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INTERACTIVE EFFECTS OF TILLAGE AND FERTILIZER TYPE AND APPLICATION ON CYLAS WEEVIL, SOIL PROPERTIES, AND ORANGE-FLESHED SWEET POTATO YIELD IN SOUTHERN GUINEA SAVANNA, NIGERIA.

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ABSTRACT

Orange-fleshed sweet potato (OFSP) is a biofortified crop crucial for addressing vitamin A deficiency in sub-Saharan Africa. Yet, yields remain constrained by poor soil fertility, suboptimal tillage, and pest pressure. This two-season (2024–2025) study evaluated the interactive effects of three tillage systems (mounds, ridges, flat beds) and four fertilizer treatments (NPK 20:10:10 at 200 kg/ha, poultry manure at 5 t/ha, urea at 200 kg/ha, and an unfertilized control) on Cylas weevil infestation, soil properties, and tuber yield of the OFSP variety 'Mother's Delight' in Abuja, Nigeria. The experiment was a 3 × 4 factorial in a randomized complete block design with three replications, analysed using combined ANOVA ($\alpha = 0.05$). NPK significantly increased root yield (35.5 t/ha) relative to the control (21.7 t/ha; +63.6%) but also raised weevil infestation by 84.3%. Poultry manure produced a moderate yield (28.9 t/ha; +33.2%) with reduced infestation. Mound tillage gave the highest mean yield (29.4 t/ha), although infestation exceeded that of flat beds. The mound × NPK combination achieved the maximum yield (38.5 t/ha; +91.5% over flat/no fertilizer). Seasonal effects were not significant ($p > 0.05$), indicating stable treatment performance. Poultry manure improved soil pH (4.6–6.7), organic carbon, exchangeable K, and cation exchange capacity, whereas NPK reduced soil pH (to 4.4). Root yield correlated strongly with fresh biomass ($r = 0.971$) and weevil infestation ($r = 0.877$). Mound tillage with NPK maximises yield but increases pest risk and soil acidification, underscoring the need for integrated nutrient and pest management.

Keywords: *Cylas weevil; orange-fleshed sweet potato; poultry manure; soil health; tillage.*

INTRODUCTION

INTRODUCTION Orange-fleshed sweet potato (*Ipomoea batatas* Lam) is a biofortified root crop cultivated to combat vitamin A deficiency, which currently affects about 30% of children less than 5 years in sub-Saharan Africa (Low *et al.,* 2019; Tanumihardjo *et al.,* 2020). Nigeria is Africa's second-largest producer with an average annual production of 2.88 million tonnes. Yield levels, however, have been grossly low (<10 t/ha) in Nigeria, whereas achievable yields of 27–35 t/ha have been reported (FAO, 2022; Chipungu *et al.,* 2021). Yield is lowest in the Federal Capital Territory (FCT), Abuja, due to declining soil fertility from years of cultivation without replacement of nutrients mined from the soil and tillage practices that have generally failed to optimise root-zone soil properties for OFSP cultivation (Agbede and Adekiya, 2022; Onwueme, 2021). Improved root-zone soil aeration, lower soil bulk density and enhanced root penetration ability have been reported with mound and ridge tillage methods compared to flat beds (Dumbuya *et al.,* 2022; Tsegaye *et al.,* 2023).

Tillage practices can influence the microenvironment experienced by pests and can determine pest incidence and infestation levels of root-crop pests such as the sweet potato weevil

(*Cylas puncticollis* Fabricius). Sweet potato weevils (Cylas) cause a storage root loss of between 20 and 80% in West Africa (Kibrom, 2021; Stathers *et al.,* 2020). Nitrogen fertilisation improves tuber yield but increases tuber succulence and free amino acids, making storage roots attractive to weevil damage (*Mbua et al.,* 2021; Mesele *et al.,* 2020). Fertilizer type also determines changes in soil chemical properties. While inorganic fertilizers such as NPK and Urea can quickly supply nutrients to crops, these fertilizers have no liming effect and do not improve soil acidity or build soil organic matter over time when used as the sole fertilizer source (Egata Shunka *et al.,* 2021; Nedunchezhiyan et al., 2022). Poultry manure has slower nutrient release rates but could improve soil pH due to its liming ability. The effect of poultry manure on Cylas damage as well as yield tradeoffs is not documented for FCT-derived savanna ecology and could differ between growing seasons (Olatunji and Adeyongu, 2022; Anyaegbu andIbrahim, 2022). By conducting the trial across two growing seasons, year-to-year variation in rainfall and temperature would be accounted for and validate any agronomic recommendations made (Motsa *et al.,* 2019; Adebayo *et al.,* 2023).

Tillage effects on Cylas incidence and post-harvest soil properties following two growing seasons have not been quantified in Nigeria' Capital Territory. Similarly, tillage-fertilizer interactions on OFSP tuber yield have not been studied across two consecutive seasons. Thus, this study sought to: (1) identify the best tillage–fertiliser combination to minimise Cylas damage whilst maximising tuber yield; (2) determine the influence of treatments on post-harvest soil chemical properties; (3) validate if treatment effects were consistent across both the 2024 and 2025 growing seasons; and (4) provide sustainable agronomic recommendations for OFSP cultivation.

MATERIALS AND METHOD

Study Area The field experiment was carried out in two growing seasons of 2024 and 20 25 (May–September) at the University of Abuja Teaching and Research Farm, Kwongworr Jos East Campus, Federal Capital Territory, Nigeria (Latitude 9° 4′ 24.45″ N; Longitude 7° 27′ 40.59″ E, elevation 480 m above sea level). The experimental site falls within the Southern Guinea Savanna agroecological zone, characterised by rainfall in two distinct seasons. Mean annual rainfall ranges from 80 to 180 cm, with mean temperatures ranging from 22 to 38 °C. Relative humidity ranges from 60–80% during the cropping season (Barnabas and Nwaka, 2014). The study site soil is a sandy loam Alfisol (70% sand, 20% clay and 10% silt) developed from granitic gneiss. Before planting season 1 in 2024, preplanting soil chemical properties at 0–30 cm were: pH (H_2O) 4.7, pH (KCl) 4.6, organic carbon (%OC) 0.67%, total N (%TN) 0.35%, available P (Bray 2) 8.6 ppm, exchangeable K 0.09 cmol$^+$/100 g soil, exchangeable Mg 0.75, Ca 0.66, Na 0.7 cmol$^+$/100 g soil, total exchangeable bases (TEB) 1.45 cmol$^+$/100 g soil, exchangeable acidity (EA) 0.81, ECEC 1.67 cmol$^+$/100 g soil and base saturation (BS) 57%. Similar soil properties were recorded before planting season 2 in 20 25 (pH 4.7, %OC 0.65 and %TN 0.34%), suggesting the absence of carryover effects since different plots within the same block were used each season.

Land Preparation and Soil Sampling

Before planting commenced each season, the entire experimental area was cleared of weeds using cutlasses, levelled and stumped using machetes. Plots were subsequently ploughed and harrowed thereafter to produce fine soil tilth suitable for planting the selected sweet potato variety. This tillage layout was replicated again in the second growing season. Soil samples were obtained from five randomly selected points within the field using a handheld auger at 0–30 cm soil depth before planting each season. Each soil sample was thoroughly mixed using a plastic stick to produce a homogenous composite sample.

Composite samples were air-dried and passed through a 2 mm sieve before being sent to the soil testing laboratory for analysis. Soil pH (water and potassium chloride extracts), %OC, %TN, and available P (Bray II) were analysed according to methods described in page 85 of the FAO soil taxonomy guidebook (FAO, 2019). Exchangeable K, Mg, Ca and Na were extracted with 1 N ammonium acetate solution (pH 7). Their concentrations were determined using an atomic absorption spectrophotometer. Exchangeable acidity was determined by subtracting total exchangeable bases (TEB) from the effective cation exchange capacity (ECEC). Post-harvest soil samples (0–15 cm and 15–30 cm) were collected from five random locations within each plot after harvest had been concluded each season.

Experimental Materials

UMUSP3 (CIP 440293), a single sweet potato genotype released by the International Potato Centre as a vitamin A-biofortified sweet potato genotype, was used for this study. Sweet potato planting materials were sourced from the National Root Crops Research Institute (NRCRI) outstation, Nyanya axis of FCT/ Nasarawa state, Nigeria and fresh vine cuttings were collected at deployment before planting commenced for each of the two seasons. UMUSP3 contain high levels of β-carotene (provitamin A), dietary fibre and is rich in several nutrients that are needed by the body, including potassium, manganese and magnesium, as well as antioxidants such as Vitamin C (Tumuhimbise *et al.,* 2019; Amagloh *et al.,* 2021). Due to its low dry matter content compared to other available genotypes, the flesh tastes sweeter and has a softer consistency when cooked, making it ideal for nutritional evaluation and consumer acceptability studies.

Experimental Design and Treatments

Eighteen plots were used for the entire experiment (9 treatments × 2 replicates each), and this was considered sufficient to obtain precise estimates of tillage-fertilizer interactions under FCT field conditions. The experiment was laid out in a 3 × 4 factorial design in a Randomized Complete Block Design (RCBD) with three replications per season. Factor A had three tillage systems, which included mounds (experimental plots shaped into heaps or mounds raised above the normal soil level), ridges (similar to mounds but without the heap), and flat beds, while Factor B had four fertilizer treatments, including unfertilized control, poultry manure, NPK 20:10:10 and urea. NPK 20: 10:10 was applied at 200 kg/ha, which is the rate recommended by National Office for Technology Acquisition and Promotion (NOTAP, 2021) brochure on fertilizer use in Nigeria.

Poultry manure was applied at 5 t/ha, while Urea was applied at its recommended rate of 200 kg/ha by the manufacturer. Each replicate consisted of 12 plots (three tillage methods × four fertilizer treatments), giving an overall plot number of 36 per season and 72 for both seasons. Plot size was 3 m × 3 m, giving a net plot area of 324 m^2 per season. Considering a 0.5 metre border between plots within each replicate and an alley of 1 m wide separating each replicate, the gross plot size was therefore 432 m^2 per season. An entire replicate, therefore, covered an area of 10 m × 13.5 m (135 m^2).

Cultural Practices

Planting was done at a 60° angle such that two-thirds of the cutting was beneath the soil surface, while firm downward pressure was applied as the set transplant was pushed into the soil to ensure good soil-cutting contact needed for sprouting. Gap filling was done seven days after planting (DAP). Weed control was done manually twice at 21 DAP and at 56 DAP to ensure weed-free conditions persisted throughout the experimental period.

Broiler-house poultry manure was sun-dried, crushed into smaller particles, and sieved before application to the plots. The poultry manure contained 2.5% N, 1.8% P and 1.5% K. The poultry manure was applied at 5 t/ha, which is equivalent to Anyaegbu (2013) recommended rate of 4.5 kg per plot or 0.125 kg per plant stand. NPK fertilizer was applied as a basal application by banding it three weeks after planting at 200 kg/ha, which is equivalent to 0.36 kg per plot. Urea (46-0-0) was applied at its recommended rate of 200 kg/ha. Harvesting took place 16 weeks after planting with a hoe, followed by sorting tubers by size and marketability and collecting data for analysis.

Data Collection

Soil physical and chemical analyses were determined following standard methods described in Page-86 of the FAO soil taxonomy guideline book (FAO, 2019). Particle size distribution was determined using the Bouyoucos hydrometer method. Soil reaction was determined using a pH meter, while %OC and %TN were determined using the Walkley–Black and Macro Kjeldahl methods, respectively. Available P was determined by extracting soil samples with Bray No. 2, while exchangeable cations were extracted with 1 N neutral ammonium acetate solution. The concentration of the solutions was determined using an atomic absorption spectrophotometer. Exchangeable acidity was determined by subtracting the summation of bases from the estimated cation exchange capacity (ECEC), while ECEC was determined by summation of all exchangeable cations. Soil samples were taken at two depths: 0–30 cm depth before planting and at 0–15 cm and 15–30 cm after harvest. Yield and Cylas infestation data were collected at harvest, which was 16 weeks after planting had begun. Harvesting was done carefully using a hoe. Plants were uprooted, and storage roots were sorted into marketable and unmarketable classes. Fresh weights were obtained by weighing storage roots harvested from each net plot to give yield (t/ha) using the appropriate factor for plot area. Other yield components, like total root number (marketable + unmarketable roots) were also determined. Cylas weevil infestation was assessed by counting the number of storage roots with Cylas adult feeding lesions or larval tunnels per net plot.

Statistical Analysis

The data generated was analysed as a combined analysis of variance in R version 4.0.3 using the agricolae package. Season, tillage and fertilizer effects were treated as fixed effects, while replication nested within seasons was treated as a random effect. Treatment means were separated using Fisher's least significant difference test when $p \leq 0.05$. Standard error of means (SEM) was also calculated. Pearson correlation coefficients (r) were calculated using the combined dataset in order to determine relationships between root yield, Cylas infestation and other parameters measured during the study. Percentage (%) increase/decrease was determined using the formula: [(Treatment mean – control mean)/ control mean] × 100.

RESULTS

Figure 1 shows the effects of fertilizer type and tillage practice on Cylas infestation levels across two seasons, means combined separately as well as their interaction. Fertilizer treatment had a highly significant effect on Cylas infestation levels ($p < 0.001$). Application of NPK fertilizer (20: 10:10) significantly increased Cylas infestation (mean = 9.4 infected roots per plot) by about 84.3% compared to unfertilized plots (mean = 5.1 infected roots per plot). The two intermediate fertilizers gave means that followed similar trends; poultry manure resulted in a mean of 7.6 Cylas infected roots per plot, while urea fertilized plots had a mean infestation of 6.7 Cylas infected roots per plot. Tillage had a significant effect on Cylas weevil infestation across both seasons ($p = 0.0\ 118$). Plots with mounds (mean = 7.8 infected roots per plot) and ridges (mean = 7.6 infected roots per plot) had higher numbers of infected roots compared to flat beds (mean = 6.3 infected roots per plot) by 23.8 and 20.6%, respectively. Tillage × fertilizer interaction was, however, not significant ($p = 0.690$). In an attempt to get an overall best treatment that minimizes Cylas damage whilst maximizing yield, if we consider means across all fertilizer and tillage combinations, the mound/ NPK treatment combination recorded the highest mean infestation levels (10.3 infected roots per plot), while the flat/ no fertilizer treatment had the least mean number of infected roots per plot (mean = 4 infected roots per plot). Across both growing seasons, Cylas infestation was slightly higher during season 2 in 20 25 compared to season 1 in 20 24, but this was not significant ($p = 0.298$). Neither fertilizer treatment, nor tillage method × season interaction were significant.

Table 1: Effect of fertilizer types and tillage on the number of roots infected by *Cylas* weevil (2024, 2025, and combined)

Factor	Treatment	2024 Mean	2025 Mean	Combined Mean	SE	p value
Fertilizer	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 superscript letters within the same column are significantly different at $p \leq 0.05$ (Fisher's LSD). SE = standard error of the mean.

Root yield (t/ha)

Table 2 shows the effects of tillage and fertiliser treatments on root yield in the two seasons. Main effects of tillage and fertiliser type were highly significant ($p < 0.001$), as was their interaction ($p = 0.0015$). Mounds had the largest yield (29.4 t/ha), which was significantly larger (14.0%) than flat beds (25.8 t/ha). Yields from ridges (28.2 t/ha) were not significantly different from mounds. NPK produced the largest yield (35.5 t/ha), which was significantly higher (63.6%) than the unfertilised control (21.7 t/ha). Poultry manure (28.9 t/ha) and urea (25.1 t/ha) produced yield increases of 33.2 and 15.7%, respectively. The largest yield was from mound/NPK (38.5 t/ha), which was significantly higher (91.5%) than the flatbed control with no fertiliser (20.1 t/ha). Ridge/NPK (36.7 t/ha) gave a yield similar to that of mound/NPK. Yields were marginally but not significantly higher in 2025 (28.2 t/ha) than in 2024 (27.5 t/ha) ($p = 0.234$).

Table 2: Effect of fertilizer types and tillage on root yield (t/ha) (2024, 2025, and combined)

Factor	Treatment	2024 Mean (t/ha)	2025 Mean (t/ha)	Combined Mean (t/ha)	SE	p value
Fertilizer	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 superscript letters within the same column are significantly different at $p \leq 0.05$ (Fisher's LSD).

Summary of soil chemical properties after harvest (mean of 2024 and 2025)

The tillage–fertiliser interactions selected for study influenced soil chemical properties measured after harvest (Table 3). Application of poultry manure significantly increased soil fertility in all tillage treatments. pH increased from a baseline pre-planting level of 4.6 to 6.7 (+46%). Organic carbon increased from 0.67% to 0.82 – 0.86% (+28–48%). Total nitrogen increased from 0.35% to 1.43 – 1.46% (+309–317%). Exchangeable potassium increased from 0.09 to 1.28 – 1.56 cmol(+)/kg soil (+1322–16 33%). Cation exchange capacity increased from 1.67 to 3.08 – 3.78 cmol(+)/kg soil (+84–126%). NPK and urea further acidified soils (pH 4.4–4.6), and had no discernible positive effect on organic carbon or exchangeable cations. Available phosphorus marginally increased from 8.6 ppm to 9.6 – 10.7 ppm under NPK treatments, but declined to 4.5 – 4.8 ppm where poultry manure had been applied. P immobilisation or crop uptake may account for this decline.

Table 3: Postharvest soil chemical properties as influenced by tillage and fertilizer type (average of 2024 and 2025)

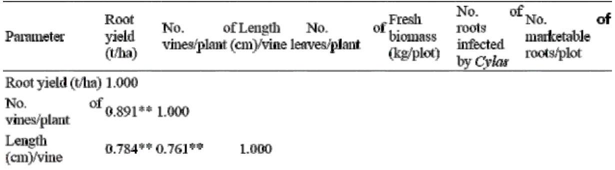
Sample	Ph	Org C (%)	N (%)	P (ppm)	K (cmol⁺ /100g)	Mg	Ca	CEC
Flat/NPK	4.4	0.58	1.33	10.7	1.25	0.68	0.58	1.57
Ridge/Poultry manure	6.7	0.84	1.45	4.5	1.56	0.82	0.98	3.48
Mound/NPK	4.4	0.61	1.35	10.6	1.28	0.70	0.58	1.96
Flat/Poultry manure	6.7	0.82	1.43	4.8	1.38	0.80	0.92	3.08
Mound/Poultry manure	6.7	0.86	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

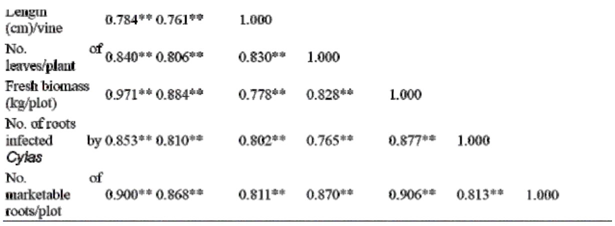
Soil texture remained sandy loam (70% sand, 10% silt, 20% clay) across all treatments.

Correlation analysis (combined seasons)

The Pearson correlation matrix among selected variables is shown in Table 4. Root yield (t/ha) was very strongly positively correlated with fresh biomass (r = 0.971; p < 0.001), marketable roots (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). Most importantly, Cylas weevil damage was strongly positively correlated with fresh biomass (r = 0.877; p < 0.001) and root yield (r = 0.853; p < 0.001). This suggests that heavily attacked plants are high-yielding and vigorously growing plants. The correlation patterns among the variables were similar across the two seasons.

Table 4: Matrix correlation coefficient between root yield, *Cylas* infestation, and other parameters (combined 2024–2025 data)





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 (2tailed). DF = 70 (combined across seasons).*

Combined ANOVA Summary

Table 5 presents the summary ANOVA results for main and interactive effects of season, tillage and fertilizer treatment on response variables of most interest. The three-way ANOVA analysis confirms that treatment effects were similar between both seasons tested (no significant S × T, S × F, or S × T × F interactions). Tillage significantly affected root yield (p < 0.001), weevil infestation (p = 0.0118), and fresh biomass (p < 0.001), but did not significantly affect post-harvest soil pH levels. Fertilizer treatment had the greatest influence on all measured yield and pest variables (p < 0.001) and was the only treatment factor to significantly influence soil pH (p < 0.001). Tillage × fertilizer interaction was significant for root yield (p = 0.0015) and fresh biomass production (p < 0.05), suggesting that the best fertilizer choice may depend on tillage method when targeting maximum yield. For weevil infestation, however, the interaction was not significant (p = 0.690), suggesting that increased infestation with NPK occurred regardless of tillage method.

Table 5: Combined ANOVA summary for main and interactive effects of season, tillage, and fertilizer on key response variables (2024–2025)

Source of variation	DF	Root yield (t/ha)	*Cylas* infestation	Fresh biomass (kg/plot)	Marketable roots /plot	Soil pH (post-harvest)
Season (S)	1	NS	NS	NS	NS	NS
Tillage (T)	2	***	*	***	***	NS
Fertilizer (F)	3	***	***	***	***	***
S × T	2	NS	NS	NS	NS	NS
S × F	3	NS	NS	NS	NS	NS
T × F	6	**	NS	*	*	NS
S × T × F	6	NS	NS	NS	NS	NS
Error	48					

****, **, *, NS indicate significance at p < 0.001, p < 0.01, p < 0.05, and not significant, respectively. DF = degrees of freedom.*

Fresh Biomass (kg/plot)

Mean fresh biomass yields as affected by tillage and fertilizer treatments are presented in Table 6. As with root yield, fresh biomass production followed a similar trend. Plants grown with NPK fertilizer produced the largest biomass (9.7

kg/plot) compared to the unfertilised control (6.2 kg/plot), which was 56% greater. Plots with mound tillage had significantly higher fresh biomass production (8.1 kg/plot) than flat beds (7.3 kg/plot), which was 11% greater. Maximum biomass (10.1 kg/plot) was recorded with the mound tillage and NPK combination out of all 12 treatment combinations. The very high correlation between fresh biomass yield and root yield (r = 0.971, Table 4) suggests that vine growth largely determines storage root production in OFSP (Nedunchezhiyan *et al.* 2022; Byju and Nedunchezhiyan 2023).

Table 6: Effect of tillage and fertilizer on fresh biomass (kg/plot) – combined 2024–2025

Tillage	No fertilizer	NPK 20:10:10	Poultry manure	Urea	Mean (tillage)
Flat	5.8 d	9.2 a	7.5 b	6.7 c	7.3 b
Mound	6.5 c	10.1 a	8.2 b	7.4 bc	8.1 a
Ridge	6.3 c	9.8 a	8.0 b	7.1 bc	7.8 a
Mean (fertilizer)	6.2 d	9.7 a	7.9 b	7.1 c	

Means followed by different letters within rows or columns are significantly different at $p \leq 0.05$ (LSD); SE (combined) = 0.29.

Post-harvest soil properties by fertilizer type (depth averaged)

Table 7 shows post-harvest soil chemical properties depth averaged to 0-30 cm and grouped by fertilizer type. Compared to the initial soil conditions, poultry manure increased soil chemical fertility dramatically relative to all other treatments. pH increased from 4.65 to 6.70 (+44%). Organic carbon was 27% higher than pre-planting levels, and total N more than quadrupled (0.35% → 1.45%). Exchangeable K also increased significantly, by 16-fold – this is especially important because sweet potato crops remove >200 kg K_2O ha^{-1} (Byju and Nedunchezhiyan, 2023). Available P decreased under poultry manure (8.55 → 4.63 ppm), indicating likely immobilisation or fixation; this issue could potentially be remedied by applying phosphate-solubilising bacteria as a soil amendment (Olowe *et al.,* 2023). In contrast, NPK and urea caused further acidification of the soil (pH 4.42–4.48) and did not increase organic carbon or CEC.

Table 7: Postharvest soil chemical properties as influenced by fertilizer type (depthaveraged, 0–30 cm) – combined 2024–2025

Parameter	Pre-planting	No fertilizer	NPK 20:10:10	Poultry manure	Urea	LSD (0.05)
pH (H_2O)	4.65 b	4.50 b	4.42 b	6.70 a	4.48 b	0.21
Organic C (%)	0.66 b	0.54 c	0.60 bc	0.84 a	0.58 bc	0.09
Total N (%)	0.35 c	0.34 c	1.34 b	1.45 a	1.31 b	0.08
Available P (ppm)	8.55 b	8.30 b	10.65 a	4.63 c	8.22 b	1.12
Exch. K (cmol(+)/kg)	0.085 d	0.041 e	1.27 b	1.41 a	1.18 c	0.09
Exch. Ca (cmol(+)/kg)	0.66 b	0.59 b	0.58 b	0.95 a	0.61 b	0.11
CEC (cmol(+)/kg)	1.66 d	1.30 e	1.77 c	3.45 a	1.68 cd	0.15

Means in the same row with different letters are significantly different at $p \leq 0.05$ (LSD).n = 18 per treatment (2 seasons × 3 tillage replicates).

Depth-wise distribution of soil pH and organic carbon

As shown in Table 8, selected contrasting treatments influenced soil pH and organic carbon at depths of 0–15 cm and 15–30 cm. Application of poultry manure increased pH and organic carbon across the 0–30 cm profile, with slightly higher increments in the surface horizon due to incorporation. Lack of difference in depth-wise distribution between mound and flat bed under the same fertilizer treatment suggests that organic amendment was the overriding factor affecting soil chemical properties. Interestingly, pH remained >6.5 and organic C remained >0.78% at the 15–30 cm depth in plots amended with poultry manure, implying percolation of soluble organics or soil mixing by organisms (bioturbation) (Ewulo *et al.,* 2023). This subsurface improvement has implications for deep-rooting sweet potato cultivars.

Table 8: Depthwise changes in postharvest soil pH and organic carbon under contrasting treatments (average of 2024–2025)

Treatment combination	pH (0–15 cm)	pH (15–30 cm)	Organic C (%) (0–15 cm)	Organic C (%) (15–30 cm)
Flat / No fertilizer	4.48 c	4.52 c	0.56 d	0.52 d
Flat / NPK	4.40 c	4.44 c	0.62 cd	0.58 d
Flat / Poultry manure	6.75 a	6.62 a	0.86 a	0.78 b
Mound / NPK	4.42 c	4.46 c	0.63 cd	0.59 d
Mound / Poultry manure	6.78 a	6.65 a	0.90 a	0.82 ab
Ridge / Poultry manure	6.70 a	6.58 a	0.85 a	0.80 ab
LSD (0.05)	0.24	0.22	0.08	0.09

Statistical Analysis

Economic analysis of tillage–fertiliser combinations

Table 9 shows an economic comparison of selected tillage-fertiliser combinations using combined two-season yields. Although mound/NPK produced the highest gross revenue ($7,700 ha-1), its benefit-cost ratio (16.5) was lower than the flat/no-fertiliser control (32.5) because it incurred higher input costs. The tillage-fertiliser combination with the highest net revenue was mound/NPK ($7,260 ha-1), 86% greater than the control treatment. Flat/no fertilizer may look appealing for short-term profit to farmers who lack production resources, but we have evidence that soil health begins to decline using this practice (Table 7), indicating that yields would not be sustained in the following seasons. Tillage-fertiliser combinations with poultry manure resulted in intermediate net revenues ($5,000-$5,580 ha-1), while having positive effects on soil health and fertility. Thinking beyond one or two growing seasons is important when considering the profitability of these practices. Although mound construction is costly ($200 ha-1), the benefits of raised beds did not become evident until they were combined with NPK or poultry manure. In fact, Chipungu *et al.* (2021) just reported that these findings were expected and that the greatest contributions to long-term soil capital came from organic amendments, despite higher short-term returns likely using inorganic fertilizer.

Table 9: Economic analysis of tillage–fertilizer combinations based on combined 2024–2025 yield (USD/ha)

Treatment combination	Root yield (t/ha)	Gross revenue* (USD)	Fertilizer cost** (USD)	Tillage labour*** (USD)	Net revenue (USD)	Benefit-cost ratio
Flat/No fertilizer	20.1	4,020	0	120	3,900	32.5
Flat /NPK	32.8	6,560	240	120	6,200	17.2
Flat/Poultry manure	26.5	5,300	180	120	5,000	16.7
Mound/No fertilizer	22.8	4,560	0	200	4,360	21.8
Mound /NPK	38.5	7,700	240	200	7,260	16.5
Mound/Poultry manure	29.8	5,960	180	200	5,580	14.7
Ridge/NPK	36.7	7,340	240	180	6,920	16.5

*Assumptions: Farmgate price of OFSP = 200 USD/t (approx. 80,000 NGN/t). **NPK 20:10:10 at 200 t/ha = 240 USD/ha (1.2 USD/kg); poultry manure 5 t/ha = 180 USD/ha (36 USD/t). ***Tillage labour: flat = 120 USD/ha; ridge = 180 USD/ha; mound = 200 USD/ha (based on local rates in FCT Abuja).*

DISCUSSION

The present study evaluated the effects of tillage practices and fertilizer sources on Cylas weevil infestation, soil physicochemical properties, biomass accumulation, and root yield of orange-fleshed sweet potato (OFSP) in the southern Guinea savanna of Abuja, Nigeria. It further examined the stability of treatment responses across two consecutive cropping seasons under varying climatic conditions, with emphasis on pest dynamics, soil fertility changes, and yield performance under integrated crop management. Results showed that agronomic and nutrient management practices significantly influenced OFSP productivity and weevil infestation, with evident trade-offs between yield enhancement and pest pressure.

Mound tillage and mineral NPK fertilizer consistently promoted higher root yield and vegetative growth, whereas poultry manure more strongly improved soil chemical properties and long-term fertility indicators. The consistency of treatment effects across the 2024 and 2025 seasons indicates that responses were largely stable under seasonal variation in rainfall and temperature, reinforcing their reliability in tropical Alfisol environments. However, the findings also highlight important interactions between productivity, pest vulnerability, and soil health outcomes. This preamble introduces the subsequent discussion of seasonal consistency, tillage effects, fertilizer trade-offs, soil quality, economic implications, and study limitations.

Seasonal consistency and treatment effects

The non-significance of season × treatment interactions (Table 5) suggests that tillage and fertilizer treatments had similar effects on Cylas weevil infestation, soil properties and root yield in both the 2024 and 2025 seasons. In other words, treatment rankings were consistent between seasons. The consistency between seasons suggests that our treatments produced dependable responses that were unlikely to change because of normal interannual variation in rainfall and temperature in Abuja's derived savanna environment. Although rainfall was marginally lower in 2025 (850 vs 867 mm), mean temperatures actually decreased slightly (-0.2 ^{o}C). Despite recording slightly higher weevil infestation (7.5 vs 7.1) and marginally higher yields (28.2 vs 27.5 t/ha) in 2025, these differences were not statistically significant. Multi-season consistency in pest dynamics has previously been documented for sweet potato ecosystems in West Africa (Mbua *et al*., 2021; Adebayo *et al.,* 2023).

Tillage effects on yield and weevil infestation

Planting on mounds increased root yield by 29.4 t/ha, which is 14.0% higher than planting on flat beds. This is consistent with similar findings from Ghana (Dumbuya *et al*., 2022) and Ethiopia (Tsegaye *et al.,* 2023). Mounds improve root yield by increasing the proportion of topsoil (higher plant available water and nutrients) and enhancing soil aeration, allowing greater tuber expansion before harvest (Onwueme, 2021; Ilozobhie *et al.,* 2024). On the downside, planting on mounds resulted in 23.8% higher Cylas weevil infestation relative to flat beds. This agrees with findings by Kibrom (2021), who noted that mound planting systems of sweet potato generate a humid microclimate around the soil surface that is conducive to *Cylas spp.* oviposition and larval survival. The significant positive correlation between vine length and weevil infestation ($r = 0.802$, $p < 0.001$) reinforces this theory, suggesting that the lush canopy supported by mounds increases attractiveness to adult weevils. Crucially, this yield-infection trade-off remained consistent between seasons, implying that farmers practising mound tillage should consider IPM regardless of seasonal fluctuations. Recommended IPM practices for sweet potato systems include early planting (better to avoid peak adult weevil activity), earthing up (effectively buries exposed roots), field sanitation and pheromone traps to reduce breeding populations (Stathers *et al.,* 2020; Mesele *et al*., 2020; Ogunlade *et al*., 2023).

Fertilizer trade-offs: yield vs pest pressure

Relative to unfertilized control plots, NPK fertilizer application produced the greatest root yield (35.5 t/ha, +63.6%) but also the highest weevil infestation (+84.3%). This trade-off is attributed to the exudation of free amino acids from roots fertilized with mineral NPK. These compounds increase tuber succulence, which attracts feeding by gravid weevils and their larvae (Mbua *et al.,* 2021; Egata Shunka *et al.,* 2021). Fresh shoot biomass was positively correlated with weevil infestation (r = 0.877, Table 4), confirming that above-ground biomass can be used as a proxy for attractive host tissue quality. Application of poultry manure represents a compromise option: moderately increased yield (28.9 t/ha, +33.2%) coupled with intermediate weevil infestation (7.6 infected roots/plot, +49% relative to control but 19% lower than NPK treatment). Pest suppression by poultry manure could be explained by microbial antagonists capable of degrading chitin exoskeletons (Nedunchezhiyan *et al.,* 2022) or induced systemic resistance (Olatunji and Adeyongu, 2022). Studies by Adebayo *et al.* (2022) found that poultry manure-treated sweet potato suffered 30% less weevil damage compared with NPK fertilizer. This reduction was attributed to lignification of storage roots elicited by poultry manure. Given that these fertilizer responses were stable across both seasons, farmers can expect this trade-off effect to persist year-on-year.

Soil health implications

Post-harvest soil analysis data (Tables 3, 7 and 8) clearly demonstrate the benefits of organic vs inorganic fertilization. Poultry manure application: increased pH from acidic 4.6 to near-neutral pH 6.7 (+46%), increased organic carbon content by 28–48%, increased exchangeable K by >1,300%, and improved cation exchange capacity (CEC) by 84 – 126%. These improvements would, over time, dramatically improve soil health and productivity by addressing the 3 major limitations to productivity in tropical Alfisols: acidity, low soil organic matter levels, and poor nutrient retention capacity (Anyaegbu and Ibrahim, 2022). Particularly relevant to sweet potato production is the positive impact on exchangeable K, since this nutrient is required for sucrose translocation from vines to storage roots (Byju and Nedunchezhiyan, 2023).

In contrast, NPK fertilizer and urea further acidified the soil (decreasing pH to 4.4 – 4.6), had no positive effect on soil organic carbon levels, and did not meaningfully increase CEC. Continuous usage of these acid-forming fertilizers without liming will cause aluminium and manganese toxicity, leading to progressively poorer tuber quality (Agbede and Adekiya, 2022; Nedunchezhiyan and Ray, 2022). While poultry manure increased available P after one season (Table 8), the values recorded in 2025 actually decreased compared with 2024 (4.5 – 4.8 ppm vs 8.6 ppm), which indicates that some P immobilization occured.

Future studies should look at applying P-solubilising bio-fertilisers such as Bacillus megaterium to poultry manure plots in order to increase available P from organic sources (Chipungu *et al.,* 2021; Olowe *et al*., 2023). The consistency in soil properties between the two harvest periods suggests that the benefits of poultry manure application to soil health compound with continued usage, whereas the detrimental effects of NPK fertilizer application accrue over time. This follows intuitively but agrees with long-term field trials by Adekiya *et al.* (2021).

Economic and social dimensions of adoption

In theory, mound/NPK treatment offers sweet potato growers the highest net revenue ($7260 USD/ha) but comes with considerable cash input costs ($440 USD/ha for fertilizer + additional labour inputs). For subsistence farmers in the FCT who rarely have access to credit, this is likely to be cost-prohibitive. Compared to NPK fertilizer at 200 kg/ha, poultry manure costs 180 USD/ha to source and apply when using 5 t/ha. Combined with mounds, poultry manure produced an estimated net revenue of $5580 USD/ha, which is ~23% less than mound/NPK but does not require farmers to shell out cash for fertilizer. If farmers raise backyard poultry or already source poultry manure from neighbours, the required inputs might actually cost less than NPK fertilizer. From a poverty alleviation standpoint, this makes the mound/poultry manure system much easier to adopt at scale. The Nigerian government and NGOs could facilitate adoption of this practice by subsidizing or giving away "input packs" of 2.5 t/ha poultry manure with 100 kg/ha blended NPK fertilizer. Although we did not test this hypothesis, blending different fertilizer types can produce synergistic effects on yield (Ewulo *et al*., 2023) and allow farmers to experience the immediate yield boost of mineral fertilizers while building soil health with manure.

Limitations and future research

This study has four key limitations. Firstly, planting material was restricted to a single OFSP variety ('Mother's Delight'/UMUSP3). Sweet potato weevils show variable preference among genotypes and physiological races (Stathers *et al.,* 2020). Secondly, measurements of soil weevil populations (adult counts, egg counts, larval/rootworm densities) were not made. Only weevil-induced root damage at harvest was scored. Thirdly, measuring effects across two seasons cannot capture long-term cumulative changes to soil fertility or soil weevil populations that would occur over decades.

Finally, our economic analysis only considered standard input costs and did not account for price fluctuations that occur in the real world. We recommend that future studies: (i) screen local OFSP clones and varieties for tolerance to weevil attack under integrated mound/poultry manure system, (ii) run a long-term trial of ≥5 years duration measuring changes in soil organic carbon and baseline weevil populations over time, (iii) test integrated nutrient management approaches using reduced rates of NPK + poultry manure (e.g. 50 kg/ha NPK with 2.5 t/ha poultry manure) and (iv) conduct crop adoption studies with gender disaggregated data since women typically oversee sweet potato production systems in Nigeria (Tanumihardjo *et al.,* 2020).

CONCLUSION AND RECOMMENDATIONS

Results obtained during the 2024 and 2025 cropping seasons showed that different tillage systems and fertilizer sources significantly affected orange-fleshed sweet potato yield, weevil infestation, and post-harvest soil properties within the inland-derived savanna agroecology. Mound tillage increased root yield by 14.0% compared with flat beds, but also increased weevil infestation by 24%. Application of NPK fertilizer (20:10:10 at 200 kg/ha) under mound tillage produced the highest root yield (38.5 t/ha), although it also increased weevil infestation (+84%) and reduced soil pH after harvest.

Application of poultry manure at 5 t/ha improved soil pH, organic carbon, exchangeable potassium, and cation exchange capacity while reducing weevil infestation compared with NPK-treated plots. However, sweet potato yield under poultry manure remained about 18% lower than the mound + NPK treatment combination.

Mound tillage combined with NPK fertilizer is therefore suitable for commercial farmers targeting maximum short-term productivity, provided integrated pest management practices such as early planting, earthing-up, field sanitation, and pheromone trapping are adopted to reduce weevil damage.

For resource-poor farmers interested in improving soil fertility while maintaining acceptable yields, mound tillage with poultry manure at 5 t/ha represents a practical alternative. Farmers with access to fertilizer may also combine 100 kg/ha NPK with 2.5 t/ha poultry manure to balance productivity and soil improvement. Increased government support for poultry manure availability and farmer training on IPM practices would support sustainable sweet potato production in Nigeria.

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