

RESPONSE OF TWO SWEET POTATO (*Ipomoea batatas* L.) VARIETIES TO DIFFERENT LAND PREPARATION METHODS AND FERTILIZER TYPES IN ABUJA, NIGERIA

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ABSTRACT

In sub-Saharan Africa, soil acidity, low fertility, and *Cylas* weevil infestation limit sweet potato output in degraded savanna soils. A three-year field experiment (2023–2025) was conducted in Abuja to evaluate the interactive effects of different cultivars, tillage practice, and fertilizer type on soil chemical properties, growth, root yield, and *Cylas* incidence. Treatments consisted of two cultivars (white-fleshed ‘TIS-87/0087’ and orange-fleshed ‘UMUSP3’), three tillage systems (flat, mound, and ridge), and four fertilizer treatments (control, green manure from *Hyptis suaveolens*, NPK 15:15:15, and poultry manure) arranged in a randomized complete block design with three replications. The experimental soil was strongly acidic (pH 4.5) with low organic carbon (0.31%), total nitrogen (0.011%), and available phosphorus (4.40 mg/kg). Significant three-way interactions influenced root yield. The white-fleshed cultivar under mound cultivation with NPK fertilizer produced the highest root yield (41.53 t/ha), representing a 279% increase over the control. Mound and ridge tillage improved soil pH (6.2–6.3), organic carbon, and effective cation exchange capacity relative to flat tillage. Poultry manure recorded the highest improvement in soil pH (6.5), organic carbon (1.63%), and ECEC (9.56 cmol/kg). *Cylas* incidence declined by 73–80%, with orange-fleshed plants showing the greatest suppression. Root yield was strongly correlated with fresh biomass ($r = 0.98$). Orange-fleshed sweet potato achieved its highest yield (36.15 t/ha) under ridge cultivation with poultry manure. White-fleshed cultivars with mound + NPK maximized caloric yield, while orange-fleshed cultivars under ridge + poultry manure are suitable for biofortification.

.Keywords: Biofortification; *Cylas weevil*; Degraded Alfisol; Fertilizer management; Sweet potato; Yield performance.

INTRODUCTION

Sweet potato (*Ipomoea batatas* L.) is one of Africa’s most important food security crops. Smallholder farmers rely on the crop for carbohydrates, vitamins, and income (Low *et al.*, 2017). Average yields ($\sim 5 \text{ t ha}^{-1}$) in sub-Saharan Africa (SSA) are low compared to attainable yields realized in other parts of the world. Sweet potato production in SSA faces complex challenges, including poor soils, sub-optimal agronomic practices, and relative lack of research compared to other staple grains like maize, wheat, and rice (Mudege *et al.*, 2017). Low soil organic carbon, nutrient deficiencies and acidity characterize many African soils under agriculture (Tully *et al.*, 2015; Giller *et al.*, 2021). In fact, over 70% of African soils are degraded

largely due to unsustainable agricultural practices. Soil fertility management is thus critical for sustainable sweet potato production systems on the continent. Although inorganic fertilizers give plants quick access to nutrients, they are costly, occasionally unavailable, and, if used carelessly, can acidify the soil (Masso *et al.*, 2017). In addition to supplying nutrients to plants, organic fertilisers, such as compost made from poultry manure, green manures, cover crops, etc., can enhance the physical characteristics of soil, water-holding capacity, and nutrient cycling (Agegnehu *et al.*, 2016; Olujugba *et al.*, 2016; Chivenge *et al.*, 2022). Land preparation influences soil physical properties and crop growth and yield

performance. Tillage practices like mounds and ridges improve soil aeration, drainage, and penetration resistance, particularly in soils prone to compaction and poor drainage (Djaman *et al.*, 2021). Sweet potatoes can be grown on flat beds and raised beds as well. However, the best configuration of land configuration and nutrient sources, including biofortified orange-fleshed versus traditional white-fleshed sweet potato varieties are not known for the savanna agroecology of Nigeria.

The experiment was designed to: (i) determine effect of land configuration on sweet potato growth and yield, (ii) compare the effect of fertilizer types on crop growth and yield, (iii) assess the response of orange fleshed vs. white fleshed varieties to the agronomic practices and (iv) identify the best combination of integrated land configuration and fertilizer type practice for optimal nutrient uptake and highest root yield for sweet potato in Abuja, Nigeria.

MATERIALS AND METHODS

Description of Study Location, Climate and Soil Characteristics

The experiment was carried out during the 2023, 2024 and 2025 growing seasons at the Teaching and Research Farm of the Faculty of Agriculture, University of Abuja, situated at N 8°59'24.46944" E 7°11'8.46708". The region experiences two rainy seasons, with a major rainy season from April to October. Rainfall ranges from 1,100 to 1,800 mm annually. Average temperature and relative humidity are about 30 °C and 60 – 80%, respectively (Barnabas and Nwaka, 2014; Idoko and Bisong, 2010). Dry season temperatures average 28–30 °C but can reach >40 °C in some places like Gwagwalada axis. Average wind speed during the dry season is 10 km/hour from the northeast direction. The soils are deep, well-drained sandy loams developed from granite and migmatite parent material. Textural classes include loamy sand (52.5%), clay loam (23%), sandy clay (10.5%) and sandy clay loam (14%) (Ishaya and Grace, 2007). They have moderate runoff potential, average fertility levels and a pH of 4.5 before planting.

Site Preparation and Soil Sampling

Site was cleared, levelled and destumped with the help of machetes, raked, and dibbed. Ploughing and cross-harrowing were done to achieve fine tilth. Composite soil samples were collected at random from ten points within each plot at 0–30 cm depth using a soil auger. Collected soil samples were composited per plot, air-dried, ground and passed through a 2 mm sieve. Organic carbon, total nitrogen, and available phosphorus were determined using standard methods of analysis described by FAO (2019).

Experimental Materials

Varieties of sweet potato (*Ipomoea batatas* L.) used for the study included UMUSP3 orange-fleshed biofortified variety and TIS-87/0087 white-fleshed variety. Parent vines for both varieties were obtained from the National Root Crops Research Institute (NRCRI) outstation located at Nyanya (FCT/Nasarawa), Nigeria. UMUSP3 variety was chosen because of its relatively high β -carotene, antioxidant activity, dietary fibre and density of micronutrients. It can be used to combat vitamin A deficiency (Tumuhimbise *et al.*, 2019; Amagloh *et al.*, 2021). The genotype has a soft flesh texture and low dry matter content, which makes it ideal for use in nutrition studies and consumer preference evaluation. TIS-87/0087 was chosen because of its high yield potential, good adaptability to different ecological zones and consistent agronomic performance (Mwanga *et al.*, 2016; Abidin *et al.*, 2020). This variety has high dry matter content, and it can be processed into sweet potato chips and flour.

Experimental Treatments and Design

Treatments included two varieties, three tillage systems (mounds, ridges, flat beds), and four fertilizer types: NPK15:15:15: poultry manure, green manure (*Hyptis suaveolens*), and control. Treatments were laid out in a factorial design in a Randomised Complete Block Design (RCBD) with three replications. There were 24 plots per replication, making a total of 72 plots.

Plot Size

Dimensions of each plot were 3 m × 3 m. Space between plots in a replication was 0.5 m, while space between replicates was 1 m, serving as alleys. The total area covered by the experiment was 918.5 m² (83.5 m × 11 m).

Cultural Practices

Vines used for planting were cuttings of length 30 cm planted at 50 cm × 50 cm spacing, equivalent to 40,000 plants ha⁻¹ and 36 stands per plot. Plants were set at a 60° angle from horizontal, such that two-thirds of the cutting is buried and well pressed against the soil at planting to ensure good soil contact and sprouting. Hoe was used for weeding at 3, 6, and 9 weeks after planting (WAP).

The organic amendments (poultry manure and green manure) were air-dried and passed through a 10 mm sieve. Amendments were applied three weeks before planting as background soil dressing and thoroughly mixed into the soil. The poultry manure had N:P:K = 2.5%: 1.8%: 1.5%. *Hyptis suaveolens* biomass was harvested fresh, chopped and applied as green manure at the rate of 5 t/ha (4.5 kg per plot or 0.125 kg per plant stand) following Anyaegebu (2013). NPK 15: 15:15 was band applied three weeks after planting at a rate of 400 kg/ha (0.36 kg per plot or

0.01 kg per plant). Manual labour using hoes was used to harvest sweet potatoes at 12 WAP. Harvested roots were sorted into marketable and unmarketable root categories before collecting data.

Variables Measured and Data Analysis

Data collected include percent sprouting, plant survival at harvest, number of vines per stand, vine length (cm), number of leaves per plant, SPAD chlorophyll content, leaf area per plant (cm²), fresh biomass yield (kg/ plot), total number of roots, marketable roots, unmarketable roots, cyas weevil damaged roots, harvest index (HI) and root yield (t/ha). Means were analyzed in R (Version 4.5.2) using the agricolae package. Analysis of variance (ANOVA) was performed. Significant treatment means were separated using Student-Newman-Keuls (SNK) test at $p \leq 0.05$ probability level. Least Squares Means (LSMEANS) were estimated for traits that had significant interaction effects, and statistical significance was determined using the standard error of the LSMEANS and associated p-values at a probability level of 0.05. Furthermore, Pearson correlation coefficients were computed to examine relationships among the measured variables.

RESULTS

Site Soil Physical and Chemical Properties

Baseline (0–30 cm) soil properties of the experimental site before planting showed that the field experimental area in Abuja, Nigeria, was dominated by strongly acidic, infertile sandy loam texture (70% sand; 10% silt; 20% clay). This textural class was retained during the three-season survey (2023-2025) since this was determined by coarse nature and its proneness to nutrient loss through leaching, which is common to most weathered savanna Oxisols and Alfisols associated with the basement complex rocks of FCT (Barnabas and Nwaka, 2014; Ishaya and Grace, 2007).

Baseline soil property also revealed that soil reaction was strongly acidic $\text{pH}(\text{H}_2\text{O})=4.5$; $\text{pH}(\text{KCl})=4.8$ suggesting the presence of Al^{3+} and H^+ on the exchange complex, which impedes root growth and nutrient availability (Sanchez, 2019). Inherent fertility of the soils based on organic carbon and matter content was very low, having values below 1.5% OM needed to maintain soil tilth and microbial population in tropical agroecosystems (Brady and Weil, 2017). The experimental soil presented with critically low levels of total nitrogen (0.011%) and available phosphorus (4.40 mg kg^{-1}), the latter falling significantly short of the 10–15 mg/kg benchmark essential for optimal root crop yields in savanna environments (Kihara *et al.*, 2020).

Likewise, low effective cation exchange capacity (ECEC) 6.54 $\text{cmol}(+)/\text{kg}$ and exchangeable bases present in very small amounts: $\text{Ca}^{2+} = 2.33 \text{ cmol}(+)/\text{kg}$, $\text{Mg}^{2+} = 1.20 \text{ cmol}(+)/\text{kg}$, $\text{K}^+ = 0.51 \text{ cmol}(+)/\text{kg}$. implies little or nothing nutrients retention capacity and is highly prone to nutrient loss through base leaching whenever there is heavy rainfall, as obtainable in the tropics (Idoko and Bisong, 2010; Tully *et al.*, 2015). This is a common feature of highly weathered savanna soils that have been degraded by years of cultivation. These limiting soil factors have been reported to impair the availability of essential nutrients, restrict rooting and reduce early plant establishment ability of root and tuber crops, including sweet potato (Brady and Weil, 2017; Sanchez, 2019; Anyaegebu, 2013; Agegnehu and Amede, 2021).

Table 1: Pre-planting physicochemical properties of the experimental soil (0-30 cm depth)

Property	Value	Rating/Implication
Physical		
Sand: Silt: Clay (%)	70: 10: 20	Sandy Loam (SL)
Chemical		
pH (H ₂ O)	4.5 4.8	Strongly Acidic
pH (KCl)	0.31 0.98	Strongly Acidic
Organic Carbon (%)	0.011	Very Low
Organic Matter (%)	4.40 0.51	Very Low
Total Nitrogen (%)	2.33 1.20	Very Low
Available P (mg kg^{-1})	6.54	Very Low
Exchangeable K $\text{cmol}(+)/\text{kg}$		Low
Exchangeable Ca $\text{cmol}(+)/\text{kg}$		Low
Exchangeable Mg $\text{cmol}(+)/\text{kg}$		Low
ECEC $\text{cmol}(+)/\text{kg}$		Low

Post-Harvest Soil Chemical Properties as Influenced by Tillage and Fertilizer

As shown in Table 2, most soil chemical properties varied significantly after harvest following three cropping seasons, with differences largely attributable to the treatments applied. Tillage method and fertilizer type had highly significant main effects ($p < 0.01$ to $p < 0.001$) on post-harvest soil pH, OC, TN, available P, and ECEC. Tillage had significant interactive effects with fertilizer on OC ($p = 0.008$), TN ($p = 0.042$), available P ($p = 0.006$), and ECEC ($p = 0.003$). However, soil pH did not significantly interact with tillage \times fertilizer treatments ($p = 0.342$). These significant interactive effects suggest synergy between tillage and fertilizer.

Effects of Tillage Alone

In comparison with flat tillage, mound tillage resulted in significantly higher post-harvest soil pH (6.3 vs. 5.9, $p = 0.003$). However, mound pH did not differ significantly from that of ridge tillage (6.2, $p > 0.05$). Compared to flat beds, mound tillage increased OC by 25.6% (1.52% vs. 1.21%, $p = 0.002$), TN by 36.1% (0.098% vs. 0.072%, $p = 0.008$), available P by 19.1% (7.68 vs 6.45 mg kg^{-1} , $p = 0.004$), and ECEC by 13.2%

(8.92 vs. 7.88 cmol(+)/kg, $p = 0.001$). Ridge tillage recorded intermediate values that were not significantly different from those of mound tillage ($p > 0.05$) for all parameters, but were higher than those of flat tillage. The increased values under raised beds are attributed to increased aeration (increase in macroporosity by 15–20%), which favoured microbial decomposition of OM and immobilisation of added nutrients, increased resistance to surface crusting and reduced nutrient leaching losses (Udom *et al.*, 2021; Djaman *et al.*, 2021; Nciizah and Wakindiki, 2021; Ilozobhie *et al.*, 2024).

Effects of Fertilizer Application Alone

Application of poultry manure yielded the highest pH (6.5) compared to control plots (pH 5.1, $p < 0.001$). Application of poultry manure increased OC, TN, and ECEC by 91.8% (1.63% vs. 0.85%, $p < 0.001$), 200% (0.105% vs. 0.035%, $p < 0.001$), and 48.2% (9.56 cmol(+)/kg $p < 0.001$), respectively. These increases are attributable to the addition of OM, which is incorporated into the soil from poultry manure. Poultry manure contains 40–50% OC and is rich in nutrients and substrates that stimulate microbial growth (as indicated by microbial biomass carbon, which can increase by as much as 60% following its application) (Agegnehu *et al.*, 2016; Adekiya *et al.*, 2020; Chivenge *et al.*, 2022). Materials degrade over time, releasing nutrients slowly.

NPK 15: 15:15 application resulted in the highest available P concentration (8.45 mg kg⁻¹). This concentration was significantly higher than that of the control (5.12 mg.kg, $p < 0.001$) and green manure (6.98 mg/kg, $p = 0.002$). The readily available nature of chemical fertilizers explains the high P concentration following NPK application because this formulation has high solubility (Brady and Weil, 2017). However, NPK had a lesser effect on OC (1.31%) than poultry manure (1.63%, $p = 0.001$) and green manure (1.38%, $p = 0.042$). Chemical fertilizers add no organic matter to the soil and thus do little to replenish OM quickly (Masso *et al.*, 2017).

Application of green manure (*Hyptis suaveolens*) improved OC (1.38%, $p < 0.001$ vs control) and TN (0.085%, $p < 0.001$). This finding agrees with studies that advocated for the application of labile organic inputs in restoring the fertility of degraded soils (Palm *et al.*, 2014; Thiour-Mauprivez *et al.*, 2019).

Effects of Tillage × Fertilizer Interactions

The significant interactive effects of tillage with fertilizer on OC ($p = 0.008$), TN ($p = 0.042$), available P ($p = 0.006$), and ECEC ($p = 0.003$) suggest that nutrient amendments are likely to work better under better soil physical conditions.

For example, mound tillage + poultry manure resulted in ECEC of 9.56 cmol(+)/kg, which is about 48% higher than the control and 25–30% higher than what would have been achieved if either amendment was applied alone (estimated from average effect). Tillage and fertilizer improved fertility by stimulating microbial growth (higher aeration under raised beds), increasing rates of mineralisation, accelerating root growth and penetration, and increasing the formation of organo-mineral complexes (Lal, 2015; Giller *et al.*, 2021). Raised beds (mound and ridge) all resulted in higher pH, OC, TN, available P and ECEC than plots under flat tillage because they improved aeration and reduced OM decomposition and nutrient losses by leaching (Djaman *et al.*, 2021; Ilozobhie *et al.*, 2024). The significance of the tillage × fertilizer interaction further suggests that fertilizer use efficiency can be improved by ensuring that organic or mineral fertilizers are applied under conducive soil physical conditions.

Table 2: Postharvest soil chemical properties as influenced by main effects of tillage and fertilizer (combined over three seasons, 2023–2025)

Factor	Level	pH (H±O)	OC (%)	TN (%)	Avail. P (mg/kg)	ECEC (cmol/kg)
Tillage	Flat	5.9 b	1.21 b	0.072 b	6.45 b	7.88 b
	Mound	6.3 a	1.52 a	0.098 a	7.68 a	8.92 a
	Ridge	6.2 a	1.44 a	0.090 a	7.12 a	8.67 a
	SE±	0.08	0.05	0.004	0.21	0.18
Fertilizer	Control	5.1 c	0.85 c	0.035 c	5.12 c	6.45 c
	Green Manure	6.0 b	1.38 b	0.085 b	6.98 b	8.12 b
	NPK 15:15:15	6.4 a	1.31 b	0.092 ab	8.45 a	8.34 b
	Poultry Manure	6.5 a	1.63 a	0.105 a	7.55 ab	9.56 a
	SE±	0.09	0.06	0.005	0.24	0.18
Significance	Tillage	*	*	*	*	*
		($p=0.003$)	($p=0.002$)	($p=0.008$)	($p=0.004$)	($p=0.001$)
	Fertilizer	*	*	*	*	*
		($p<0.001$)	($p<0.001$)	($p<0.001$)	($p<0.001$)	($p<0.001$)
T × F	NS	*	*	*	*	
	($p=0.342$)	($p=0.008$)	($p=0.042$)	($p=0.006$)	($p=0.003$)	

Within each factor (tillage or fertilizer), means in a column with the same letter are not significantly different (SNK, $p<0.05$). SE± = standard error. NS = not significant ($p>0.05$); * = $p<0.05$. T×F = tillage × fertilizer interaction.

Crop Establishment and Early Vegetative Growth

Sprouting and Plant Survival

Land preparation significantly affected sprouting and plant survival early in crop establishment ($p < 0.01$). At 3 weeks after planting (WAP), higher sprouting percentages were recorded under ridge (97.6%, $p=0.002$ vs flat) and mound (97.1%, $p=0.003$ vs flat) compared to flat beds (92.5%). This represents a relative improvement of 4.6 and 5.1%, respectively. Improved physical conditions of soil following ridge and mound tillage account for this response as porosity was

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found to increase by 15–20%, surface crusting reduced due to decreased chances of waterlogging, and soil temperature rose by 1.5–2.5°C during emergence (Udom *et al.*, 2021; Djaman *et al.*, 2021).

Sprouting percentage was also affected by fertilizer application ($p < 0.05$). Specifically, NPK 15: 15:15 (96.2%) and poultry manure (95.8%) increased sprouting percentage by 3 and 4%, respectively, compared to the control (92.4%). This increase can be attributed to the demand of sprouting for readily available nutrients like nitrogen, which is required for enzyme production, and phosphorus for energy transfer during rapid cell division events taking place at sprouting (Omondi *et al.*, 2021).

Plant survival percentage at harvest (16 WAP) followed a similar trend. Plant survival was highest under mound tillage (94.3%) and ridge tillage (93.8%), which were significantly higher than flat tillage (88.6%, $p = 0.007$). The varieties examined did not exhibit any statistically significant variations. This indicates that there were no differences in establishment capability between the white-fleshed (TIS-87/0087) and orange-fleshed (UMUSP3) varieties.

Vegetative Growth Parameters

Varietal differences were recorded in canopy development between orange- and white-fleshed cassava. The white-fleshed variety had higher vegetative vigour than the orange-fleshed variety, as indicated by higher vines per stand (4.64 vs 4.40 vines, $p = 0.023$) and vine length (206.8 cm vs 196.2 cm, $p = 0.018$). This represents relative increases of 5.2% and 5.4%, respectively. These differences could be due to genetic differences influencing the partitioning of photosynthates towards vegetative growth vs storage roots (Mwanga *et al.*, 2016; Lebot, 2020). Tillage Fertilizer interaction effects were recorded for leaf number per plant ($p < 0.001$). Mound tillage followed by application of NPK 15: 15:15 produced the highest leaf numbers (70.9 leaves/plant), followed by mound and poultry manure (65.9) and ridge – NPK (65.8). Rates of leaf production from fertilizer application on flat beds were much lower, as plants receiving NPK fertilizer on flat beds produced 49.4 leaves/plant, which was 30.3% fewer leaves compared to their counterparts on the mound ($p < 0.001$). This shows that nutrients cannot act independently of the physical environment they are found in, as raised beds improved uptake efficiency by 20–25% due to improved aeration, moisture content and geometry of the root zone (Ilozobhie *et al.*, 2024; Hasan *et al.*, 2024).

Table 3: Interaction effect of tillage method and fertilizer type on number of leaves per plant (combined data for 2023 and 2025)

Tillage Method	Fertilizer Type	Leaves per Plant	SE±	P-value (vs. control)
Flat	Control	26.70g	1.35	
Flat	Green Manure	55.23cd	1.35	
Flat	NPK 15:15:15	49.43de	1.35	
Flat	Poultry Manure	49.94de	1.35	
Mound	Control	45.77ef	1.35	
Mound	Green Manure	45.49f	1.35	
Mound	NPK 15:15:15	70.89a	1.35	
Mound	Poultry Manure	65.92ab	1.35	
Ridge	Control	38.08f	1.35	
Ridge	Green Manure	59.33bc	1.35	
Ridge	NPK 15:15:15	65.77ab	1.35	
Ridge	Poultry Manure	56.92cd	1.35	

Letter superscripts (a–g) are from the Student-Newman–Keuls (SNK) test at ≤ 0.05 for comparisons within the column. The separate p-value column shows comparisons vs the control within each tillage method. SE± = standard error of the mean (based on pooled error). Interaction: Tillage × Fertilizer ($F_{6,72} = 8.34$, $p < 0.001$).

Yield Components and Root Yield Fresh Biomass and Root Numbers

The positive effects on vegetative development carried over to components of yield. Fresh biomass production (kg/plot) was higher under mound tillage (mean 12.84 kg/plot) than ridge (11.96 kg/plot) or flat (10.23 kg/plot), which was a 25.5% difference ($p = 0.002$). NPK fertilizer produced the highest biomass (13.21 kg plot⁻¹), significantly higher than control (8.45 kg/plot, $p < 0.001$), green manure (11.87 kg plot⁻¹, $p = 0.014$) or poultry manure (12.34 kg/plot, $p = 0.038$).

Table 4 (interaction means). The total number of roots per plot had a significant Tillage × Fertilizer interaction ($p = 0.003$). Following the same trend as leaf number, mound tillage × NPK 15: 15:15 produced the highest number of roots (74.06 roots/plot), confirming a clear mechanism between dense canopy formation and initiation of storage roots. It had 11.0% more roots than flat tillage × NPK (66.72 roots/plot) and 81.8% more roots than flat tillage × control (40.72 roots/plot).

Table 4: Interaction between tillage method and fertilizer type on total number of roots per plot (combined seasons, 2023–2025)

Tillage	Fertilizer Type	Total Roots/Plot	SE±	% Increase vs. Control
Flat	Control	40.72f	1.87	
Flat	Green Manure	59.83cd	1.87	
Flat	NPK 15:15:15	66.72abc	1.87	
Flat	Poultry Manure	65.56bcd	1.87	
Mound	Control	53.28e	1.87	
Mound	Green Manure	69.33ab	1.87	
Mound	NPK 15:15:15	74.06a	1.87	
Mound	Poultry Manure	65.94bcd	1.87	
Ridge	Control	51.22e	1.87	
Ridge	Green Manure	57.00d	1.87	
Ridge	NPK 15:15:15	70.78ab	1.87	
Ridge	Poultry Manure	69.94ab	1.87	

Means followed by different letters are significantly different at ≤ 0.05 (Student-Newman–Keuls test). SE± = standard error of the mean. % Increase vs. Control = ((treatment mean – control mean)/control mean) × 100. Interaction: Tillage × Fertilizer ($F_{6,72} = 4.92$, $p = 0.003$).

Marketable yield and pest infestation

Variety (V) × Fertilizer (F) interaction was significant ($p < 0.001$) for Cylas weevil infestation, as shown in Table 5. Application of green manure reduced the level of weevil infestation substantially (79.6% decrease in number of infected roots; from 16.74 to 3.41 infected roots per plot, $p < 0.001$, in the orange-

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fleshed variety and 73.3%; from 14.26 to 3.81 infected roots per plot, $p < 0.001$, in the white-fleshed variety) relative to control.

Mechanisms through which green manure suppressed *C. cf. indoamericanus* could include: (i) modification of the rhizosphere environment, thereby deterring oviposition by adult females; (ii) induced physical resistance as plants fertilized with green manure may uptake silicon liberated through decomposition of *Hyptis suaveolens* tissues; and (iii) stimulation of antagonistic soil microorganisms by organic amendments (Thiour-Mauprivez et al., 2019; Olatunji et al., 2024). NPK and poultry manure also lowered infestation levels compared to control, but had a lesser impact compared to green manure amendments ($p < 0.01$ for all comparisons).

Table 5: Interaction between variety and fertilizer type on Cylas weevil infestation (number of infected roots/plot, combined seasons, 2023-2025)

Variety	Fertilizer Type	Infected Roots/Plot	SE±	Reduction vs. Control
Orange-fleshed	Control	16.74a	0.70	
Orange-fleshed	Green Manure	3.41e	0.70	
Orange-fleshed	NPK 15:15:15	10.15c	0.70	
Orange-fleshed	Poultry Manure	12.85b	0.70	
White-fleshed	Control	14.26b	0.70	
White-fleshed	Green Manure	3.81e	0.70	
White-fleshed	NPK 15:15:15	7.33d	0.70	
White-fleshed	Poultry Manure	7.70d	0.70	

Means with different letters are significantly different at ≤ 0.05 (SNK). SE±= standard error. Reduction vs Control = % decrease relative to control. Interaction: Variety × Fertilizer ($F_{3,64}=12.67$, $p < 0.001$).

Variety x Tillage x Fertilizer Interaction for Final Root Yield

There was a highly significant variety x tillage x fertilizer interaction for final root yield (expressed as tonnes per hectare) (Table 6). The highest yield of 41.53 t ha⁻¹ was recorded for the white-fleshed variety TIS 87 0087 planted on mound tillage and fertilised with NPK 15 15 15 fertilizer. This treatment resulted in 279 per cent more yield compared to the lowest yield, which was for the orange-fleshed variety planted on flat tillage without fertilizer application at 10.96 t ha⁻¹ ($p < 0.001$). This also resulted in 33.8 per cent more yield than the white fleshed check planted on a mound without fertilizer at 31.05 t/ha ($p = 0.002$). This treatment also gave 14.9 per cent higher yields than the best orange-fleshed treatment combination planted on ridge and amended with poultry manure at 36.15 t/ha ($p = 0.018$).

Generally, the white-fleshed variety gave its highest yield under the high input system of mound tillage and chemical fertilizer application. On the other hand, the orange-fleshed variety recorded its highest yield under the lowest input and a more sustainable system of ridge tillage

integrated with organic nutrient sources. The orange flesh trait causes more assimilates to be shunted towards carotenoid production than is directed towards storage root biomass production. Carotenoid synthesis is energetically expensive (Low et al., 2017; Tumuhimbise et al., 2019).

Table 6: Three-way interaction (Variety × Tillage × Fertilizer) on root yield (t ha⁻¹, combined seasons, 2023-2025)

Variety	Tillage	Fertilizer	Yield (t/ha)	SE±	Maximum
Orange	Flat	Control	10.96j	2.08	26.4%
Orange	Flat	NPK 15:15:15	26.72defg	2.08	64.3%
Orange	Mound	NPK 15:15:15	32.37bede	2.08	78.0%
Orange	Ridge	Poultry Manure	36.15ab	2.08	87.1%
White	Flat	NPK 15:15:15	31.05bedef	2.08	74.8%
White	Mound	Green Manure	34.26bc	2.08	82.5%
White	Mound	NPK 15:15:15	41.53a	2.08	100%
White	Ridge	NPK 15:15:15	33.93bc	2.08	81.7%

Means with different letters are significantly different at ≤ 0.05 (SNK). SE±= standard error. % of Maximum = (yield / 41.53) × 100. Interaction: Variety × Tillage × Fertilizer ($F_{12,144}=5.83$, $p < 0.001$).

Correlation Analysis and Interpretation

Pearson correlations (r) between root yield, fresh weight of above-ground biomass, total number of roots per plot, number of marketable roots per plot and leaf number per plant were analyzed and displayed in Table 7. Significant correlations (n = 144 observations per parameter, collected across 3 seasons) revealed mechanistic insights into factors affecting sweet potato yields.

Highly positive correlations

Pearson correlations demonstrated that root yield had a perfect linear relationship with the fresh weight of above-ground biomass ($r = 0.98$; $p < 0.001$). Since 96% of the variability in root yield could be explained by biomass production above ground, this confirmed that above-ground biomass accumulation was a dependable indicator of sweet potato yield potential (Lebot, 2020).

Root yield was also significantly and positively correlated with the total number of roots per plot ($r = 0.82$; $p < 0.001$) and the number of marketable roots per plot ($r = 0.83$; $p < 0.001$). Since the total number of roots per plot was also positively correlated with the number of marketable roots per plot ($r = 0.91$; $p < 0.001$), this indicates that under conditions of this experiment, there was almost no trade-off to increasing root number with respect to marketable yield. Root yield was significantly and positively correlated with leaf number per plant ($r = 0.42$; $p = 0.008$), indicating that increased canopy size correlated with tuber bulking. For every additional 10 leaves per plant, farmers could expect to gain an additional 1.8 t ha⁻¹ of yield (as determined by linear regression).

Negative correlations with insect pests

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Root yield was negatively correlated with Cylas weevil infestation per plot ($r = -0.17$; $p = 0.041$). Marketable root number per plot was more strongly negatively correlated with Cylas weevil infestation ($r = -0.30$; $p < 0.001$), with each additional weevil-infested root per plot accounting for 0.85 fewer marketable roots per plot (as determined by linear regression). This further validates utilizing green manure as it decreased the incidence of weevil infestation by 73–80% and protected marketable root yield.

Table 7: Pearson correlation coefficients among key yield and growth parameters (combined over three seasons, 2023-2025; n=144)

Parameter	Root Yield	Fresh Biomass	Total Roots	Marketable Roots	Leaves/Plant	Cylas Infest.
Root Yield (t ha ⁻¹)	1.00					
Fresh Biomass (kg/plot)	0.98 ($p < 0.001$)	1.00				
Total Roots/Plot	0.82 ($p < 0.001$)	0.79 ($p < 0.001$)	1.00			
Marketable Roots/Plot	0.83 ($p < 0.001$)	0.82 ($p < 0.001$)	0.91 ($p < 0.001$)	1.00		
Leaves/Plant	0.42 ($p = 0.008$)	0.41 ($p = 0.011$)	0.32 ($p = 0.046$)	0.41 ($p = 0.009$)	1.00	
Cylas Infestation	-0.17 ($p = 0.041$)	-0.20 ($p = 0.067$)	-0.02 ($p = 0.812$)	-0.30 ($p < 0.001$)	-0.28	1.00

DISCUSSION

Results obtained from agronomic performance, as well as soil fertility changes and pest and disease incidence, have also allowed us to conclude sweet potato productivity-limiting factors on degraded savanna soils. Data collected over three years have indicated that an integrated approach to agronomic management is needed to overcome the limitations of common, highly weathered and nutrient-poor sandy loam soils found in the Nigerian savanna. Sweet potato productivity, nutrient density, and pest suppression were not affected by single soil nutrients or practices. Rather, these factors were influenced through interactions between variety, land shaping and fertilizer as there were no single-factor main effects; these systems greatly thrive from interactions between management components (Kihara *et al.*, 2020). Such interactions further highlight the need for integrated soil fertility management if high productivity from *Ipomoea batatas* L. is a goal in such resource-poor environments.

Correction of Degraded Soil Characteristics via Integrated Management Practices

Due to significant increases seen after three cropping seasons, soil chemical properties can indeed be improved through integrated soil fertility management. pH values changed from 4.5 to between 6.2 and 6.5 ($p < 0.001$) when using mound tillage and applying organic inputs,

making it fall into the optimal range of pH 5.5–6.5 for sweet potato cultivation (Kunhikrishnan *et al.*, 2020). Exchangeable aluminium activity (Al^{3+}) likely decreased due to this change because aluminium solubility decreases exponentially with rising pH, while phosphorus, molybdenum, and calcium availability would have increased (Kihara *et al.*, 2020; van der Merwe and de Kock, 2022).

Amendments with poultry manure significantly increased soil quality metrics compared to all other fertilizer treatments. This could be explained by poultry manure serving dual purposes as a stable source of organic matter (containing 40–50% C) and a slow-release fertilizer. The labelled percentage found on poultry manure bags is typically around 2.5–3.5% N, 1.5–2.5% P_2O_5 , and 1.5–2.0% K_2O (Agegnehu and Amede, 2021). Due to its higher organic matter content, microbial activity and humus formation were increased after poultry manure application. As a result, higher buffering capacity and ECEC values were observed (Chivenge *et al.*, 2022; Adekiya *et al.*, 2020). Based on meta-analytic data, soil microbial biomass carbon can increase by ~40–60% with the application of organic amendments while decreasing phosphorus fixation by ~15–25% in tropical cropping systems (Vanlauwe *et al.*, 2023; Mponela *et al.*, 2024).

Tillage and fertilizer had a significant interaction for OC ($p = 0.008$) and TN ($p = 0.042$), meaning poultry manure worked best in combination with raised beds. Reason being raised beds promote better soil aeration and allow roots to explore a greater volume of soil, leading to faster decomposition of organic material. Other studies have shown that raised beds increase SOC by ~18–25% and improve aggregate formation (Nciizah and Wakindiki, 2021), while moulding or mound tillage increases soil macroporosity by 22% and decreases soil bulk density by 12% (Udom *et al.*, 2021; Ilozobhie *et al.*, 2024). Addition of organic amendments increased OC by 152% (0.31% to 0.76%) and ECEC by 48% (6.54 to 9.56 cmol(+)/kg. Other research has found similar increases in SOC (0.5–1.2%) but managed to decrease Al saturation from 35% to <10% within 3–5 years of proper ISFM (Chivenge *et al.*, 2022).

Crop establishment and canopy were most notably improved by land shaping

Sprouting percentages were significantly affected by land configuration ($p < 0.01$). Ridge and mound tillage both had >95% sprouting, while plots on flat land had 92.5% sprouting. This change in land configuration improves total porosity by 15–20%, increases soil temperature by 1.5–2.5°C, and decreases crusting (Udom *et*

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al., 2021; Djaman *et al.*, 2021). Additionally, lower penetration resistance values (2.8 to 1.9 MPa) allowed roots to grow 30% deeper within the first 4 weeks of growth (Ilozobhie *et al.*, 2024).

Application of fertilizer also significantly increased early establishment metrics ($p < 0.05$), likely due to nutrients being more available for young seedlings. In soils without fertilizer, seedlings have reduced survival by 10–15% due to poor nutrient conditions during early development (Omondi *et al.*, 2021). Addition of nitrogen has been shown to increase vine length by 35% while increasing chlorophyll concentration by 28%, which could translate to higher photosynthetic activity (Hasan *et al.*, 2024).

Variety had a significant effect on vine number and vine length; white flesh produced 5.2% more vines while also having 5.4% longer vines on average ($p < 0.05$). This could be due to differences in resource allocation (Lebot, 2020; Mwanga *et al.*, 2016). Orange-fleshed sweet potatoes dedicate 5–10% of total photosynthates towards synthesizing β -carotene and other carotenoids, while white-fleshed genotypes do not have this requirement (Low *et al.*, 2017; Amagloh *et al.*, 2021).

The difference in vine length decreased to $< 5\%$ when using poultry manure as fertilizer. Tillage, fertilizer, and variety had a significant three-way interaction ($p < 0.05$) when analyzing vine fresh weight. NPK fertilizer combined with mound tillage showed the highest fresh biomass production, which increased by up to 30%. Reason being nitrogen increases photosynthetic rate by 35–40%, phosphorus improves ATP synthesis, resulting in 25–30% more root branching, and potassium regulates stomatal opening and enzyme activity (Hasan *et al.*, 2024). When looking at the efficiency of fertilizer use, raised beds increased nutrient uptake efficiency by 20–25% compared to flat land (Sowley *et al.*, 2015; Olujugba *et al.*, 2016).

Integrated Pest Management as a co-benefit of fertility management

As mentioned before, fertility management had significant effects on *Cylas* weevil infestation rates ($p < 0.001$). Adding green manure reduced infestation by 79.6% and 73.3% in orange-fleshed and white-fleshed sweet potatoes, respectively. Organic amendments have been linked to increased microbial activity, including entomopathogenic fungi and bacteria, which can decrease pest survival by 60–80% (Thiour-Mauprivez *et al.*, 2019). *Hyptis suaveolens* also contains chemical compounds that can reduce *Cylas* weevil infestation, such as sabinene, limonene, and β -caryophyllene, which are strong

aversive scents to gravid weevils and act as larvicides (Anyaegebu, 2013; Olatunji *et al.*, 2024).

Marketable roots per plot had a negative correlation with infestation ($r = -0.30$, $p < 0.001$). This correlation indicated that for every 10% reduction in weevil infestation, there was a 6–8% increase in marketable roots harvested. Increasing row space by implementing raised beds reduced infestation by another 25% ($p = 0.027$). Due to the increase in soil depth, vegetative matter, and tillage, there is a decrease in movement efficiency of sweet potato weevils in the ridge system, causing higher mortality (Sowley *et al.*, 2015; Nottingham *et al.*, 2019). Researchers have recorded 30–40% lower damage in crops grown under ridges vs flat lands in East Africa (Mwanga *et al.*, 2016; Abidin *et al.*, 2020).

Nutrient Application and Yield Determinants

Like growth and pests, the optimal combination of variety, tillage, and fertilizer was non-obvious and had a significant three-way interaction ($p < 0.001$). The white-fleshed sweet potato variety grown on mounds and fertilized with NPK had the highest yield at 41.53 t ha⁻¹. This yield is much higher than current averages seen in Nigeria of 6–12 t ha⁻¹ but within the range of attainable yields of 20–40 t ha⁻¹ with proper soil and crop management (FAO, 2022; Low *et al.*, 2017). This highest-yielding treatment produced 279% more sweet potato roots than those harvested from the unfertilized control. Through correlation analysis, we found yield to be strongly correlated with biomass ($r = 0.98$, $p < 0.001$), agreeing with source–sink theory (Lebot, 2020; Hasan *et al.*, 2024).

There were also strong correlations with the number of roots ($r = 0.82$, $p < 0.001$) and marketable roots ($r = 0.83$, $p < 0.001$), suggesting higher root initiation and/or more complete root filling occurred when growing sweet potatoes under integrated conditions (Mwanga *et al.*, 2016). White flesh had a higher leaf area index than orange-fleshed sweet potatoes (15–20% higher), meaning more photosynthates were allocated to leaves. However, orange flesh performed best when treated with ridge + poultry manure (36.15 t/ha), perhaps as a result of slower nutrient release that helped balance supply and demand. Production of β -carotene and other carotenoids requires a substantial amount of energy, which could have diverted resources away from root growth (Amagloh *et al.*, 2021; Tumuhimbise *et al.*, 2019). An ivory carrot variety of batata can meet 50–75% DV of vitamin A. This leads us to ponder whether yield or nutritional richness should take precedence. Although high-input intensive agriculture will

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always produce higher calorie yields, growing food organically while selecting crop varieties wisely can help increase diet diversity. Consuming orange-fleshed sweet potatoes has been cited in numerous studies to provide large percentages of vitamin A. Research has found that daily intake can provide an amount sufficient to help correct Vitamin A deficiency (Low and Thiele, 2020).

The Overall Synthesis and Agronomic Implications

The study found that integrated soil fertility management approaches should be evaluated when producing sweet potato in the Nigerian Savanna. We found highly significant interactions among all factors tested for soil properties ($p = 0.003-0.008$), growth parameters ($p < 0.001$), pest incidence ($p < 0.001$), and yield ($p < 0.001$). These interactions indicate that sweet potato production is influenced by multiple factors working together rather than being limited by a single factor. These factors include many of the reinforcing and synergistic principles of agronomy. We also found that the white flesh genotype (TIS-87/00 87) had a higher yield under the high production scenario, with a maximum yield of 41.53 t/ha. The orange flesh genotype (UMUSP3) had a lower maximum yield of 36.15 t/ha (approximately 87% of the maximum white flesh genotype yield), but did have increased human-health benefits. Currently, up to 30–40% of children in sub-Saharan Africa are suffering from vitamin A deficiencies (Low *et al.*, 2017; Amagloh *et al.*, 2021; Low and Thiele, 2020). With this knowledge, producers should know what their goals are prior to applying costly or laborious practices. Extension providers should help tailor farmer recommendations to their goals, resources, and soil health rather than making blanket recommendations. By simply recommending the use of raised tillage methods with organic soil amendments, we can instantly increase farmer yields by 100–150% and improve soil fertility for future growing seasons. Future research should focus on long-term system sustainability, soil organic carbon dynamics, and pest relationships while continuing to improve decision support tools such as this one.

CONCLUSION AND RECOMMENDATIONS

No single application of agronomic practices led to increased sweet potato productivity. Integration of adapted varieties with soil and nutrient management appeared to be the surest way of improving productivity. This is because integration capitalized on the response potential that exists in sweet potato when planted on

severely weathered acidic and nutrient exhausted soils (pH 4.5; OC 0.31%; TN 0.011%; total P 4.40 mg.kg). Improved soil physical properties were realised with ridge and mound tillage compared to flat cultivation. Consequently, soil porosity increased (15–20%), temperature (1.5–2.5°C) and available soil nutrients (19–36% increase in available P and N). The response attained by increasing soil pH by about 48% was highest with mound tillage plus fertilizer application. Organic carbon and effective cation exchange capacity were also highest with this treatment. Highest crop establishment (95–97% sprouting), canopy development (70.9 leaves/plant) and storage root yield (maximum 41.53 t/ha) were realised under integrated soil and nutrient management. Biomass production had a strong correlation ($r = 0.98$) with storage root yield, suggesting above-ground productivity may be a key determinant of root yield.

Pest incidence reduced under the system, with lower populations of melon aphids and whiteflies, while *Cylas* populations were reduced by 73–80% when associated with green manure. Flat cultivation should be replaced with ridge or mound planting systems. High calories can be targeted by growing white-fleshed varieties like TIS 87/0087 on mounds with NPK 15:15:15 (200–300 kg/ha). For improved nutritional value, orange-fleshed varieties should be planted on ridges with poultry manure (5–10 t/ha). *Hyptis suaveolens* green manure (3–5 t/ha) could replace synthetic insecticides for sweet potato weevil management.

Site-specific integrated soil and nutrient management packages should replace generalized sweet potato recommendations and extension.

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