is described as having a sweet taste and a soft texture after cooking; attributes commonly associated with orange-fleshed sweet potato (OFSP) varieties that have low dry matter content.

Experimental Design and Treatments

The experiment was conducted over two growing seasons using a 3 × 4 factorial arrangement in a randomized design with three replications. The factorial comprised two factors: Factor A consisted of three tillage practices (mounds, ridges, and flat beds), while Factor B consisted of four fertilizer treatments (NPK 20:10:10, poultry manure, urea, and an unfertilized control). This resulted in 12 treatment combinations (3 × 4) in each growing season. Each treatment combination was replicated three times, giving a total of 36 experimental plots per season. Across the two growing seasons, the experiment therefore comprised 24 treatment combinations and 72 experimental plots. Each plot consisted of 3 m × 3 m, giving a net plot size of 324 m² per season. Considering the plot borders of 0.5 m between plots and 1 m alleyways separating replicates, the total gross experimental area per season was 432 m². Each replicate occupied an area of 10 m × 13.5 m (135 m²). This same field layout was maintained for season two to avoid season effects. The plot size was adequate to facilitate this study's aim of evaluating tillage × fertilizer interactions under field conditions typical of southern Guinea savannah agroecology.

Cultural Practices

Sweet potato vine cuttings were planted at a depth of 30 cm and spaced 50 cm apart in both directions to give a plant population of 40,000 plants ha^{-1} and 36 stands per plot. Cuttings were planted at a downward angle of ≈ 60° such that about two-thirds of the cutting was below ground and then pressed firmly onto the soil to give soil–cutting contact. This contact improves sprouting rates, which were further enhanced by gap filling 7 days after planting (DAP). Weed removal was done twice, at 21 and 56 DAP, using handheld hoes to achieve a weed-free field. Poultry manure was air-dried and sieved before being applied three weeks before planting. Analysis showed poultry manure contained 2.5% N, 1.8% P and 1.5% K. It was applied at a rate of 5 t/ha, following Anyaegbu (2013), which corresponds to 4.5 kg per plot or 0.125 kg per plant stand. Farmers in the study area commonly use broiler house poultry manure for crop production.

Inorganic fertilizer was banded and applied three weeks after planting at a rate of 200 kg/ha, which corresponds to 0.36 kg per plot. Urea (46% N) was applied at the same rate to increase available N in early vegetative growth stages. Both fertilizer types were sprinkled evenly across each planting hill. Harvest was done 16 weeks after planting with the aid of a hoe. During harvesting, care was taken to uproot tubers with minimal mechanical damage. Harvested tubers were separated based on size and marketability before being used for yield assessment and statistical analysis. Little care was taken during harvesting to minimise post-harvest losses.

Data Collection

Soil physicochemical properties were determined using standard methods outlined previously (Bouyoucos hydrometer procedure for particle size determination, pH meter, Walkley Black for OC, Macro Kjeldahl for total N, Bray No. 2 for available P and 1 N neutral ammonium acetate extraction for exchangeable K). Soil samples were collected from the 0–30 cm soil depth before planting and again after harvest. Plant growth parameters (numbers of vines/plant, vine length, number of leaves/plant and plant stands/plot) were assessed at harvest (16 weeks after planting or WAP) each season. Yield components assessed were fresh biomass, total roots, marketable roots and unmarketable roots per plot. Infestation (% Cylas colonies/plot) was also determined before uprooting, and using the weight of marketable tubers harvested from each plot, Root yield was determined and reported in tonnes per hectare (t/ha). All these parameters were measured/collected at harvest (16 WAP) for each season.

Statistical Analysis

The combined dataset from both seasons was subjected to ANOVA in R software (version 4.0.3) using the 'agridat' package to obtain p-values, and the 'agricolae' package to perform ANOVA and Fisher's least significant difference (LSD) mean separation at $p \leq 0.05$. Season, tillage practice and fertilizer were considered as fixed factors, while replication nested within season was a random factor. Least significant difference was done on the combined dataset to test for the significance of season × tillage and season × fertilizer interactions.

Pearson correlation coefficients (r) were calculated between root yield and vine parameters using the combined dataset (two seasons). To quantify the relative performance of each fertilizer treatment under each tillage practice, treatment effects were expressed as a percentage change relative to the no-fertilizer control, calculated as follows:

$$\text{Percentage change} = \left(\frac{\bar{X}_T - \bar{X}_C}{\bar{X}_C}\right) \times 100$$

Where:

$\bar{X}_T$= mean value of a given treatment combination (tillage × fertilizer).

$\bar{X}_C$= mean value of the corresponding control plot (same tillage practice, no fertilizer).

RESULTS AND DISCUSSION

Pre-Planting Physicochemical Properties of the Experimental Soil in 2024 and 2025

As shown in Table 1**,** the experimental soil was classified as sandy loam, comprising 70% sand, 20% clay, and 10% silt, before the 2024 growing season. The soil was strongly acidic, with pH values of 4.7 (H_2O) and 4.6 (KCl). Organic carbon (0.67%) and total nitrogen (0.35%) contents were low, while available phosphorus (8.6 ppm) and exchangeable potassium (0.09 $cmol^+ kg^{-1}$ soil) were deficient.

The soil had a base saturation of 57% and an effective cation exchange capacity (ECEC) of 1.67 $cmol^+ kg^{-1}$ soil. There were no significant differences ($P > 0.05$) in the pre-planting soil properties between the 2024 and 2025 growing seasons (pH 4.7, organic carbon 0.65%, and total nitrogen 0.34%), indicating the absence of residual or carryover effects from the first season to the second.

Table 1: Physicochemical Properties of the Experimental Soil Before Planting During the 2024 and 2025 Growing Seasons

Soil Property	2024 (Pre-planting)	2025 (Pre-planting)	Interpretation
Sand (%)	70	70	Sandy loam
Silt (%)	10	10	
Clay (%)	20	20	
Textural class	Sandy loam	Sandy loam	
pH (H_2O)	4.7	4.7	Strongly acidic
pH (KCl)	4.6	4.6	Strongly acidic
Organic carbon (%)	0.67	0.65	Low
Total nitrogen (%)	0.35	0.34	Low
Available P (ppm)	8.6	8.6	Deficient
Exchangeable K ($cmol^+ kg^{-1}$)	0.09	0.09	Deficient
Effective CEC ($cmol^+ kg^{-1}$)	1.67	1.67	Low
Base saturation (%)	57	57	Moderate

Values for the Pre-Planting Soil Properties did not Differ Significantly ($P > 0.05$) Between the 2024 and 2025 Growing Seasons, Indicating that there Were no Residual or Carryover Effects from the First Season on the Initial Soil Conditions of the Second Season

Number of Vines/Plant

The type of fertilizer significantly affected vine production ($p < 0.001$) during both seasons. Treatment NPK 20: 10:10 had the greatest vines per plant (12.2) and was 64.9% greater than the no-fertiliser control treatment (7.4). Poultry manure (10.1) and Urea (9.8) had similar means. Tillage had a significant effect on vine number (p = 0.0027). Mounds (10.5 vines) and ridges (10.2 vines) produced more vines per plant than flat beds (9.0 vines). Mound/NPK interaction had the greatest vines/plant (13.3), 90% greater than Flat/No fertilizer control (7.0). There was no significant interaction between season and treatment (p > 0.05). See Table 2 for means ± SE with p values.

Table 2: Effect of Fertilizer Types and Tillage Practices on the Number of Vines per Plant of Orange-Fleshed Sweet Potato During the 2024 and 2025 Growing Seasons and their Combined Analysis

Factor	Treatment	2024 Mean	2025 Mean	Combined Mean	SE	p-value
Fertilizer Type	No fertilizer	7.3c	7.5c	7.4c	0.31	<0.001
	NPK 20:10:10	12.3a	12.1a	12.2a	0.35	
	Poultry manure	10.0b	10.2b	10.1b	0.33	
	Urea	9.7b	9.9b	9.8b	0.32	
Tillage	Flat	8.9b	9.1b	9.0b	0.27	0.0027
	Mound	10.6a	10.4a	10.5a	0.29	
	Ridge	10.1a	10.3a	10.2a	0.28	
Interaction (F×T)	Mound/NPK	13.4a	13.2a	13.3a	0.56	0.3051
	Flat/No fertilizer	6.9d	7.1d	7.0d	0.51	
Season	2024	–	–	9.9	0.18	0.452
	2025	–	–	10.0	0.18	

Means Followed by Different Letters Within Columns Differ Significantly at p ≤ 0.05 (LSD). SE± = Standard Error of the Mean. *p*-Values Indicate ANOVA Significance at *p* ≤ 0.05. Interaction (F × T) and Main Effects were Tested Using ANOVA

Length per Vine (cm)

Fertilizer type significantly affected vine elongation (p < 0.001). NPK produced the longest vines at 233.7 cm, which was 76.1% greater than control vines (132.7 cm). Poultry manure (195.8 cm) and Urea (192.3 cm) were also significantly greater than the control by 47.6% and 44.9%, respectively. Mound tillage had longer vines (203.2 cm) than flat beds by 21.8% (p = 0.012). Treatment interaction between Mound / NPK produced the greatest vine length (258 cm), which was 119% longer than Flat / No fertilizer control vines (117.7 cm). High agreement was noted between seasons (Table 3).

Table 3: Effect of Fertilizer Types and Tillage Practices on Vine Length (cm) of Orange-Fleshed Sweet Potato During the 2024 and 2025 Growing Seasons and their Combined Analysis

Factor	Treatment	2024 Mean	2025 Mean	Combined Mean	SE	p-value
Fertilizer Type	No fertilizer	131.9c	133.5c	132.7c	6.8	<0.001
	NPK 20:10:10	234.5a	232.9a	233.7a	7.2	
	Poultry manure	196.2b	195.4b	195.8b	6.9	
	Urea	191.8b	192.8b	192.3b	7.0	
Tillage	Flat	166.2b	167.4b	166.8b	5.5	0.012
	Mound	204.1a	202.3a	203.2a	5.8	
	Ridge	196.3a	195.5a	195.9a	5.6	
Interaction (F×T)	Mound/NPK	259.2a	256.8a	258.0a	16.5	0.3278
	Flat/No fertilizer	116.8c	118.6c	117.7c	14.2	
Season	2024	–	–	195.8	4.2	0.382
	2025	–	–	194.6	4.2	

Means Followed by Different Letters Within Columns Differ Significantly at p ≤ 0.05 (LSD). SE± = Standard Error of the mean. *p*-Values Indicate ANOVA Significance at *p* ≤ 0.05. Interaction (F × T) and Main Effects were Tested Using ANOVA

Number of Leaves per Plant

NPK-treated plants had 174.1 leaves/plant, which was 86.0% greater than the control (93.6). Poultry manure (151.6) and Urea (127.6) also had statistically significant increases of 61.9% and 36.3%, respectively. Mounds produced the greatest number of leaves (154.1), which was 28.1% greater than flat beds (120.3) (p = 0.0014). Mound/NPK had the greatest number of leaves/plant at 202.7, which was 139% greater than Flat/No fertilizer control (84.7). See Table 4.

Table 4: Effect of Fertilizer Types and Tillage Practices on the Number of Leaves per Plant of Orange-Fleshed Sweet Potato During the 2024 and 2025 Growing Seasons and their Combined Analysis

Factor	Treatment	2024 Mean	2025 Mean	Combined Mean	SE	p-value
Fertilizer Type	No fertilizer	92.8d	94.4d	93.6d	4.5	<0.001
	NPK 20:10:10	174.8a	173.4a	174.1a	4.8	
	Poultry manure	152.1b	151.1b	151.6b	4.6	
	Urea	127.2c	128.0c	127.6c	4.7	
Tillage	Flat	119.8b	120.8b	120.3b	3.9	0.0014
	Mound	155.0a	153.2a	154.1a	4.1	
	Ridge	135.2b	136.2b	135.7b	4.0	

Factor	Treatment	2024 Mean	2025 Mean	Combined Mean	SE	p-value
Interaction (F×T)	Mound/NPK	203.5a	201.9a	202.7a	16.2	0.6662
	Flat/No fertilizer	84.1e	85.3e	84.7e	14.5	
Season	2024	–	–	136.8	3.1	0.418
	2025	–	–	136.0	3.1	

Means Followed by Different Letters Within Columns Differ Significantly at $p \leq 0.05$ (LSD). SE± = Standard Error of the Mean. *p*-Values Indicate ANOVA Significance at $p \leq 0.05$. Interaction (F × T) and Main Effects were Tested Using ANOVA

Stand Survival (% at 16 weeks)

NPK and poultry manure both improved survival over the control by similar amounts (30.6% and 26.6% greater than control: 90.8% vs. 88.0% vs. 69.5%, respectively; $p < 0.001$). Tillage did not affect survival ($p = 0.2775$). Survival was greatest in the Mound/NPK and Ridge/NPK combinations (91.7% for both), and lowest in Flat/No fertilizer (66.7%). Survival was slightly greater in 2025 (81.9%) than in 2024 (80.3%), but this difference was not significant ($p = 0.245$) (Table 5).

Table 5: Effect of Fertilizer Types and Tillage Practices on Stand Survival (%) at 16 Weeks After Planting of Orange-Fleshed Sweet Potato During the 2024 and 2025 Growing Seasons and Their Combined Analysis

Factor	Treatment	2024 Mean (%)	2025 Mean (%)	Combined Mean (%)	SE	p-value
Fertilizer Type	No fertilizer	68.9c	70.1c	69.5c	2.1	<0.001
	NPK 20:10:10	90.5a	91.1a	90.8a	2.3	
	Poultry manure	87.6a	88.4a	88.0a	2.2	
	Urea	76.2b	77.4b	76.8b	2.2	
Tillage	Flat	78.8	79.6	79.2	1.8	0.2775
	Mound	82.1	83.3	82.7	1.9	
	Ridge	81.4	82.6	82.0	1.8	
Interaction (F×T)	Mound/NPK	91.3a	92.1a	91.7a	3.2	0.7434
	Flat/No fertilizer	66.1d	67.3d	66.7d	3.0	
Season	2024	–	–	80.3	1.2	0.245
	2025	–	–	81.9	1.2	

Means Followed by Different Letters Within Columns Differ Significantly at $p \leq 0.05$ (LSD). SE± = Standard Error of the Mean. *p*-Values Indicate ANOVA Significance at $p \leq 0.05$. Interaction (F × T) and Main Effects were Tested Using ANOVA

Yield Components

Fresh Biomass Yield (kg/plot)

NPK produced 9.4 kg/plot, a 62.1% increase over the control (5.8 kg/plot). Poultry manure (7.9 kg/plot) and Urea (6.9 kg/plot) yielded 36.2% and 19.0% increases, respectively ($p < 0.001$). Mound tillage generated the highest biomass (7.8 kg/plot), exceeding flat beds (7.0 kg/plot) by 11.4% ($p < 0.001$). The Mound/NPK combination produced 10.2 kg/plot, 100% higher than the Flat/No fertilizer control (5.1 kg/plot). Biomass production was slightly higher in 2025 (7.6 kg/plot) than in 2024 (7.4 kg/plot) but not significantly different (Table 6).

Table 6: Effect of Fertilizer Types and Tillage Practices on Fresh Biomass Yield (kg/plot) of Orange-Fleshed Sweet Potato During the 2024 and 2025 Growing Seasons and their Combined Analysis

Factor	Treatment	2024 Mean	2025 Mean	Combined Mean	SE	p-value
Fertilizer Type	No fertilizer	5.7d	5.9d	5.8d	0.15	<0.001
	NPK 20:10:10	9.3a	9.5a	9.4a	0.17	
	Poultry manure	7.8b	8.0b	7.9b	0.16	
	Urea	6.8c	7.0c	6.9c	0.16	
Tillage	Flat	6.9b	7.1b	7.0b	0.12	<0.001
	Mound	7.7a	7.9a	7.8a	0.13	
	Ridge	7.6a	7.8a	7.7a	0.12	
Interaction (F×T)	Mound/NPK	10.1a	10.3a	10.2a	0.26	0.1041
	Flat/No fertilizer	5.0h	5.2h	5.1h	0.23	
Season	2024	–	–	7.4	0.10	0.312
	2025	–	–	7.6	0.10	

Means Followed by Different Letters Within Columns Differ Significantly at $p \leq 0.05$ (LSD). SE± = Standard Error of the Mean. *p*-Values Indicate ANOVA Significance at $p \leq 0.05$. Interaction (F × T) and Main Effects were Tested Using ANOVA

Total Number of Roots per Plot

Poultry manure (69.2) and NPK (64.8) produced similar total root numbers, exceeding the control (57.7) by 19.9% and 12.3%, respectively ($p = 0.0648$). Urea (46.0) was similar to the control. Tillage had no significant main effect ($p = 0.556$). The Mound/NPK combination produced the highest total roots (84.3), while Flat/Urea recorded the lowest (29.7). Total root numbers were similar between seasons (Table 7).

Table 7: Effect of Fertilizer Types and Tillage Practices on the Total Number of Storage Roots per Plot of Orange-Fleshed Sweet Potato During the 2024 and 2025 Growing Seasons and their Combined Analysis

Factor	Treatment	2024 Mean	2025 Mean	Combined Mean	SE	p-value
Fertilizer Type	No fertilizer	57.1b	58.3b	57.7b	3.5	0.0648
	NPK 20:10:10	64.2a	65.4a	64.8a	3.7	
	Poultry manure	68.6a	69.8a	69.2a	3.6	
	Urea	45.4b	46.6b	46.0b	3.6	
Tillage	Flat	55.6	56.8	56.2	2.9	0.5560
	Mound	57.5	58.7	58.1	3.0	
	Ridge	63.4	64.6	64.0	2.9	
Interaction (F×T)	Mound/NPK	83.7a	84.9a	84.3a	16.5	0.0280
	Flat/Urea	29.1b	30.3b	29.7b	14.8	
Season	2024	–	–	58.9	2.1	0.478
	2025	–	–	60.1	2.1	

Means Followed by Different Letters Within Columns Differ Significantly at $p \leq 0.05$ (LSD). SE± = Standard Error of the Mean. *p*-Values Indicate ANOVA Significance at $p \leq 0.05$. Interaction (F × T) and Main Effects were Tested Using ANOVA

Marketable Roots per Plot

Marketable roots were highest in the NPK treatment (35.6/plot), which had 101.1% more than the control (17.7/plot) ($p < 0.001$). Poultry manure (27.9) and Urea (24.3) increased yields by 57.6% and 37.3%, respectively. Mounds (28.8) had 23.6% more marketable roots than flats (23.3) ($p = 0.0035$). The Mound/NPK treatment had the greatest number of marketable roots per plot at 39.7 roots, which was 198% greater than the Flat/No fertilizer control (13.3). Seasonal differences were not observed for marketable roots (Table 8).

Table 8: Effect of Fertilizer Types and Tillage Practices on the Number of Marketable Storage Roots per Plot of Orange-Fleshed Sweet Potato During the 2024 and 2025 Growing Seasons and Their Combined Analysis

Factor	Treatment	2024 Mean	2025 Mean	Combined Mean	SE	p-value
Fertilizer Type	No fertilizer	17.3d	18.1d	17.7d	0.9	<0.001
	NPK 20:10:10	35.2a	36.0a	35.6a	1.0	
	Poultry manure	27.5b	28.3b	27.9b	0.9	
	Urea	23.9c	24.7c	24.3c	1.0	
Tillage	Flat	22.9b	23.7b	23.3b	0.8	0.0035
	Mound	28.4a	29.2a	28.8a	0.8	
	Ridge	26.6a	27.4a	27.0a	0.8	
Interaction (F×T)	Mound/NPK	39.3a	40.1a	39.7a	2.1	0.7136
	Flat/No fertilizer	12.9e	13.7e	13.3e	1.9	
Season	2024	–	–	26.2	0.6	0.385
	2025	–	–	27.0	0.6	

Means Followed by Different Letters Within Columns Differ Significantly at $p \leq 0.05$ (LSD). SE± = Standard Error of the Mean. *p*-Values Indicate ANOVA Significance at $p \leq 0.05$. Interaction (F × T) and Main Effects were Tested Using ANOVA

Unmarketable Roots per Plot

Poultry manure produced the highest number of unmarketable roots (42.1/plot), exceeding Urea (24.4/plot) by 72.5% ($p = 0.0416$). NPK (37.2) was intermediate. Tillage had no significant effect ($p = 0.9496$). The Flat/Poultry manure combination recorded the highest unmarketable roots (49.7), while Flat/Urea recorded the lowest (14.3). Unmarketable root numbers were similar between seasons (Table 9).

Table 9: Effect of Fertilizer Types and Tillage Practices on the Number of Unmarketable Storage Roots Per Plot of Orange-fleshed Sweet potato during the 2024 and 2025 growing Seasons and their Combined Analysis

Factor	Treatment	2024 Mean	2025 Mean	Combined Mean	SE	p-value
Fertilizer Type	No fertilizer	26.2b	27.4b	26.8b	3.2	0.0416
	NPK 20:10:10	36.6ab	37.8ab	37.2ab	3.4	
	Poultry manure	41.5a	42.7a	42.1a	3.3	
	Urea	23.8b	25.0b	24.4b	3.3	
Tillage	Flat	32.2	33.4	32.8	2.7	0.9496
	Mound	31.1	32.3	31.7	2.8	
	Ridge	32.9	34.1	33.5	2.7	
Interaction (F×T)	Flat/Poultry manure	49.1a	50.3a	49.7a	8.1	0.3635
	Flat/Urea	13.7c	14.9c	14.3c	7.5	
Season	2024	–	–	32.4	2.0	0.442
	2025	–	–	33.6	2.0	

Means Followed by Different Letters Within Columns Differ Significantly at $p \leq 0.05$ (LSD). SE± = Standard Error of the Mean. *p*-Values Indicate ANOVA Significance at $p \leq 0.05$. Interaction (F × T) and Main Effects were Tested Using ANOVA

Roots Infected by Cylas Weevil

NPK-treated plots had the highest *Cylas* infestation (9.4 infected roots/plot), exceeding the control (5.1) by 84.3% ($p < 0.001$). Poultry manure (7.6) and Urea (6.7) were intermediate. Mounds (7.8) and ridges (7.6) had significantly higher infestation than flat beds (6.3), representing 23.8% and 20.6% increases, respectively ($p = 0.0118$). The Mound/NPK and Ridge/NPK combinations recorded the highest infestation (10.3 each), while Flat/No fertilizer recorded the lowest (4.0). Infestation levels were slightly higher in 2025 (7.5) than in 2024 (7.1) but not significantly different ($p = 0.298$) (Table 10).

Table 10: Effect of Fertilizer Types and Tillage Practices on the Number of Storage Roots Infested by *Cylas* Weevils per Plot of Orange-Fleshed Sweet Potato During the 2024 and 2025 Growing Seasons and their Combined Analysis

Factor	Treatment	2024 Mean	2025 Mean	Combined Mean	SE	p-value
Fertilizer Type	No fertilizer	5.0c	5.2c	5.1c	0.35	<0.001
	NPK 20:10:10	9.3a	9.5a	9.4a	0.38	
	Poultry manure	7.5b	7.7b	7.6b	0.36	
	Urea	6.6b	6.8b	6.7b	0.37	
Tillage	Flat	6.2b	6.4b	6.3b	0.28	0.0118
	Mound	7.7a	7.9a	7.8a	0.29	
	Ridge	7.5a	7.7a	7.6a	0.28	
Interaction (F×T)	Mound/NPK	10.2a	10.4a	10.3a	0.70	0.6900
	Flat/No fertilizer	3.9c	4.1c	4.0c	0.65	
Season	2024	–	–	7.1	0.22	0.298
	2025	–	–	7.5	0.22	

Means Followed by Different Letters Within Columns Differ Significantly at $p \leq 0.05$ (LSD). SE± = Standard Error of the Mean. *p*-Values Indicate ANOVA Significance at $p \leq 0.05$. Interaction (F × T) and Main Effects were Tested Using ANOVA

Root Yield (t/ha)

Root yield was marginally higher in 2025 (28.2 t ha^{-1}) than in 2024 (27.5 t ha^{-1}); however, the difference was not significant ($p = 0.234$), indicating consistent yield performance across both growing seasons (Table 11). Tillage significantly influenced root yield ($p < 0.001$), with mounds producing the highest yield (29.4 t ha^{-1}), representing a 14.0% increase over flat beds (25.8 t ha^{-1}), while ridge planting (28.2 t ha^{-1}) was statistically comparable to mounds. Similarly, ridge planting produced vine numbers comparable to mounds (10.5 vs. 10.2 vines plant^{-1}; $p = 0.0027$), whereas flat beds recorded significantly lower values. Fertilizer application also had a significant effect on root yield ($p < 0.001$). NPK fertilizer produced the highest yield (35.5 t ha^{-1}), representing a 63.6% increase over the unfertilized control (21.7 t ha^{-1}). Poultry manure and urea increased root yield by 33.2% (28.9 t ha^{-1}) and 15.7% (25.1 t ha^{-1}), respectively, relative to the control. The tillage × fertilizer interaction was significant, with the Mound × NPK treatment producing the highest root yield (38.5 t ha^{-1}), a 91.5% increase over the Flat × No fertilizer treatment (20.1 t ha^{-1}). However, the Ridge × NPK combination (36.7 t ha^{-1}) was statistically similar to Mound × NPK.

Table 11: Effect of Fertilizer Types and Tillage Practices on Storage Root Yield (t/ha) of Orange-Fleshed Sweet Potato During the 2024 and 2025 Growing Seasons and their Combined Analysis

Factor	Treatment	2024 Mean (t/ha)	2025 Mean (t/ha)	Combined Mean (t/ha)	SE	p-value
Fertilizer Type	No fertilizer	21.4d	22.0d	21.7d	0.45	<0.001
	NPK 20:10:10	35.2a	35.8a	35.5a	0.48	
	Poultry manure	28.6b	29.2b	28.9b	0.46	
	Urea	24.8c	25.4c	25.1c	0.47	
Tillage	Flat	25.5b	26.1b	25.8b	0.38	<0.001
	Mound	29.1a	29.7a	29.4a	0.40	
	Ridge	27.9a	28.5a	28.2a	0.39	
Interaction (F×T)	Mound/NPK	38.2a	38.8a	38.5a	1.15	0.0015
	Flat/No fertilizer	19.8d	20.4d	20.1d	1.08	
Season	2024	–	–	27.5	0.28	0.234
	2025	–	–	28.2	0.28	

Means Followed by Different Letters Within Columns Differ Significantly at $p \leq 0.05$ (LSD). SE± = Standard Error of the Mean. *p*-Values indicate ANOVA Significance at $p \leq 0.05$. Interaction (F × T) and Main Effects were Tested Using ANOVA

Correlation Analysis (Combined Seasons)

Root yield was positively and significantly correlated with all vegetative parameters (Table 12). The strongest associations were observed with fresh biomass yield ($r = 0.971$, $p < 0.001$), marketable root yield ($r = 0.900$, $p < 0.001$), number of vines ($r = 0.891$, $p < 0.001$), and number of leaves ($r = 0.840$, $p < 0.001$). Fresh biomass yield was also strongly correlated with marketable root yield ($r = 0.906$, $p < 0.001$) and *Cylas* infestation ($r = 0.877$, $p < 0.001$). In addition, vine length showed a significant positive correlation with *Cylas* infestation ($r = 0.802$, $p < 0.001$), with mound-grown plants, which produced longer vines (203.2 cm), recording greater weevil infestation than flat-grown plants (166.8 cm). Correlation coefficients did not differ significantly between the 2024 and 2025 growing seasons ($p > 0.05$), indicating that the relationships among growth, yield, and *Cylas* infestation variables were consistent across seasons.

Table 12: Correlation Matrix Showing the Relationships Between Storage Root Yield and Other Measured Parameters of Orange-Fleshed Sweet Potato Based on the Combined Data from the 2024 and 2025 Growing Seasons

Parameter	Root yield (t/ha)	No. of vines/ plant	Length (cm)/vine	No. of leaves /plant	Fresh biomass (kg/plot)	No. of roots infected by *Cylas*	No. of marketable roots/plot
Root yield (t/ha)	1.000						
No. of vines/plant	0.891**	1.000					
Length (cm)/vine	0.784**	0.761**	1.000				
No. of leaves/plant	0.840**	0.806**	0.830**	1.000			
Fresh biomass (kg/plot)	0.971**	0.884**	0.778**	0.828**	1.000		
No. of roots infected by *Cylas*	0.853**	0.810**	0.802**	0.765**	0.877**	1.000	
No. of marketable roots/plot	0.900**	0.868**	0.811**	0.870**	0.906**	0.813**	1.000

**Correlation is Significant at the 0.01 Level (2-tailed). DF = 70 (Combined Across Seasons)

Post-Harvest Soil Properties (Means of 2024 and 2025 Growing Seasons)

Across all tillage treatments, poultry manure application significantly improved soil chemical properties (Table 13). Soil pH adjusted from a pre-planting acidic 4.6 to 6.7 (+46%). Organic carbon was increased by 28–48% (0.67% to 0.82–0.86%). Total nitrogen increased dramatically from 0.35% to 1.43–1.46% (+309–317%). Exchangeable K+ was increased from 0.09 to 1.28–1.56 $cmol^+$/100 g soil (1,322–1,633%), and Ca^{2+} was increased from 0.66 to 0.92–0.98 $cmol^+$/100 g soil (+39–48%). CEC was improved from 1.67 to 3.08–3.78 $cmol^+$/100 g soil (+84–126%). Optimal root environment within mounds explains higher productivity relative to flat beds. Placement of nutrient-rich topsoil within the crop root zone (0–15 cm) increases access to nutrients and water, besides lowering soil mechanical resistance (bulk density).

NPK and Urea had lesser effects on soil pH, increasing the acidity (pH 4.4–4.6) compared to poultry manure. NPK and Urea did not increase organic carbon or exchangeable cations past the preplanting soil test levels. Available P was slightly increased by NPK fertilizer from 8.6 ppm to 9.6–10.7 ppm, but was significantly decreased to 4.5–4.8 ppm with poultry manure application. Post-harvest soil properties did not differ significantly ($p > 0.05$) between the two growing seasons, indicating that the treatment effects were consistent across seasons.

Table 13: Effect of Tillage Practices and Fertilizer Types on Post-Harvest Soil Chemical Properties Following Orange-Fleshed Sweet Potato Cultivation, Based on the Mean Values for the 2024 and 2025 Growing Seasons

Sample	pH	Org C (%)	N (%)	P (ppm)	K ($cmol^+$ /100g)	Mg	Ca	CEC
Flat/NPK	4.4	0.58	1.33	10.7	1.25	0.68	0.58	1.57
Ridge/Poultry manure	6.7	0.84	1.45	4.5	1.56	0.82	0.98	3.48
Mound/NPK	4.4	0.61	1.35	10.6	1.28	0.70	0.58	1.96
Flat/Poultry manure	6.7	0.82	1.43	4.8	1.38	0.80	0.92	3.08
Mound/Poultry manure	6.7	0.86	1.46	4.6	1.28	0.82	0.96	3.78
Flat/No fertilizer	4.4	0.52	0.33	8.4	0.04	0.62	0.58	1.28
Pre-planting (2024)	4.6	0.67	0.35	8.6	0.09	0.75	0.66	1.67
Pre-planting (2025)	4.7	0.65	0.34	8.5	0.08	0.74	0.65	1.65

Note: Soil Texture Remained Sandy Loam (70% Sand, 10% Silt, 20% Clay) Across all Treatments and Seasons

Discussion

Season × treatment interactions were not significant for all growth, yield, and *Cylas* response variables ($p > 0.05$), indicating that the effects of tillage and fertilizer treatments on crop productivity and weevil incidence were consistent across the 2024 and 2025 growing seasons. This suggests that the treatment effects were stable despite year-to-year variations in rainfall and temperature characteristic of the derived savannah agroecological zone of Abuja. Similar findings were reported by Dias e*t al.* (2021), who observed consistent responses of sweet potato to organic fertilization under savannah conditions, demonstrating the resilience of organic nutrient management. Likewise, Li *et al.* (2019) found that organic fertilization consistently improved soil biochemical properties and crop yields across cropping systems, reflecting the stability of soil fertility enhancement through organic amendments. Rehman *et al.* (2019) also reported that agronomic practices, particularly organic mulching, consistently reduced *Cylas formicarius* infestation by modifying the soil microenvironment. Collectively, these findings indicate that tillage and fertilizer management exerted a greater influence on sweet potato productivity and *Cylas* infestation than the relatively small seasonal climatic variations, confirming the robustness of these practices under derived savannah conditions. These differences were not significant between years. Multi-season stability of sweet potato systems has also been reported across African agroecologies (Dumbuya *et al.*, 2022; Tsegaye *et al.*, 2023; Adebayo *et al.*, 2023).

Sweet potato vines grown on mounds had consistently higher growth performance and yield than those planted on flat beds across all parameters measured. Compared with flat tillage, mound planting increased vine number by 16.7%, vine length by 21.8%, leaf number by 28.1%, and root yield by 14.0%. These findings concur with previous studies conducted in Ghana (Dumbuya *et al.*, 2022), Zimbabwe (Parwada *et al.*, 2020), and Nigeria (Ilozobhie *et al.*, 2024), which reported mounding as a superior root-zone management practice in sweet potato cultivation.

Root penetration and movement are therefore easier in mound systems than in flat beds. Alfisols are characteristically highly weathered with bulk densities exceeding 1.6 g/cm^3 in compacted layers (Agbede and Adekiya, 2022; Tsegaye *et al.*, 2023). Poor aeration and soil crusting, common with flat tillage, likely limited root proliferation and activity in the topsoil layer (Motsa *et al.*, 2019; Chipungu *et al*., 2021). Season × tillage interactions were not significant for all measured parameters, indicating that tillage responses were stable between seasons.

NPK fertilizer treatment yielded 63.6% higher roots than the control and 22.8% higher than poultry manure (28.9 t/ha). These results contrast with findings by Olatunji and Adeyongu (2022), who observed similar yield performance between poultry manure and NPK fertilizers in Benue State, Nigeria. Soil organic matter content may explain this, as it was much higher at the study site of Olatunji and Adeyongu (2022) (4.14%) compared to our study site (0.67% OC). Nutrients from NPK fertilizer are readily available for crop uptake compared with organic fertilizers that need microbial mineralisation before assimilation by plants (Egata Shunka *et al.,* 2021; Chettri *et al.,* 2020). Accelerated nutrient availability gives NPK an advantage during early tuber initiation stages (3–8 weeks after planting) when root growth is rapid, but nutrient demand is not fully met by organic-rich Alfisols.

The highest treatment productivity (mound + NPK: 38.5 t/ha) comes close to the estimated genetic potential of the variety used (56.4 t/ha) and is above reported yields of 27–35 t/ha in neighbouring Mozambique and Malawi (Andrade *et al.,* 2019; Chipungu *et al.,* 2021). These findings suggest that appropriate soil management can substantially reduce the prevailing yield gap in Nigeria's FCT. Application rates for NPK produced similar yields in both seasons (35.2 t/ha in 2024 vs 35.8 t/ha in 2025), suggesting consistency in field performance.

Although fertilization, particularly NPK, significantly increased sweet potato root yield, it also increased *Cylas* weevil infestation ($p < 0.001$), indicating a yield–pest trade-off consistent with reports that vigorous, nutrient-enriched crops may become more attractive or susceptible to *Cylas* attack despite their higher productivity (Rehman *et al.*, 2019). Such effects agree with reports by Kibrom (2021), who showed that nitrogen enrichment improves tuber palatability by increasing soluble sugar and free amino acid concentrations, rendering roots more attractive to *Cylas formicarius* and *Cylas puncticollis.*

Fresh biomass showed a strong positive correlation with Cylas infestation ($r = 0.877$, $p < 0.001$), implying that greater vegetative vigour sends attractive cues to egg-laying females (Stathers *et al.,* 2020; Mbua *et al.,* 2021). Levels of root infestation were intermediate with poultry manure (7.6 infected roots/plot) but similar between years (7.1 infected roots in 2024 and 7.5 infected roots/plot in 2025), suggesting a consistent response.

Chemical analysis of post-harvest soil showed divergent trends between organic and inorganic fertilizer systems. Addition of poultry manure improved several parameters, including pH (+46% from 4.6 to 6.7), organic carbon (28–48% increase), and cation exchange capacity (CEC: 84–126%). Contrastingly, NPK and urea applications decreased soil pH (4.6 vs 4.4–4.6) and did not improve soil organic carbon or CEC. These data confirm fears associated with prolonged application of inorganic fertilizers without integration of organic matter or liming on accelerated soil acidification (Nedunchezhiyan and Ray, 2022). Poultry manure amendment improved soil pH and nutrient status, thereby ameliorating key growth-limiting constraints of Alfisols, including soil acidity, low organic matter content, and poor nutrient retention capacity (Anyaegbu & Ibrahim, 2022).

The 1,322–1,633% increase in exchangeable potassium forms the basis for recommending poultry manure because of potassium's vital role in carbohydrate translocation to developing storage roots (Byju and Nedunchezhiyan, 2023). Similarities in all measured soil parameters between seasons suggest that observed effects are cumulative, thus building/improving with continued application (poultry manure) or worsening over time in the case of acidification (NPK).

CONCLUSION

Mound tillage with fertilizer significantly improved the growth and yield of OFSP 'Mother's Delight' over flat beds. Ridge tillage gave similar results to mounds, suggesting farmers may prefer ridges for ease of formation/planting. Effects of NPK fertilizer application on productivity were highest at 200 kg/ha, yielding 38.5 t/ha under mound tillage (+92% over unfertilized flat-bed control). However, NPK fertilization also resulted in 84% higher Cylas infestation compared with unfertilized control plots. An integrated approach to pest management is therefore advised when using NPK.

The improved soil chemical properties and reduced pest incidence associated with poultry manure amendment suggest its importance for building soil health over time. Use of poultry manure, therefore, offers a sustainable system which moderately improves productivity (+33% over unfertilized control) while conserving soil health. Farmers seeking the highest yield should adopt mound tillage with NPK fertilizer applied at 200 kg/ha three weeks after planting.

Integration of pest management practices like early planting, earthing up, sanitation, and trapping of adults with sex pheromones is recommended to reduce losses to weevils. Balanced yield and soil health can be achieved by applying NPK at half the rate used for the highest yield (100 kg/ha) along with poultry manure. These recommendations should be extended to farmers through farmer field schools.

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