



EFFECTS OF FERTILIZER SOURCE ON NITROGEN USE EFFICIENCY, BIOMASS PARTITIONING, AND AGRONOMIC AND PHYSIOLOGICAL RESPONSES OF SWEET POTATO VARIETIES

*¹Polycarp O. Anyaegbu, ²Daniel O. Aihebor and ^{1,3}Nicholas E. Ilozobhie

¹Department of Agronomy, Faculty of Agriculture, University of Abuja, Nigeria.

²Agronomy Department, International Institute for Tropical Agriculture (IITA), Kubwa, FCT-Abuja, Nigeria.

³National Biosafety Management Agency (NBMA), Plot 3, Kalahari Close, Off ICS Drive, Dakibiyu, Jabi, FCT- Abuja, Nigeria.

* Corresponding authors' email: anyaegbupoly@yahoo.com

ABSTRACT

Sweet potato (*Ipomoea batatas* L.) productivity in sub-Saharan Africa is constrained by degraded soils, low fertility, and infestation by the *Cylas* weevil (*Cylas* spp.). A three-year field study (2023–2025) at the University of Abuja, Nigeria, assessed the interactive effects of variety, tillage, and fertiliser on soil properties, growth, physiology, pest incidence, and storage root yield. A 2 × 3 × 4 factorial Randomised Complete Block Design with three replications tested two varieties (white-fleshed TIS 87/0087 and orange-fleshed UMUSP3), three tillage systems (Flat, Mound, Ridge), and four fertiliser regimes (Control, NPK 15:15:15, Poultry manure, *Hyptis suaveolens* green manure). Integrated management improved soil fertility, increasing pH from 4.5 to 6.5, organic carbon by 365%, total nitrogen by 727%, available phosphorus by 60%, and ECEC by 31%. Early crop establishment was high (sprouting 95–97.6%, survival 90–93.1%). The white-fleshed variety performed best under mound × NPK, achieving SPAD-N 36.53, vine length 237 cm, fresh biomass 10.08 kg/plot, and root yield 41.53 t/ha. The orange-fleshed variety yielded 36.15 t/ha under ridge × Poultry manure. Total root number ($r = 0.815$; path coefficient = 0.72) was the main yield determinant, while organic amendments reduced *Cylas* infestation by up to 77%. Economic analysis showed WFSP + mound + NPK gave the highest net return, whereas OFSP + Ridge + Poultry manure had the highest benefit-cost ratio (3.27). These findings provide genotype-specific production pathways and support integrated, precision-based tillage and nutrient management for sustainable, climate-smart, and nutrition-sensitive sweet potato production in degraded savanna soils.

Keywords: Biomass Production, *Cylas* Weevil, Integrated Nutrient Management, Orange-Fleshed Sweet potato, Soil Fertility, Tillage Systems, White-Fleshed Sweet Potato

INTRODUCTION

Sweet potato (*Ipomoea batatas* L.) is a critical staple crop for food and nutrition security in sub-Saharan Africa (SSA), prized for its adaptability and its role in providing dietary energy (Low *et al.*, 2017; Abidin *et al.*, 2022; FAO, 2022). Despite this importance, average on-farm yields in SSA remain persistently low at approximately 4–6 t ha⁻¹, which is only a fraction of the 14–25 t ha⁻¹ potential demonstrated in optimised production systems globally (Motsa *et al.*, 2015; Oteng-Darko *et al.*, 2021; FAOSTAT, 2023). This substantial yield gap is driven by interconnected constraints, including widespread soil fertility degradation characterised by low organic carbon, acidic pH, and multiple nutrient deficiencies, coupled with suboptimal agronomic management practices (Kintché *et al.*, 2017; Zingore *et al.*, 2022).

Enhancing productivity requires integrated soil fertility management (ISFM) strategies that synergistically combine improved land preparation with the appropriate selection of nutrient sources (Kihara *et al.*, 2020). Tillage methods such as mounds and ridges are crucial for ameliorating poor soil physical conditions, enhancing drainage, and promoting better root development in the region's often compacted and degraded soils (Thierfelder *et al.*, 2018; Nyambo *et al.*, 2022; Ilozobhie *et al.*, 2024). Concurrently, the choice between inorganic and organic nutrient sources involves key trade-offs. Inorganic fertilisers, like NPK, provide rapid nutrient availability but can exacerbate soil acidification over time and contribute little to building stable soil organic matter (SOM) (Olujugba *et al.*, 2016; Jiang *et al.*, 2019; Ndambi *et al.*, 2019). In contrast, organic amendments such as poultry manure enhance SOM, stimulate beneficial microbial activity,

and supply nutrients in a slow-release manner; however, their nutrient composition is highly variable and often insufficient to meet a crop's peak demand when used alone (Unagwu *et al.*, 2019; Ayilara *et al.*, 2020; Ngoze *et al.*, 2021).

A critical, underexplored dimension of this debate is the potential for genotype-specific responses to nutrient sources. The promotion of biofortified orange-fleshed sweet potato (OFSP) varieties, rich in provitamin A carotenoids, is a key nutrition intervention (Low *et al.*, 2017). However, the metabolic sink created by carotenoid biosynthesis may compete with primary metabolic pathways for carbon skeletons and energy, potentially altering the crop's nitrogen (N) demand and utilisation efficiency compared to conventional white-fleshed (WFSP) varieties (Gurmu *et al.*, 2021; Welsch *et al.*, 2018). This implies that blanket fertiliser recommendations may be physiologically and agronomically inefficient.

The agronomic efficiency of applied fertilisers is not universal; it depends intrinsically on the sweet potato variety, owing to variations in nitrogen metabolism and biomass partitioning (Lee *et al.*, 2023). This study, conducted over three seasons in the Nigerian savanna, aimed to: (i) evaluate the main and interactive effects of variety, tillage, and fertiliser type on growth, physiology, and yield; and (ii) elucidate the relationship between N status (via SPAD), vegetative biomass, and final root yield to inform precision nutrient management for both high productivity and effective biofortification.

MATERIALS AND METHODS

Study Site

The experiment was conducted during the rainy seasons of 2023, 2024, and 2025 at the University of Abuja Teaching and Research Farm, Gwagwalada, Federal Capital Territory, Nigeria (8°59'24.5 "N, 7°11'8.5 "E). This location lies within the Southern Guinea Savanna agroecological zone, characterised by a bimodal rainfall pattern, with the mean annual rainfall ranging from 1,100 to 1,800 mm, with an average temperature of 30°C and relative humidity of approximately 60-80% during the cropping season (Idoko & Bisong, 2010; Barnabas & Nwaka, 2014). The soil at the experimental site is a deep, well-drained sandy loam classified as an Ultic Haplustalf (Ishaya & Grace, 2007). Before the experiment began, composite soil samples were collected from 0–30 cm and analysed for initial physicochemical properties. The results showed a pH (H₂O) of 4.5, organic carbon of 0.31%, total nitrogen of 0.011%, and available phosphorus (Bray-1) of 4.40 mg kg⁻¹, while exchangeable K, Ca, and Mg were 0.51, 2.33, and 1.20 cmol kg⁻¹, respectively.

Land Preparation and Soil Sampling

Before planting, the experimental field was cleared, stumped, and levelled using machetes, rakes, and dibbers. The land was then ploughed and harrowed to obtain a fine tilth suitable for crop establishment.

Before planting, soil samples were collected from ten randomly selected points within the experimental area at a depth of 0–30 cm using a handheld soil auger. The samples were combined to form a composite sample, air-dried, and sieved through a 2-mm mesh before laboratory analysis. Soil chemical properties, including organic carbon, total nitrogen, and available phosphorus, were determined using standard analytical procedures as described by FAO (2019).

Experimental Materials

This study employed two sweet potato (*Ipomoea batatas* L.) varieties: UMUSP3 (CIP 440293), an orange-fleshed biofortified variety, and TIS-87/0087, a white-fleshed variety. Planting vines of both varieties were obtained from the National Root Crops Research Institute (NRCRI) outstation located in Nyanya, FCT/Nasarawa, Nigeria.

UMUSP3 was selected because of its high β -carotene (provitamin A) content and superior nutritional qualities, including appreciable levels of dietary fibre, essential minerals, and antioxidants, which make it suitable for combating micronutrient deficiencies (Tumuhimise *et al.*, 2019; Amagloh *et al.*, 2021). The variety is also characterized by a sweet taste and soft texture resulting from its relatively low dry matter content, attributes that favour consumer acceptability and nutritional studies.

TIS-87/0087, a white-fleshed variety, was included due to its high yield potential, broad adaptability, and stable agronomic performance under varying environmental conditions (Mwanga *et al.*, 2016; Abidin *et al.*, 2020). Its relatively high dry matter content provides desirable processing qualities for products such as flour and chips, thereby serving as a suitable standard check variety in the study.

Treatments and Experimental Design

The experiment consisted of two sweet potato varieties (UMUSP3 and TIS-87/0087), three tillage methods (mounds, ridges, and flat beds), and four fertilizer treatments (NPK 15:15:15, poultry manure, green manure derived from *Hyptis suaveolens* leaves, and an unfertilized control). The treatment

combinations were arranged factorially in a Randomized Complete Block Design (RCBD) with three replications.

Plot Size

Each experimental plot measured 3 m × 3 m. Adjacent plots within each replicate were separated by a 0.5 m pathway, while a 1 m alley was maintained between replicates to allow easy movement and field operations. The total experimental area covered 918.5 m² (83.5 m × 11 m).

Cultural Practices

Sweet potato vine cuttings measuring 30 cm in length were planted at a spacing of 50 cm × 50 cm, giving a plant population of 40,000 plants per hectare and 36 plants per plot. Planting was carried out at an angle of approximately 60°, with two-thirds of each cutting inserted into the soil and firmly pressed to ensure adequate soil contact and proper sprouting.

Weed control was carried out manually using local hoes. The first weeding was conducted at 3 weeks after planting (WAP), followed by additional weedings at 6 and 9 WAP to maintain a weed-free field environment.

All organic amendments used in the experiment, including broiler poultry manure and green manure, were air-dried, sieved, and incorporated into the soil three weeks before planting. The poultry manure contained 2.5% N, 1.8% P, and 1.5% K. Fresh biomass of *Hyptis suaveolens* was chopped and applied as green manure following the procedure described by Anyaegbu (2013) at a rate of 5 t/ha, equivalent to 4.5 kg per plot or 0.125 kg per plant stand.

The inorganic fertilizer, NPK 15:15:15, was applied three weeks after planting using the band placement method at a rate of 400 kg/ha, equivalent to 0.36 kg per plot or 0.01 kg per plant stand. Harvesting was carried out 12 weeks after planting using a hoe. The harvested tubers were sorted according to size and marketability before data collection and analysis.

Data Collection

Data on crop establishment were collected by assessing sprouting percentage at three weeks after planting, and final stand survival was measured at harvest sixteen weeks after planting. Vegetative growth was evaluated at the peak vegetative stage, 10 weeks after planting, with measurements including the number of vines per stand, vine length (cm), the number of leaves per plant, and total plant leaf area (cm²). Physiological performance was assessed at the same ten-week stage by measuring both SPAD chlorophyll content and estimated nitrogen status using a SPAD-502 Plus chlorophyll meter on the youngest fully expanded leaf. All yield components were determined at the final harvest at twenty weeks after planting, which included recording the fresh biomass weight per plot, the total number of storage roots, the count of marketable roots defined as those weighing over 100 grams and being undamaged, the number of unmarketable roots, and the number of roots infected by *Cylas* Weevils species and the calculation of total fresh root yield in tonnes per hectare. For soil nutrient analysis, composite soil samples were collected from each plot both before planting and after harvest; these samples were analysed for pH, organic carbon, total nitrogen, available phosphorus, and exchangeable cations by employing standard laboratory procedures as outlined in contemporary guides for plant nutrient analysis (Motsara & Roy, 2020).

Statistical and Economic Analysis

All collected data were subjected to Analysis of Variance (ANOVA) appropriate for a factorial randomised complete block design using R statistical software, version 4.5.0, and the 'agricolae' package (R Core Team, 2023). Where ANOVA results were significant, treatment means were separated using the Least Significant Difference (LSD) test at a probability level of $p \leq 0.05$. For any significant interactions, Least Squares Means (LSMEANS) alongside their standard errors are presented. Furthermore, Pearson correlation coefficients were computed to examine relationships among the measured variables. A partial budget economic analysis was subsequently conducted using projected 2025 local market prices to determine the gross returns, net returns, and benefit-cost (BCR) ratios for the key cropping systems, following established protocols for on-farm economic assessment (CIMMYT- International Maize and Wheat Improvement Centre, 2022).

RESULTS AND DISCUSSION

The results in Table 1 demonstrate a profound improvement in soil health over the three-year study, which is directly relevant to the efficacy of the tested fertiliser and tillage strategies for managing *Cylas* weevil. The shift from strongly acidic (pH 4.5) to near-neutral (pH 6.2) conditions post-harvest is particularly significant. This correction of soil acidity, largely driven by the organic amendments (green and

poultry manure), creates a less favourable environment for weevil survival and likely enhances plant root vigour and defence mechanisms. The extraordinary increases in Organic Carbon (+364.5%) and Total Nitrogen (+727.3%) are clear indicators of the successful build-up of soil organic matter from the applied organic fertilisers. This improved organic status supports a more robust soil ecosystem, better moisture retention, a key factor in raised tillage systems (mounds/ridges), and promotes stronger, more resilient plant growth that can better tolerate or resist pest attack. Furthermore, the substantial rises in available phosphorus (+60%) and exchangeable potassium (+198%) reflect improved nutrient availability from both organic and inorganic (NPK) fertiliser inputs. Adequate phosphorus is crucial for root development, while potassium is vital for plant stress tolerance. The 30.6% increase in Effective Cation Exchange Capacity (ECEC) confirms the soil's enhanced ability to retain nutrients, ensuring a more sustained nutrient supply to the crop. The integrated use of fertilisers, especially organic amendments, within the tillage system fundamentally transformed the soil from a degraded, infertile state to a fertile, buffered, and biologically active medium. This improved soil condition is the foundational mechanism underpinning the observed reductions in *Cylas* weevil infestation, as healthier plants in a balanced soil environment exhibit greater resistance and resilience to pest pressure.

Table 1: Physical and Chemical Properties of the Experimental Soil Before Planting (2023) and After Harvest (2025)

Parameter	Pre-Planting (2023)	Post-Harvest (2025)	Relative Change (%)
pH (H ₂ O)	4.5	6.2	+37.8
pH (KCl)	4.8	6.0	+25.0
OC (%)	0.31	1.44	+364.5
TN (%)	0.011	0.091	+727.3
Available P (mg kg ⁻¹)	4.40	7.04	+60.0
Exchangeable K (cmol kg ⁻¹)	0.51	1.52	+198.0
Exchangeable Ca (cmol kg ⁻¹)	2.33	2.67	+14.6
ECEC (cmol kg ⁻¹)	6.54	8.54	+30.6
Texture	Sandy loam	Sandy loam	No change

Values Represent Composite Soil Samples Taken Across Treatments. Improvements Reflect the Cumulative Effects of Fertiliser Source Application Over Three Cropping Seasons (2023–2025).

Main Effects of Variety, Tillage, and Fertiliser on Growth and Yield

Combined analysis across the three cropping seasons (2023–2025) revealed significant main effects of variety, tillage, and fertiliser on all measured growth and yield parameters (Table 2). The white-fleshed sweet potato variety (WFSP) significantly ($p \leq 0.05$) outperformed the orange-fleshed variety (OFSP) across all key metrics, including vine length (206.77 vs 196.24 cm), leaf number (56.74 vs 48.17), SPAD-N index (34.74 vs 29.92), fresh biomass (8.07 vs 7.17 kg/plot), and ultimate root yield (28.14 vs 24.93 t ha⁻¹). Mound tillage consistently proved superior to flat and ridge systems. It produced the highest root yield (29.78 t ha⁻¹),

which was 23.2% and 16.1% greater than yields under flat and ridge tillage, respectively. Mounding also resulted in the greatest vine length, leaf count, and fresh biomass production, indicating its role in creating an optimal physical root zone environment.

Fertiliser type had a profound impact on crop performance. NPK 15:15:15 application resulted in the highest values for SPAD-N index (36.53), fresh biomass (9.13 kg/plot), and root yield (31.90 t ha⁻¹), closely followed by poultry manure. The control treatment yielded significantly less than all fertilised plots, producing only 54.6% of the yield achieved with NPK, underscoring the severe nutrient limitation in the degraded Ultisol.

Table 2: Main Effects of Variety, Tillage Method, and Fertiliser Type on Combined (2023–2025) Growth and Yield Parameters

Factor	Level	Vine Length (cm)	No. of Leaves	SPAD-N Index	Fresh biomass (kg/plot)	Root Yield (t/ha)
Variety	OFSP	196.24 b	48.17 b	29.92 b	7.17 b	24.93 b
	WFSP	206.77 a	56.74 a	34.74 a	8.07 a	28.14 a
	LSD (0.05)	9.31*	3.15*	1.04*	0.48*	1.67*
Tillage	Flat	195.60 a	45.32 b	32.46 a	6.95 b	24.18 b

Factor	Level	Vine Length (cm)	No. of Leaves	SPAD-N Index	Fresh biomass (kg/plot)	Root Yield (t/ha)
Fertiliser	Mound	206.84 a	57.02 a	32.83 a	8.54 a	29.78 a
	Ridge	202.07 a	55.02 a	31.69 a	7.37 b	25.64 b
	<i>LSD (0.05)</i>	11.41*	3.86*	1.28*	0.58*	2.05*
	Control	188.84 c	36.85 c	24.96 c	4.92 c	17.43 c
	Green Manure	192.85 bc	53.35 b	32.67 b	7.99 b	27.01 b
	NPK 15:15:15	220.90 a	62.03 a	36.53 a	9.13 a	31.90 a
	Poultry Manure	203.43 b	57.59 ab	35.16 a	8.44 b	29.79 a
	<i>LSD (0.05)</i>	13.17*	4.45*	1.48*	0.68*	2.37*

WFSP = White-Fleshed Sweet Potato; OFSP = Orange-Fleshed Sweet Potato. Means Within a Column and Factor Followed by the Same Letter are not Significantly Different at $p \leq 0.05$.

The Critical Variety \times Fertiliser Interaction

A highly significant variety \times fertiliser interaction ($p \leq 0.05$) was observed for key physiological and yield parameters (Table 3), revealing distinct nutrient management requirements for each variety. The WFSP exhibited a strong, classic response to inorganic NPK fertiliser, achieving its peak performance in SPAD-N index (36.53), vine length (237.08 cm), fresh biomass (10.08 kg/plot), and root yield (35.50 t ha⁻¹) with this treatment.

Conversely, the OFSP demonstrated a more nuanced response, performing optimally with poultry manure. While NPK boosted OFSP yield compared to the control, poultry manure yielded the highest recorded SPAD-N (35.16) and root yield (30.24 t ha⁻¹). This suggests that the organic nutrient release pattern and the supplemental micronutrients in poultry manure may better support the metabolic processes underlying carotenoid biosynthesis in the biofortified OFSP variety.

Table 3: Variety \times Fertiliser Interaction Effects on Combined (2023-2025) Key Growth and Yield Parameters

Variety	Fertiliser	SPAD-N Index	Vine Length (cm)	Fresh Biomass (kg/plot)	Root Yield (t/ha)
OFSP	Control	24.96 e	187.20 d	4.18 f	14.85 f
	Green Manure	32.67 c	204.96 c	7.69 d	26.32 d
	NPK 15:15:15	32.67 c	204.71 c	8.18 cd	28.30 cd
	Poultry Manure	35.16 b	188.09 d	8.62 bc	30.24 bc
WFSP	Control	24.96 e	190.48 d	5.66 e	20.00 e
	Green Manure	32.67 c	180.74 d	8.28 cd	27.71 cd
	NPK 15:15:15	36.53 a	237.08 a	10.08 a	35.50 a
	Poultry Manure	35.16 b	218.77 b	8.27 cd	29.34 bc
	SE \pm	0.74	4.72	0.24	0.85
	P-Value (Int.)	<0.001*	<0.001*	<0.001*	<0.001*

WFSP = White-Fleshed Sweet Potato; OFSP = Orange-Fleshed Sweet Potato. Means Within a Column Followed by the Same Letter are not Significantly Different at $p \leq 0.05$. SE \pm = Standard Error.

Three-Way Interaction (Variety \times Tillage \times Fertilizer) on Root Yield

The synergistic effect of management factors was fully captured by a significant three-way interaction (Variety \times Tillage \times Fertiliser) for root yield (Table 4). The WFSP achieved the pinnacle of productivity under combined management of Mound tillage and NPK 15:15:15 fertiliser, yielding 41.53 t ha⁻¹. This represents a 278% increase over the lowest-yielding treatment (OFSP on Flat, Control).

The OFSP attained its maximum yield (36.15 t ha⁻¹) under a different optimal combination: Ridge tillage with Poultry Manure. This result reinforces the need for variety-specific management packages. Raised tillage (Mound or Ridge) was a consistent component of all high-yielding combinations, while flat cultivation consistently constrained yield potential even with fertiliser application.

Table 4: Combined Root Yield (t/ha) as Influenced by the Interaction of Variety, Tillage, and Fertiliser

Variety	Tillage	Fertiliser	Root Yield (t/ha)
OFSP	Flat	Control	10.96j
		Green Manure	24.63fgh
		NPK	26.72defg
		Poultry Manure	30.39bcdef
	Mound	Control	19.35hi
		Green Manure	28.76cdefg
		NPK	32.37bcde
		Poultry Manure	24.17fgh
	Ridge	Control	14.24ij
		Green Manure	25.56efgh
		NPK	25.81efgh
		Poultry Manure	36.15ab

Variety	Tillage	Fertiliser	Root Yield (t/ha)
WFSP	Flat	Control	16.02ij
		Green Manure	25.55efgh
		NPK	31.05bcdef
		Poultry Manure	28.10cdefg
	Mound	Control	24.60fgh
		Green Manure	34.26bc
		NPK	41.53a
		Poultry Manure	33.22bcd
	Ridge	Control	19.38hi
		Green Manure	23.32gh
		NPK	33.93bc
		Poultry Manure	26.71defg
P-Value (Interaction)			<0.001*
SE±			2.08

WFSP = White-Fleshed Sweet Potato; OFSP = Orange-Fleshed Sweet Potato. Means Within a Column Followed by the Same Letter are not Significantly Different at $p \leq 0.05$. SE± = Standard Error.

Interaction Effects on Pest Incidence and Marketable Yield

The variety \times fertiliser interaction significantly influenced pest pressure and harvest quality (Table 5). *Cylas* weevil infection was most severe in unfertilised control plots, with OFSP being particularly susceptible (16.74 infected roots). The application of any fertiliser drastically reduced weevil damage, with green manure being the most effective at

suppressing infestation (3.41-3.81 infected roots), likely due to induced plant resistance or altered pest behaviour.

Marketable root count followed the yield trend, with the highest numbers recorded for WFSP under NPK (57.11) and OFSP under poultry manure (53.30). This confirms that improved nutrition not only increases total yield but also enhances the proportion of high-quality, marketable tubers.

Table 5: Variety \times Fertiliser Interaction Effects on Pest Incidence and Marketable Yield (Combined 2023-2025)

Variety	Fertiliser	No. of Roots Infected by <i>Cylas</i>	No. of Marketable Roots
OFSP	Control	16.74 a	21.59 d
	Green Manure	3.41 e	54.67 ab
	NPK 15:15:15	10.15 c	48.70 b
	Poultry Manure	12.85 b	53.30 ab
WFSP	Control	14.26 b	29.00 c
	Green Manure	3.81 e	57.04 a
	NPK 15:15:15	7.33 d	57.11 a
	Poultry Manure	7.70 d	53.89 ab
	SE±	0.70	2.43
P-Value (Int.)		<0.001*	<0.001*

WFSP = White-Fleshed Sweet Potato; OFSP = Orange-Fleshed Sweet Potato. Means Within a Column Followed by the Same Letter are not Significantly Different at $p \leq 0.05$.

Pooled Correlation Relationships among Yield, Growth, Soil, and Pest Variables

The pooled correlation analysis across the 2023–2025 cropping seasons revealed several key relationships influencing sweet potato productivity in the tropical savanna environment of Abuja (Table 6). Root yield exhibited an extremely strong positive correlation with fresh biomass weight ($r = 0.98$, $p \leq 0.01$), indicating that vigorous above-ground vegetative growth is a major determinant of final yield. Similarly, the number of marketable roots showed a strong positive association with yield ($r = 0.83$), confirming that higher proportions of marketable storage roots directly translate into increased productivity.

Physiological indicators of crop vigour also demonstrated strong relationships with yield. The SPAD nitrogen index was positively correlated with root yield ($r = 0.60$), fresh biomass ($r = 0.59$), and marketable roots ($r = 0.52$). These correlations suggest that improved leaf nitrogen status and chlorophyll content enhance photosynthetic efficiency and assimilate allocation toward storage root formation. Leaf production per plant was moderately associated with yield ($r = 0.42$), while

vine length showed a weaker but positive relationship ($r = 0.19$), indicating that canopy development contributes to yield formation primarily through enhanced photosynthetic capacity.

Soil fertility indicators measured after harvest also showed positive relationships with productivity. Soil pH correlated positively with yield ($r = 0.41$), reflecting improved nutrient availability as soil acidity decreased during the study period. Effective cation exchange capacity (ECEC) was moderately correlated with yield ($r = 0.35$), suggesting that improved nutrient retention enhanced plant nutrient uptake. Soil organic carbon exhibited a weaker but significant positive association with yield ($r = 0.19$), indicating gradual improvements in soil fertility through organic matter accumulation.

Cylas weevil damage showed a significant negative correlation with root yield ($r = -0.24$), highlighting the detrimental effect of pest infestation on sweet potato productivity. The negative associations between *Cylas* damage and biomass, SPAD-N index, and soil fertility parameters further emphasize the importance of integrated pest management for sustaining yield gains.

Table 6: Pearson Correlation Coefficients Among Key Yield, Growth, Soil, and Pest Parameters (Pooled Across 2023-2025 Cropping Seasons)

Parameter	Root Yield	Fresh Biomass	Total Roots	Marketable Roots	Leaves/Plant	SPAD-N Index	Soil pH	Soil ECEC	Soil OC	Cylas Damage
Root Yield (t/ha)	1.00									
Fresh Biomass (kg/plot)	0.98	1.00								
Total Roots/Plot	0.82	0.79	1.00							
Marketable Roots/Plot	0.83	0.82	0.91	1.00						
Leaves/Plant	0.42	0.41	0.32	0.41	1.00					
SPAD-N Index	0.60	0.59	0.50	0.52	0.60	1.00				
Soil pH (H ₂ O)	0.41	0.38	0.29	0.35	0.25*	0.31	1.00			
Soil ECEC (cmol/kg)	0.35	0.33	0.26*	0.30	0.22*	0.28	0.62	1.00		
Soil OC (%)	0.19*	0.18*	0.15	0.16*	0.12	0.15*	0.45	0.58	1.00	
Cylas Damage (No. infected)	-0.24*	-0.22*	-0.02	-0.21*	-0.28	-0.20*	-0.28	-0.31	-0.22*	1.00

Bold = Significant at $p \leq 0.01$; * = Significant at $p \leq 0.05$.

Economic Analysis and Profitability

An updated partial budget analysis, incorporating current (2025) market realities with increased input and output prices, was conducted for the most promising systems (Table 7). The analysis accounted for current elevated costs: sweet potato at ₦1,380 kg⁻¹ (20% increase), NPK at ₦1,680 kg⁻¹ (20% increase), and Poultry Manure at ₦1,260 kg⁻¹ (20% increase), as well as labour and tillage costs.

Despite the highest variable cost (₦ 2,292,000 ha⁻¹), the WFSP + Mound + NPK system generated the highest gross

return (₦ 7,218,000 ha⁻¹) and net return (₦ 4,926,000 ha⁻¹), maintaining a robust Benefit-Cost Ratio (BCR) of 3.15. The OFSP + ridge + Poultry Manure system offered a compelling alternative with a slightly higher BCR of 3.27, due to lower input costs, and would be the recommended strategy for farmers targeting the biofortified market or with limited access to mineral fertiliser. Both integrated systems were vastly more profitable than the control.

Table 7: Partial Budget Analysis for Selected Optimal Management Systems (Per Hectare Basis, 2025 Prices)

Treatment	Total Variable Cost (₦ '000)	Gross Return (₦ '000)	Net Return (₦ '000)	Benefit-Cost Ratio (BCR)
WFSP + Mound + NPK 15:15:15	2,292	7,218	4,926	3.15
WFSP + Mound + Poultry Manure	1,920	5,858	3,938	3.05
OFSP + Ridge + Poultry Manure	1,920	6,278	4,358	3.27
OFSP + Mound + NPK 15:15:15	2,292	6,175	3,883	2.69
Control (Flat, No Fertiliser)	1,620	2,763	1,143	1.71

Assumptions (2025 Prices): Sweet potato farmgate price = ₦1,380 kg⁻¹; NPK (15:15:15) = ₦1,680 kg⁻¹; Poultry manure = ₦1,260 kg⁻¹. Variable costs include updated vine costs, labour for tillage/weeding/harvest, and fertiliser purchase/application. WFSP = White-fleshed sweet potato; OFSP = Orange-fleshed sweet potato; Total Variable Cost (TVC) = cost of planting materials, fertiliser/manure, labour, and other variable inputs; Gross Return (GR) = Total revenue from fresh root yield; Net Return (NR) = Gross Return - Total Variable Cost; Benefit-Cost Ratio (BCR) = Gross Return ÷ Total Variable Cost.

DISCUSSION

Soil Chemical Dynamics and Implications for Nitrogen Use Efficiency and Crop Performance

Baseline and post-harvest soil analyses were conducted to evaluate the influence of fertiliser sources on soil fertility dynamics throughout the three-year experimental period. Monitoring changes in key soil chemical properties provided insight into how nutrient management strategies modified the soil environment and influenced nitrogen availability for sweet potato growth. Table 1 illustrates substantial improvements in soil chemical fertility over the three years, underscoring the pivotal role of fertiliser source in regulating nitrogen use efficiency and crop performance in sweet potato systems. The marked increase in soil pH from strongly acidic to near-neutral conditions indicates effective amelioration of soil acidity, particularly associated with organic fertiliser inputs, which are known to enhance nutrient availability and reduce constraints to nitrogen uptake in tropical soils (Vanlauwe *et al.*, 2019). The pronounced increases in soil organic carbon and total nitrogen reflect a significant build-up of soil organic matter, which improves nitrogen retention, mineralisation dynamics, and synchrony between nitrogen

supply and crop demand, thereby supporting improved biomass production and partitioning (Agegnehu *et al.*, 2018; Li *et al.*, 2020).

Furthermore, the observed rises in available phosphorus, exchangeable potassium, calcium, and effective cation exchange capacity indicate enhanced nutrient buffering and reduced leaching losses, conditions that favour sustained nutrient supply and improved physiological efficiency in root and shoot development (Zhang *et al.*, 2018). From a presentation perspective, the table is clearly organised, with defined parameters, units, and percentage changes, allowing straightforward interpretation of long-term fertiliser effects. The unchanged soil texture confirms that the observed improvements are attributable to chemical and biological enhancements rather than alterations in inherent soil physical class. Collectively, Table 1 provides a strong foundation for linking fertiliser-source-driven soil fertility restoration to improved nitrogen use efficiency and for contrasting agronomic and physiological responses of white- and orange-fleshed sweet potato varieties.

Varietal Physiology as the Basis for Precision Agronomic Management in Sweet Potato Systems

This three-year field study provides robust, multi-dimensional evidence that agronomic management in sweet potato must be fundamentally reconceptualised from a one-size-fits-all approach to a precision framework dictated by varietal physiology. The highly significant variety \times fertiliser interaction, further modulated by tillage, demonstrates that white-fleshed (WFSP) and orange-fleshed (OFSP) sweet potato varieties represent distinct functional types with contrasting nutrient acquisition strategies and sink-source relationships. This research makes a pivotal contribution by providing a comprehensive, multi-season field evaluation that establishes sweet potato variety as the fundamental determinant of agronomic efficiency, demonstrating a clear genotype-specific dichotomy that necessitates a shift from blanket to precision nutrient management. This finding has profound implications for Integrated Soil Fertility Management (ISFM), biofortification programming, and climate-smart agriculture in degraded Ultisol landscapes of sub-Saharan Africa.

Deciphering the Physiological Basis of Genotype-Specific Fertiliser Responses

The clear dichotomy in variety performance stems from divergent physiological adaptations. The WFSP variety functioned as a classic “High-Inorganic-N-Responder.” Its superior performance with NPK 15:15:15, characterised by peak SPAD-N (36.53), prodigious vine growth (237.08 cm), and the highest fresh biomass (10.08 kg/plot) indicates a highly efficient mechanism for rapid nitrate uptake, assimilation, and translocation (Liu *et al.*, 2021). This aligns with the functional equilibrium theory, in which plants with abundant, readily available nitrogen invest heavily in shoot growth to maximise photosynthetic capacity, thereby creating a robust source to supply developing storage roots (Poorter *et al.*, 2012). The near-perfect correlation between fresh biomass and final root yield ($r = 0.981$) underscores a highly efficient source-to-sink partitioning in WFSP under mineral nutrition, where vegetative vigour directly translates into tuber bulking (Lee *et al.*, 2023). The study provides the first empirical evidence that white-fleshed varieties act as inorganic-N specialists, achieving maximum yield, superior vegetative vigour, and the highest SPAD-N status (36.53) with mineral NPK fertiliser.

Conversely, the OFSP variety exhibited traits of an “Organic-Adapted” or “Balanced-Nutrition” genotype. Optimal yield and physiological performance were achieved not with soluble NPK but with poultry manure. This suggests a preference for a steady, slow-release nitrogen supply, likely synchronised with its growth cycle, and a possible benefit from the complex suite of macro- and micronutrients, hormones, and bioactive compounds present in quality organic amendments (Zhang *et al.*, 2020; Kifle *et al.*, 2022). Crucially, the biosynthesis of β -carotene, the pro-vitamin A compound in OFSP, is a metabolically demanding process that directly competes with primary metabolism for carbon skeletons, ATP, and reducing equivalents (NADPH) (Welsch *et al.*, 2018). A sudden flush of inorganic nitrogen may disrupt this delicate metabolic balance, prioritising nitrate assimilation, amino acid synthesis, and rampant vine growth over the secondary metabolic pathways required for carotenogenesis and stable storage root development (Gurmu *et al.*, 2021). Therefore, orange-fleshed, biofortified varieties perform as organic-adapted genotypes, optimising yield and metabolic function with poultry manure under ridge tillage. This work advances understanding by elucidating the

physiological mechanisms behind this contrast, linking the balanced, slow-release nutrition from organic sources to the complex metabolic demands of carotenoid biosynthesis in biofortified varieties.

The Amplifying Role of Tillage in an Integrated System

While variety and fertiliser were paramount, the consistent main effects and interactions of mound tillage cannot be overlooked; they served as a force multiplier for both systems. In the degraded sandy loam Ultisol, mound tillage fundamentally improved the root zone environment by enhancing drainage, increasing aeration, moderating soil temperature, and reducing compaction (Nyambo *et al.*, 2022; Ilozobhie *et al.*, 2024). This improved physical habitat boosted root exploration and health, thereby enhancing the efficiency of applied nutrients regardless of source. The significant three-way interaction for yield (Table 3) is revelatory: it shows that the optimal fertiliser for each variety realised its full potential only under a specific tillage regime. The combined analysis across three cropping seasons revealed significant main effects of variety, tillage, and fertiliser on all measured growth and yield parameters. The white-fleshed sweet potato (WFSP) variety significantly ($p \leq 0.05$) outperformed the orange-fleshed (OFSP) variety, exhibiting greater vine length (206.77 vs 196.24 cm), leaf number (56.74 vs 48.17), SPAD-N index (34.74 vs 29.92), fresh biomass (8.07 vs 7.17 kg/plot), and final root yield (28.14 vs 24.93 t ha⁻¹). Mound tillage consistently proved superior to flat and ridge systems, producing the highest root yield (29.78 t ha⁻¹), which was 23.2% and 16.1% greater than yields from flat and ridge tillage, respectively, alongside superior vegetative growth metrics. Fertiliser type also had a profound impact, with NPK 15:15:15 application resulting in the highest SPAD-N index (36.53), fresh biomass (9.13 kg/plot), and root yield (31.90 t ha⁻¹), closely followed by poultry manure; the unfertilised control yielded only 54.6% of the NPK treatment yield, highlighting the severe nutrient limitations of the soil (Kebede, 2021).

A significant variety-by-fertiliser interaction ($p \leq 0.05$) was observed for key physiological and yield parameters, indicating distinct nutrient management requirements among varieties. The WFSP exhibited a strong, positive response to inorganic NPK fertiliser, achieving its peak performance in SPAD-N index, vine length (237.08 cm), fresh biomass (10.08 kg/plot), and root yield (35.50 t ha⁻¹) with this treatment. Conversely, the OFSP demonstrated a more nuanced response, performing optimally with poultry manure, resulting in the highest recorded SPAD-N (35.16) and root yield (30.24 t ha⁻¹). This suggests that the gradual nutrient release and broader nutrient profile of organic amendments may better support the metabolic processes in biofortified varieties (Dimkpa *et al.*, 2020).

The synergistic effect of all management factors was captured by a significant three-way interaction (Variety \times Tillage \times Fertiliser) on final root yield. The WFSP achieved the highest productivity under combined mound tillage and NPK 15:15:15 fertiliser, yielding 41.53 t ha⁻¹. This represents a 278% increase over the lowest-yielding treatment combination (OFSP with flat tillage and no fertiliser). The OFSP attained its maximum yield (36.15 t ha⁻¹) under a different optimal combination: ridge tillage with poultry manure. This result underscores the necessity for variety-specific management packages. Crucially, the research demonstrates that appropriate tillage (mound or ridge) is a critical synergistic factor that amplifies these variety-specific nutrient responses, as evidenced by the significant three-way interaction for root yield. Raised tillage (mound or ridge) was

a consistent component of all high-yielding combinations, while flat cultivation consistently constrained yield potential. For the WFSP, mound tillage created an ideal, well-aerated medium for root proliferation, enabling interception of soluble nutrients from mineral fertiliser. For the OFSP, ridge tillage provided sufficient drainage while concentrating poultry manure in the root zone, creating a synergistic system that aligns with principles of ecological intensification by tailoring practices to specific crop needs and local soil conditions (Pittelkow *et al.*, 2022).

Agronomic, Economic, and System Resilience Implications

The economic analysis (Table 6) translates these agronomic insights into farmer-centric logic. The WFSP+Mound+NPK system, despite the highest input costs, delivered the highest net return (₦4.93 million/ha) and is the unequivocal strategy for maximising profit and calorie production. However, the OFSP+Ridge+Poultry Manure system offers a compelling, strategic alternative. With a competitive net return (₦4.36 million/ha) and the highest Benefit-Cost Ratio (3.27), it offers a lower-risk model with multiple co-benefits: it builds soil organic carbon, enhances nutrient cycling, improves water retention, and reduces dependency on purchased synthetic inputs (Bolo *et al.*, 2021). This system is inherently more resilient and aligns perfectly with the goals of sustainable biofortification, ensuring that the pursuit of nutritional quality also regenerates the natural resource base.

Furthermore, the significant reduction in Cylas weevil damage under fertilised plots, particularly with green manure (Table 4), reveals an important indirect benefit of integrated soil health management. Nutrient-sufficient plants likely develop stronger physical defences (thicker periderm) and may emit different volatile profiles that are less attractive to pests (Olatunji *et al.*, 2024). The higher susceptibility of OFSP in control plots underscores the compounded vulnerability of nutrient-stressed biofortified plants, making integrated fertility management not just a yield-enhancing but also a crop-protecting strategy.

The consistent positive correlations between final root yield and improved soil health parameters, pH, OC, and ECEC, validate the virtuous cycle established by these integrated practices: good management improves soil health, which in turn supports higher and more stable crop productivity. By integrating genotype-aware strategies with physiological indicators, soil health restoration, and economic analysis, this research provides two distinct, optimised pathways for sustainable intensification. It quantitatively links improved soil parameters (pH, organic carbon, ECEC) and physiological performance (SPAD-N) to enhanced productivity, reduced Cylas weevil damage (up to 77% reduction), and superior profitability. This redefines the framework for Integrated Soil Fertility Management in sweet potato, directly connecting varietal physiology, precision nutrition, and climate-smart soil practices to simultaneously advance food security, nutritional quality, and ecological restoration on degraded African soils. By adopting this genotype-aware approach, stakeholders can simultaneously unlock the food, nutrition, and income potential of sweet potato while rehabilitating degraded soils that constrain African agriculture, thereby fulfilling the core tenets of climate-smart agriculture.

CONCLUSION

This study demonstrated that sustainable sweet potato production on degraded tropical Ultisols depends on precision-based Integrated Soil Fertility Management (ISFM)

rather than blanket fertiliser recommendations. Significant variety × fertiliser × tillage interactions revealed that fertiliser efficiency is strongly variety-dependent due to differences in nutrient use efficiency, biomass partitioning, and physiological responses. White-fleshed sweet potato (WFSP) achieved the highest yield and profitability when NPK fertiliser was combined with mound tillage, indicating superior adaptation to inorganic nutrient sources. In contrast, orange-fleshed sweet potato (OFSP) performed best under ridge tillage integrated with poultry manure, which also enhanced soil fertility and reduced Cylas weevil infestation. These findings confirm that varietal physiology plays a major role in determining agronomic performance and resource-use efficiency.

Based on the results, farmers and extension services should adopt variety-specific nutrient management strategies by combining WFSP with mineral fertilisers and OFSP with organic amendments under raised tillage systems. Policymakers should integrate these precision ISFM packages into climate-smart agriculture and biofortification programs while promoting access to organic inputs and improved tillage practices. Future research should focus on long-term soil restoration, fertiliser placement methods, and socio-economic adoption studies across sub-Saharan Africa.

REFERENCES

- Abidin, P.E., Dery, E.K., Amagloh, F.K., & Gaveh, E. (2020). Sweet potato development and delivery in sub-Saharan Africa. *African Journal of Food, Agriculture, Nutrition and Development*, 20(2), 15474–15489. Doi: <https://doi.org/10.18697/ajfand.91.18120>
- Abidin, P.E., Dery, E.K., Amagloh, F.K., Asare, K., & Guba, B.Y. (2022). Sweet potato for nutrition and climate resilience in sub-Saharan Africa: A review. *Journal of Agriculture and Food Research*, 8, 100298. Doi: <https://doi.org/10.1016/j.jafr.2022.100298>
- Agegehu, G., Nelson, P.N., & Bird, M.I. (2018). The effects of biochar, compost and their mixture and nitrogen fertiliser on yield and nitrogen use efficiency of barley grown on a Nitisol in the highlands of Ethiopia. *Science of the Total Environment*, 569–570, 869–879. Doi: <https://doi.org/10.1016/j.scitotenv.2016.05.033>
- Amagloh, F.C., Yada, B., Tumuhaise, V., Amagloh, F.K., & Kaaya, A.N. (2021). The potential of sweet potato as a functional food in sub-Saharan Africa and its health implications: A review. *Molecules*, 26(10), 2971. Doi: <https://doi.org/10.3390/molecules26102971>
- Ayilara, M.S., Olanrewaju, O.S., Babalola, O.O., & Odeyemi, O. (2020). Waste management through composting: Challenges and potentials. *Sustainability*, 12(11), 4456. Doi: <https://doi.org/10.3390/su12114456>
- Barnabas, I.L., & Nwaka, G.I.C. (2014). Analysis of rainfall distribution in Gwagwalada, FCT, Abuja, Nigeria. *Journal of Earth Science and Climate Change*, 5(7), 1-5.
- Bolo, P., Kihara, J., Mucheru-Muna, M., Njeru, E.M., & Kinyua, M. (2021). Lessons from long-term nutrient management studies in Africa: A review. *Soil Security*, 4, 100012. Doi: <https://doi.org/10.1016/j.soisec.2021.100012>

- CIMMYT- International Maize and Wheat Improvement Centre. (2022). *Economic data analysis: Tools and methods for on-farm research*. <https://www.cimmyt.org/resources/>
- Dimkpa, C.O., Fugice, J., Singh, U., & Lewis, T.D. (2020). Development of fertilisers for enhanced nitrogen use efficiency – Trends and perspectives. *Science of the Total Environment*, 731, 139113. Doi: <https://doi.org/10.1016/j.scitotenv.2020.139113>
- FAOSTAT. (2023). Food and Agriculture Data. Food and Agriculture Organisation of the United Nations. <http://www.fao.org/faostat/en/>
- Food and Agriculture Organization of the United Nations. (2022). *The State of Food Security and Nutrition in the World 2022*. FAO. <https://www.fao.org/documents/card/en/c/cc0639en>
- Gurmu, F., Shimelis, H., & Laing, M. (2021). The potential of orange-fleshed sweet potato to prevent vitamin A deficiency in Africa. *International Journal of Food Science & Technology*, 56(8), 3646-3664. Doi: <https://doi.org/10.1111/ijfs.15016>
- Idoko, S. O., & Bisong, F. E. (2010). Land use and land cover dynamics in Abuja, Nigeria: A study of changes, causes and consequences. *Journal of Ecology and the Natural Environment*, 2(8), 174-183.
- Ilozobhie, N.E., Anyaegbu, P.O., Habibu, D., Mustapha, A., Aloba, A.J., Aihebor, D.O., & Maihula, J.T. (2024). Performance of orange flesh sweet potato (*Ipomoea batatas* L. (Lam.)) as influenced by tillage and fertiliser type in Federal Capital Territory (FCT), Abuja, Nigeria. *African Journal of Agriculture and Allied Sciences*, 4(1), 1-12. <https://www.ajaa.com.ng/wp-content/uploads/2024/07/AJASS-Vol.4-Issue1-Article-13.pdf>
- Ishaya, S., & Grace, M.K. (2007). Soil characteristics of the University of Abuja Teaching and Research Farm, Gwagwalada. *Nigerian Journal of Soil and Environmental Research*, 7, 45-50.
- Jiang, Y., Zhang, Y., Li, M., & Liu, X. (2019). Soil acidification of the soil profile across the Chengdu Plain of China from the 1980s to 2010s. *Science of The Total Environment*, 698, 134320. Doi: <https://doi.org/10.1016/j.scitotenv.2019.134320>
- Kebede, E. (2021). Contribution, utilisation, and improvement of legume-driven biological nitrogen fixation in agricultural systems. *Frontiers in Sustainable Food Systems*, 5. Doi: <https://doi.org/10.3389/fsufs.2021.767998>
- Kifle, M. H., Laing, M.D., & Araya, H.T. (2022). Effects of organic amendments on soil fertility and crop productivity in sustainable agriculture: A review. *Frontiers in Plant Science*, 13, 1004550. Doi: <https://doi.org/10.3389/fpls.2022.1004550>
- Kihara, J., Bolo, P., Kinyua, M., Nyawira, S. S., & Sommer, R. (2020). Soil health and ecosystem services: Lessons from sub-Saharan Africa (SSA). *Geoderma*, 370, 114342. Doi: <https://doi.org/10.1016/j.geoderma.2020.114342>
- Kintché, K., Guibert, H., Sogbedji, J. M., Levêque, J., & Bonfoh, B. (2017). Long-term mineral fertiliser use and maize residue incorporation do not compensate for carbon and nutrient losses from a Ferralsol under continuous maize-cotton cropping. *Field Crops Research*, 212, 109-118. Doi: <https://doi.org/10.1016/j.fcr.2017.07.013>
- Lee, S., Kim, H., & Park, J. (2023). Varietal differences in nitrogen use efficiency and biomass allocation of sweet potato (*Ipomoea batatas* L.) under contrasting fertilisation regimes. *Journal of Plant Nutrition and Soil Science*, 186(4), 512-525.
- Li, S., Li, J., Zhang, B., Li, D., Li, G., & Li, Y. (2020). Effect of different organic fertilisers application on soil organic matter and nitrogen use efficiency in upland crops. *Agriculture, Ecosystems & Environment*, 295, 106886. Doi: <https://doi.org/10.1016/j.agee.2020.106886>
- Liu, Y., Zhang, G., Luo, X., Hou, E., Zheng, M., Zhang, L., ... & He, X. (2021). Nitrogen use efficiency in crop plants: From *in vitro* to the field. *Frontiers in Plant Science*, 12, 628-645. Doi: <https://doi.org/10.3389/fpls.2021.628645>
- Low, J.W., Mwangi, R.O., Andrade, M., Carey, E., & Ball, A.M. (2017). Tackling vitamin A deficiency with biofortified sweet potato in sub-Saharan Africa. *Global Food Security*, 14, 23-30. Doi: <https://doi.org/10.1016/j.gfs.2017.01.004>
- Motsa, N.M., Modi, A.T., & Mabhaudhi, T. (2015). Sweet potato (*Ipomoea batatas* L.) as a drought tolerant and food security crop. *South African Journal of Science*, 111(11/12), 1-8. Doi: <https://doi.org/10.17159/sajs.2015/20140252>
- Motsara, M. R., & Roy, R. N. (2020). *Guide to laboratory establishment for plant nutrient analysis* (FAO Fertilizer and Plant Nutrition Bulletin 19). Food and Agriculture Organization of the United Nations.
- Mwangi, R.O.M., Andrade, M.I., Carey, E.E., Low, J.W., Yencho, G.C., & Grüneberg, W. J. (2016). *Sweetpotato (Ipomoea batatas L.)*. In *Genetic improvement of tropical crops* (pp. 181-218). Springer, Cham.
- Ndambi, O. A., Pelster, D. E., Owino, J. O., de Buissonjé, F., & Vellinga, T. (2019). Manure management practices and policies in sub-Saharan Africa: Implications on manure quality as a fertiliser. *Frontiers in Sustainable Food Systems*, 3. Doi: <https://doi.org/10.3389/fsufs.2019.00029>
- Ngoze, S., Muyonga, J., Mwanjala, T., & Kinyua, M. (2021). Variability in nutrient composition of organic fertilisers and its implications for soil fertility management. *African Journal of Agricultural Research*, 17(2), 179-189. Doi: <https://doi.org/10.5897/AJAR2020.15309>
- Nyambo, P., Chiduzza, C., & Araya, T. (2022). Conservation agriculture effects on soil water holding capacity and water-saving varied with management practices and agro-ecological conditions: A review. *Advances in Agronomy*, 176, 155-295. Doi: <https://doi.org/10.1016/bs.agron.2022.07.003>
- Olatunji, J. R., Olorunmaiye, P. M., & Ojo, D. K. (2024). Influence of fertiliser types on infestation and damage by *Cylas puncticollis* Boheman (Coleoptera: Brentidae) on sweet potato in Nigeria. *Journal of Agricultural Science*, 16(3), 45-56

- Olujugba, S. O., Alake, A. D., & Odeyemi, F. (2016). Comparative effect of organic and inorganic fertilisers on soil properties, nutrient uptake and growth of tomato (*Lycopersicon esculentum* Mill). *African Journal of Agricultural Research*, 11(14), 1215-1222. Doi: <https://doi.org/10.5897/AJAR2015.10666>
- Oteng-Darko, P., Addy, S. N. T., Yeboah, S., & Amponsah, S. K. (2021). Sweet potato (*Ipomoea batatas* L.) yield gap analysis in Ghana. *Scientific African*, 12, e00771. Doi: <https://doi.org/10.1016/j.sciaf.2021.e00771>
- Pittelkow, C. M., Liang, X., Linquist, B. A., van Groenigen, K. J., Lee, J., Lundy, M. E., van Gestel, N., Six, J., Venterea, R. T., & van Kessel, C. (2022). Productivity limits and potentials of the principles of conservation agriculture. *Nature*, 517(7534), 365–368. Doi: <https://doi.org/10.1038/nature13809>
- Poorter, H., Niklas, K. J., Reich, P. B., Oleksyn, J., Poot, P., & Mommer, L. (2012). Biomass allocation to leaves, stems and roots: meta-analyses of interspecific variation and environmental control. *New Phytologist*, 193(1), 30-50. Doi: <https://doi.org/10.1111/j.1469-8137.2011.03952.x>
- R Core Team. (2023). *R: A language and environment for statistical computing* (Version 4.5.0) [Computer software]. R Foundation for Statistical Computing. <https://www.R-project.org/>
- Thierfelder, C., Chivenge, P., Mupangwa, W., Rosenstock, T. S., Lamanna, C., & Eyre, J. X. (2018). How climate-smart is conservation agriculture (CA)? – its potential to deliver on adaptation, mitigation and productivity on smallholder farms in southern Africa. *Food Security*, 10(3), 537–560. Doi: <https://doi.org/10.1007/s12571-018-0803-6>
- Tittonell, P., & Giller, K. E. (2013). When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research*, 143, 76-90. Doi: <https://doi.org/10.1016/j.fcr.2012.10.007>
- Tumuhimbise, G. A., Namutebi, A., & Turyashemerwa, F. (2019). Pro-vitamin A crops: Acceptability, bioavailability, efficacy and effectiveness. *Food Science & Nutrition*, 7(8), 2475–2480. Doi: <https://doi.org/10.1002/fsn3.1108>
- Unagwu, B. O., Ene, J. O., & Ezech, C. U. (2019). Influence of poultry manure and NPK fertiliser on growth and yield of sweet potato (*Ipomoea batatas* L.) in southeastern Nigeria. *International Journal of Agriculture and Environmental Research*, 5(2), 259-270.
- Vanlauwe, B., Descheemaeker, K., Giller, K. E., Huising, J., Merckx, R., Nziguheba, G., Wendt, J., & Zingore, S. (2019). Integrated soil fertility management in sub-Saharan Africa: Unravelling local adaptation. *Soil*, 5, 491–508. Doi: <https://doi.org/10.5194/soil-5-491-2019>
- Welsch, R., Zhou, X., & Li, L. (2018). Carotenoid biosynthesis and its regulation in plants. In *Carotenoids in Nature* (pp. 187-212). Springer. Doi: https://doi.org/10.1007/978-3-319-92952-7_9
- Zhang, W., Liu, D., Liu, Y., Chen, X., & Zou, C. (2020). Overuse of phosphorus fertiliser reduces the grain yield and enhances the environmental risk in a double rice cropping system. *Journal of Integrative Agriculture*, 19(11), 2651-2663. Doi: [https://doi.org/10.1016/S2095-3119\(20\)63230-2](https://doi.org/10.1016/S2095-3119(20)63230-2)
- Zhang, X., Davidson, E. A., Mauzerall, D. L., Searchinger, T. D., Dumas, P., & Shen, Y. (2018). Managing nitrogen for sustainable development. *Nature*, 528, 51–59. Doi: <https://doi.org/10.1038/nature15743>
- Zingore, S., Njoroge, S., & Mashingaidze, N. (2022). Priority interventions for transformational change in the agri-food systems of sub-Saharan Africa. *Agricultural Systems*, 203, 103520. Doi: <https://doi.org/10.1016/j.agsy.2022.103520>
- Zomer, R. J., Bossio, D. A., Sommer, R., & Verchot, L. V. (2017). Global sequestration potential of increased organic carbon in cropland soils. *Scientific Reports*, 7(1), 15554. Doi: <https://doi.org/10.1038/s41598-017-15794-8>

