

Integrating Variety, Land Configuration and Fertility Management for Sustainable Management of *Cylas* Weevil Infestation in Sweet Potato Under Degraded Savanna Alfisols

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ABSTRACT

The sweet potato weevil (*Cylas* spp.) is a major constraint to sweet potato production, yet the effectiveness of integrated agronomic approaches for its management remains insufficiently understood in the Nigerian savanna. A three-year field experiment (2023–2025) at the University of Abuja Teaching and Research Farm evaluated the effects and interactions of variety, land configuration, and fertilizer source on *Cylas* infestation, root quality, and marketable yield. Two varieties, orange-fleshed (OF) UMUSP3 and white-fleshed (WF) TIS-87/0087, were evaluated under flat, mound, and ridge configurations combined with NPK 15:15:15, poultry manure, *Hyptis suaveolens* green manure, and an unfertilized control in a factorial randomized complete block design with three replications. Variety significantly affected *Cylas* infestation, with OF recording 10.79 infected roots/plot compared with 8.28 roots/plot in WF, whereas land configuration alone had no significant effect. Fertilizer management strongly influenced infestation and root quality, with green manure recording the lowest *Cylas* incidence (3.61 roots/plot) and unmarketable roots (6.20 roots/plot), compared with 15.50 and 23.11 roots/plot, respectively, under the control. Significant variety × fertilizer and land configuration × fertilizer interactions indicated context-dependent responses. *Cylas* infestation was negatively correlated with marketable yield ($r = -0.301$) and fresh biomass ($r = -0.201$), indicating that increasing infestation was associated with reduced productivity. Integrating suitable varieties, organic nutrient management, and complementary land configurations can strengthen *Cylas* management, reduce weevil-associated losses, and sustain sweet potato productivity under savanna conditions.

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INTRODUCTION

Sweet potato (*Ipomoea batatas* L.) is important for food and nutrition security in sub-Saharan Africa (SSA) because of its adaptability to marginal soils, drought tolerance and nutritional value. Its importance has increased with the adoption of orange-fleshed sweet potato (OFSP), which is biofortified with beta-carotene, a precursor of vitamin A (Low *et al.*, 2020). Despite these advantages, average yields in SSA remain only 5–7 t ha⁻¹ compared with attainable yields of 25–40 t ha⁻¹ under optimal management (Kroschel *et al.*, 2024). This yield gap reflects interacting abiotic and biotic constraints, including the economically important sweet potato weevil (*Cylas* spp.) (Stathers *et al.*, 2019; Rukarwa *et al.*, 2020).

Cylas damages sweet potato throughout the crop cycle. Adults feed on foliage and stems, while larvae tunnel into vines and storage roots, reducing yield and facilitating secondary infections. Larval feeding induces bitter terpenoids such as ipomeamarone, making damaged roots unpalatable and unmarketable and increasing post-harvest losses (Mwanga *et al.*, 2024). In Nigeria, severe *Cylas* infestation has been associated with losses of 30–100%, with implications for household nutrition and farm income (Okonya *et al.*, 2019). Although synthetic insecticides are commonly used, their cost, limited smallholder accessibility, poisoning risks, environmental effects and potential for resistance constrain their sustainability (Dara, 2019). Integrated pest management (IPM) based on accessible

cultural practices is therefore needed, with cultural control reducing pest establishment and survival while improving crop vigour and resilience (Deguine *et al.*, 2021).

Land configuration and soil fertility management may provide complementary cultural IPM options. Ridges and mounds modify soil structure, temperature and moisture and may influence pupation, adult emergence and larval movement (Djaman *et al.*, 2021; Nyasani *et al.*, 2021; Ilozobhie *et al.*, 2024). Soil amendments can improve plant vigour and tolerance to pest damage, consistent with the plant vigour hypothesis (Züst & Agrawal, 2021). Poultry manure and botanically active green manures such as *Hyptis suaveolens* may additionally influence systemic resistance, rhizosphere microbial communities and bioactive compounds with pest-repellent or biofumigant effects (Ayobami *et al.*, 2021; Rahmawati *et al.*, 2023; Olatunji *et al.*, 2024).

Although land configuration and fertilization affect sweet potato growth (Abukari *et al.*, 2024), their integrated use against *Cylas* remains insufficiently investigated, particularly on weathered, nutrient-depleted Alfisols of the Nigerian savanna. Varietal differences between white-fleshed and biofortified OFSP may further influence pest responses and resource allocation (Low *et al.*, 2020). Therefore, this study evaluated the combined effects of variety, land configuration and fertilizer source on *Cylas* infestation, root damage and marketable storage-root yield, testing whether raised configurations and organic amendments could create less favourable conditions for *Cylas* while improving crop

performance relative to flat configuration and inorganic fertilization.

MATERIALS AND METHODS

Study Site

The experiment was conducted during the 2023, 2024 and 2025 cropping seasons at the Teaching and Research Farm, Faculty of Agriculture, University of Abuja, Abuja, Nigeria (8°59'24.46944" N, 7°11'8.46708" E). The area experiences a tropical wet-and-dry climate with a bimodal rainfall pattern, although rainfall amount and distribution vary considerably among seasons. Annual rainfall is approximately 1,100–1,800 mm, with a mean annual temperature of about 30 °C and relative humidity generally ranging from 60 to 80% during the cropping period (Idoko & Bisong, 2010; Barnabas & Nwaka, 2014). Recent studies characterize Abuja as a Southern Guinea Savanna environment with marked seasonal climatic variability that influences crop production (Tofa *et al.*, 2021; Beah *et al.*, 2025).

The soils are predominantly Alfisols, with Ustalfs and Typic Plinthustalfs occurring commonly under the regional ustic soil-moisture regime (Oku *et al.*, 2020). Soils at the University of Abuja Teaching and Research Farm are generally deep, well-drained, and sandy loam in texture (Ishaya & Grace, 2007). Pre-experiment sampling at 0–30 cm depth confirmed a sandy-loam texture comprising approximately 70% sand, 20% clay and 10% silt, with relatively low organic matter and available phosphorus.

Land Preparation and Soil Sampling

Before planting, the experimental site was cleared, levelled, and stumped using machetes, rakes, and dibbers, followed by ploughing and harrowing until the soil reached a fine tilth. 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 bulked into a composite, 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 procedures as outlined by the FAO (2019).

Experimental Materials

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

UMUSP3 (the orange-fleshed) variety was selected for its high β -carotene (provitamin A) content and enhanced nutritional profile, including dietary fibre, essential minerals, and antioxidants, making it suitable for addressing micronutrient deficiencies (Tumuhimbise *et al.*, 2019; Amagloh *et al.*, 2021). A sweet taste and soft texture characterize the variety due to its low dry matter content, which is desirable for nutrition and consumer acceptance studies.

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TIS-87/0087, a white-fleshed variety, was included for its high yield potential, broad adaptability, and stable agronomic performance (Mwanga *et al.*, 2016; Abidin *et al.*, 2020). Its higher dry matter content confers good processing qualities, making it suitable for products such as chips and flour, and it serves as a standard check variety in the study.

Treatments and Experimental Design

The experiment comprised two sweet potato varieties, UMUSP3, an orange-fleshed biofortified type, and TIS 87/0087, a white-fleshed type, evaluated under three tillage practices (mounds, ridges and flat beds) and four fertilizer treatments (NPK 15:15:15, poultry manure, green manure derived from *Hyptis suaveolens* leaves, and a control). These factors were combined factorially and arranged in a Randomised Complete Block Design with three replications. Each replication contained 24 plots, for a total of 72 used in the study.

Each plot measured 3 m $\times$ 3 m and was separated from adjacent plots within the replicate by a 0.5 m pathway, while a 1 m alley separated replicates to facilitate easy access. The total experimental area covered 918.5 m² (83.5 m $\times$ 11 m).

Cultural Practices

Sweet potato cuttings, 30 cm in length, were planted at a spacing of 50 cm $\times$ 50 cm, resulting in a plant population of 40,000 plants per hectare and 36 stands per plot. Planting was done at approximately 60°, with two-thirds of the cutting inserted into the soil and pressed firmly to ensure good soil contact and effective sprouting. Weeding was conducted manually using local hoes, with the first weeding at 3 weeks after planting (WAP) and subsequent weedings at 6 and 9 WAP to maintain a clean field.

All organic amendments, including broiler-house poultry manure and *Hyptis suaveolens* 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, while chopped and dried *H. suaveolens* biomass was applied as green manure at 5 t/ha (4.5 kg/plot or 0.125 kg/plant stand) following Anyaegbu (2013). NPK 15:15:15 fertilizer was band-applied three weeks after planting at 400 kg/ha (0.36 kg/plot or 0.01 kg/plant). Tubers were harvested manually with a hoe 12 weeks after planting, sorted by size and marketability, and assessed for the required study variables.

Data Collection

At harvest, conducted sixteen weeks after planting, data were collected from each experimental plot to assess sweet potato performance. The number of roots infected by *Cylas weevil*, identified by visible boring or tunnelling, was recorded. Additionally, the total number of storage roots per plot was counted, along with the number of marketable roots, defined as healthy, undamaged roots weighing more than 100 g, and the number of unmarketable roots, which included damaged, malformed, or undersized roots weighing less than 100 g. Marketable root yield was determined and expressed in tonnes per hectare. Fresh biomass weight per plot and SPAD chlorophyll content were also measured as indicators of plant vigour.

Statistical Analysis

Data collected were subjected to analysis of variance (ANOVA) in R (version 4.5.2) using the *agricolae* package. The experiment was analysed as a 2 $\times$ 3 $\times$ 4 factorial arrangement in a Randomised Complete Block Design (RCBD), comprising two varieties, three land configurations

and four fertilizer treatments, with three replications. The statistical model used was:

$$Y_{ijkl} = \mu + B_i + V_j + L_k + F_l + (VL)_{jk} + (VF)_{jl} + (LF)_{kl} + (VLF)_{jkl} + \varepsilon_{ijkl}$$

Where:

- i. Y_{ijkl} = observed response variable;
- ii. μ = overall mean;
- iii. B_i = effect of block i , where $i = 1, 2, 3$;
- iv. V_j = fixed effect of variety j , where $j = 1, 2$;
- v. L_k = fixed effect of land configuration k , where $k = 1, 2, 3$;
- vi. F_l = fixed effect of fertilizer treatment l , where $l = 1, 2, 3, 4$;
- vii. $(VL)_{jk}$ = interaction effect between variety and land configuration;
- viii. $(VF)_{jl}$ = interaction effect between variety and fertilizer treatment;
- ix. $(LF)_{kl}$ = interaction effect between land configuration and fertilizer treatment;

- x. $(VLF)_{jkl}$ = three-way interaction effect among variety, land configuration and fertilizer treatment; and

- xi. ε_{ijkl} = random residual error.

Significant treatment means were separated using the Student–Newman–Keuls (SNK) test at the 5% probability level ($p \leq 0.05$). For traits showing significant interaction effects, Least Squares Means (LSMEANS) were estimated, with differences assessed using standard errors (SE) and associated p-values at the 0.05 significance level. All treatment means are presented with their corresponding standard errors of the mean (SEM). Pearson correlation coefficients were also calculated to assess relationships among the measured variables. In addition, the relative performance of each fertilizer treatment under each land configuration and variety was quantified as the percentage change relative to the Control, calculated as follows:

$$\text{Relative change (\%)} = [(T_{ikl} - T_{ik4}) / T_{ik4}] \times 100$$

Where:

T_{ikl} = mean value of a given treatment combination, where i = variety (1–2), k = land configuration (1–3), and l = fertilizer treatment (1–4).

T_{ik4} = mean value of the corresponding Control treatment under the same variety and land configuration, where fertilizer treatment 4 represents the Control.

RESULTS AND DISCUSSION

Changes in Soil Properties Following Three Years of Tillage and Fertility Management

Table 1 shows substantial improvement in soil chemical properties following three years of land configuration and fertility management (2023–2025). Soil pH (H_2O) increased from 4.5 to 6.2 (+37.8%), while pH (KCl) increased from 4.8 to 6.0 (+25.0%), indicating marked amelioration of the initially acidic soil. These changes are consistent with the cumulative contribution of organic amendments and inorganic fertilizer to nutrient cycling, organic matter accumulation, and acidity buffering.

Organic carbon increased from 0.31% to 1.44% (+364.5%), while total nitrogen increased from 0.011% to 0.091% (+727.3%), demonstrating substantial improvement in soil organic matter and nutrient status. Available phosphorus

increased from 4.40 to 7.04 mg kg⁻¹ (+60.0%), and exchangeable potassium increased from 0.51 to 1.52 cmol kg⁻¹ (+198.0%). Exchangeable calcium also increased from 2.33 to 2.67 cmol kg⁻¹ (+14.6%). The effective cation exchange capacity increased from 6.54 to 8.54 cmol kg⁻¹ (+30.6%), indicating improved capacity for nutrient retention and supply. Soil texture remained sandy loam throughout the study.

Collectively, these changes indicate a shift from highly acidic and nutrient-limited conditions toward improved fertility and greater buffering capacity. The increases in organic carbon, nitrogen, phosphorus, potassium, calcium, and ECEC could enhance nutrient availability, soil structure, moisture retention, root development, and crop vigour, potentially supporting greater resilience under pest pressure. However, soil biological activity, plant defence responses, and *Cylas* survival were not directly measured. Therefore, the observed improvements should be regarded as favourable soil conditions associated with the management regime rather than confirmed mechanisms of *Cylas* suppression. The results nevertheless demonstrate substantial cumulative improvement in soil fertility following three years of integrated fertility management.

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

Parameter	Pre-Planting (2023)	Post-Harvest (2025)	% Change
pH (H_2O)	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
Avail. P (mg kg ⁻¹)	4.40	7.04	+60.0
Exch. K (cmol kg ⁻¹)	0.51	1.52	+198.0
Exch. 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	-

Values represent composite soil samples taken across treatments. Improvements reflect the cumulative effects of fertilizer application by source over three cropping seasons (2023–2025).

Main Effects of Agronomic Management on *Cylas* Weevil Incidence and Unmarketable Roots

The combined analysis of the 2023–2025 cropping seasons showed that *Cylas* weevil incidence was significantly affected by variety and fertilizer management, whereas tillage had no significant main effect (Table 2). Variety significantly affected the number of *Cylas*-infected roots ($p < 0.001$), but not unmarketable roots ($p = 0.095$). Fertilizer management significantly affected both variables ($p < 0.001$), whereas tillage was nonsignificant for *Cylas* incidence ($p = 0.110$) and unmarketable roots ($p = 0.201$).

The orange-fleshed (OF) variety recorded significantly more infected roots (10.79 roots/plot) than the white-fleshed (WF) variety (8.28 roots/plot), representing approximately 30.3% more infected roots. However, unmarketable roots were statistically similar between OF (14.52 roots/plot) and WF (15.72 roots/plot).

Tillage configuration produced no significant differences in *Cylas* incidence or unmarketable roots. Infected roots ranged from 9.22 roots/plot under mound cultivation to 9.89 roots/plot under ridge cultivation, with flat beds recording 9.49 roots/plot. Unmarketable roots similarly ranged from 14.56 roots/plot under flat beds to 15.58 and 15.22 roots/plot under mound and ridge cultivation, respectively.

Fertilizer management produced the strongest main effects. The control recorded the highest *Cylas* incidence (15.50 roots/plot), compared with green manure (3.61), NPK 15:15:15 (8.74) and poultry manure (10.28). Green manure also produced the fewest unmarketable roots (6.20 roots/plot), compared with 23.11 under the control, 13.56 under poultry manure and 17.61 under NPK. Overall, fertilizer management was the principal main-effect factor associated with variation in *Cylas* incidence and unmarketable roots across the three seasons.

Table 2: Main Effects of Variety, Tillage, and Fertilizer on *Cylas* Weevil Infestation and Unmarketable Roots (Combined Data, 2023-2025)

Factor	Level	Roots Infected by <i>Cylas</i> (/plot)	Unmarketable Roots (/plot)
Variety (V)	Orange-Fleshed (OF)	10.79a	14.52a
	White-Fleshed (WF)	8.28b	15.72a
	<i>LSD</i> (0.05)	*0.98*	*1.40*
	<i>P-value</i>	<0.001	0.095 NS
Tillage (T)	Flat	9.49 a	14.56a
	Mound	9.22 a	15.58a
	Ridge	9.89a	15.22a
	<i>LSD</i> (0.05)	*1.20*	*1.72*
Fertilizer (F)	<i>P-value</i>	0.110 NS	0.201 NS
	Control	15.50a	23.11a
	Green Manure (GM)	3.61d	6.20d
	NPK 15:15:15	8.74c	17.61b
	Poultry Manure (PM)	10.28b	13.56c
	<i>LSD</i> (0.05)	*1.38*	*1.98*
	<i>P-value</i>	<0.001	<0.001

Means within a column and main effect followed by the same letter are not significantly different at $p \leq 0.05$. NS = Not Significant.

Interaction Effects Elucidate Context-Dependent Pest Management

The significant two-way and three-way interactions revealed that the effectiveness of management practices was not independent but worked in complex synergy or antagonism.

Variety $\times$ Fertilizer Interaction

This highly significant interaction ($*p < 0.001$) clarified that the orange-fleshed variety's greater susceptibility was

consistent across all fertilizer types (Table 3). While both varieties benefited tremendously from Green Manure, the OF Variety remained more vulnerable under NPK and Poultry Manure regimes. Notably, the WF variety showed a stronger positive response to inorganic nutrition in terms of pest tolerance, with NPK application resulting in a lower infestation rate (7.33) than in the OF variety (10.15).

Table 3: Variety $\times$ Fertilizer Interaction Effects on *Cylas* Weevil Infestation (Combined Data, 2023-2025)

Variety	Fertilizer	Roots Infected by <i>Cylas</i> (/plot)
Orange-Fleshed (OF)	Control	16.74a
	Green Manure (GM)	3.41e
	NPK 15:15:15	10.15c
	Poultry Manure (PM)	12.85b
White-Fleshed (WF)	Control	14.26b
	Green Manure (GM)	3.81e
	NPK 15:15:15	7.33d
	Poultry Manure (PM)	7.70d
	SE $\pm$	0.70
	<i>P-value</i> (V $\times$ F)	<0.001

Means within a column followed by the same letter are not significantly different at $p \leq 0.05$.

Tillage × Fertilizer Interaction

A highly significant interaction ($p < 0.001$) indicated that the pest-suppressive effect of fertilizers was modulated by tillage environment (Table 4). The most damaging scenario was consistently the Control, regardless of tillage. The synergy between Ridge tillage and Green Manure produced the lowest

infestation level (3.39 roots/plot). Interestingly, the efficacy of Poultry Manure was context-dependent: it resulted in lower infestation under Flat and Mound tillage compared to Ridge, suggesting that its mode of action may interact with soil moisture or aeration dynamics.

Table 4: Tillage × Fertilizer Interaction Effects on Pest Incidence and Root Quality (Combined Data, 2023-2025)

Tillage	Fertilizer	Roots Infected by Cylas (/plot)	Unmarketable Roots (/plot)
Flat	Control	14.72a	20.44bc
	Green Manure (GM)	3.78d	6.00f
	NPK 15:15:15	8.94bc	17.56cd
	Poultry Manure (PM)	10.50bc	14.22de
Mound	Control	15.83a	25.22a
	Green Manure (GM)	3.67d	6.94f
	NPK 15:15:15	7.94c	17.67cd
	Poultry Manure (PM)	9.44bc	12.50e
Ridge	Control	15.9 a	23.67ab
	Green Manure (GM)	3.39d	5.67f
	NPK 15:15:15	9.33bc	17.61cd
	Poultry Manure (PM)	10.89b	13.94de
	SE±	0.86	1.23
	P-value (T×F)	<0.001	<0.001

Means within a column followed by the same letter are not significantly different at $p \leq 0.05$.

Three-Way Interaction (Variety × Tillage × Fertilizer)

To fully capture the system complexity, the three-way interaction was significant ($p < 0.05$). For brevity, a summary table of key contrasting combinations is presented (Table 5). This reveals that the optimal management strategy for minimizing pest damage while maximizing yield differed by

variety. For the WF variety, the Mound/NPK combination minimized damage (7.33 infected roots/plot). For the OF Variety, the Ridge/Poultry Manure system, while not the lowest in infestation, offered the best compromise, achieving high yield with a manageable, significantly reduced pest load compared to flat tillage or control.

Table 5: Selected Treatment Combinations from the Three-Way Interaction Illustrating Pest-Yield Relationships

Variety	Tillage	Fertilizer	Roots Infected by Cylas (/plot)	Marketable Root Yield (t ha ⁻¹)
White-Fleshed	Mound	NPK 15:15:15	7.33d	41.53a
Orange-Fleshed	Ridge	Poultry Manure	10.8 b	36.15ab
White-Fleshed	Ridge	Green Manure	3.39d	23.32cde
Orange-Fleshed	Flat	Control	14.7 a	10.96f
	SE±		0.86	2.08

Means within a column followed by the same letter are not significantly different at $p \leq 0.05$.

Correlation and Path Analysis: Quantifying the Impact of Pest Pressure

A comprehensive correlation analysis of the pooled data ($n = 216$) quantified the detrimental relationships between Cylas infestation, crop performance, and final marketable yield (Table 6). The number of roots infected by Cylas weevil showed a strong and significant negative correlation with marketable root yield ($r = -0.301$, $p < 0.01$). This direct economic impact was underpinned by significant negative correlations with key plant vigour indicators: fresh biomass weight ($r = -0.201$, $p < 0.05$) and SPAD chlorophyll content ($r = -0.309$, $p < 0.01$). Conversely, a strong positive correlation was observed between Cylas infestation and the

number of unmarketable roots ($r = 0.624$, $p < 0.01$), confirming the pest's direct role in degrading harvest quality. To assess the direct and indirect effects of Cylas infestation on marketable yield, path analysis was conducted (Figure 1). The standardized path coefficients showed that Cylas infestation had a direct negative effect on marketable yield ($r = -0.28$). Infestation also exerted a significant indirect effect through reduced fresh biomass, an indicator of plant health and source strength, which exhibited a strong positive direct effect on yield (0.65). These findings suggest that Cylas infestation may reduce marketable yield through both direct effects associated with root damage and indirect effects mediated by reductions in plant vigour.

Table 6: Pearson Correlation Matrix for Pest, Vigour, and Yield Parameters (Combined Data 2023-2025)

Parameter	1	2	3	4	5
1. Roots Infected by Cylas	1.000				
2. Unmarketable Roots	0.624**	1.000			
3. Marketable Root Yield	-0.301**	-0.093	1.000		
4. Fresh Biomass Weight	-0.201*	0.039	0.981**	1.000	
5. SPAD Chlorophyll	-0.309**	-0.295**	0.409**	0.401**	1.000

Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed)

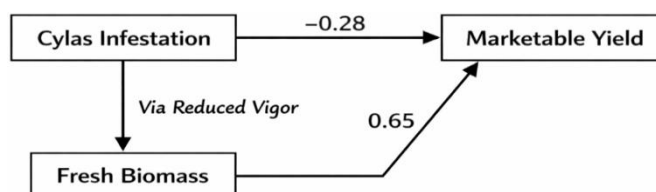


Figure 1: Standardized path coefficients are shown. The path model explained 96% of the variation in marketable root yield ($R^2 = 0.96$)

Discussion

The present study demonstrates that *Cylas* infestation and associated storage-root losses were influenced by host genotype, soil fertility and crop-growing conditions rather than by a single agronomic factor. Variety and fertilizer management exerted stronger effects on weevil incidence and root losses than land configuration alone, while significant interactions showed that responses were context-dependent. This supports an Integrated Pest Management (IPM) approach combining host-plant selection, soil fertility management and complementary cultural practices. Such integration is important because *Cylas* larvae develop within storage roots and are difficult to control after infestation (Dara, 2019; Giri *et al.*, 2022; Yada *et al.*, 2023).

The significantly higher *Cylas* incidence in the orange-fleshed (OF) variety than the white-fleshed (WF) variety, 10.79 versus 8.28 infected roots/plot, indicates distinct varietal responses to weevil infestation. Similar genotype-dependent responses have been reported, with host-plant resistance recognized as an important component of *Cylas* management. Yada *et al.* (2023) reported substantial differences among sweet potato cultivars in response to *Cylas puncticollis* and *C. brunneus*, while Nigerian evaluations also demonstrated considerable variation in *Cylas* incidence among genotypes (Ulas *et al.*, 2021; Joseph *et al.*, 2022). The greater incidence in OF therefore indicates greater susceptibility under the conditions of this study, although it should not be interpreted as an inherent disadvantage of orange-fleshed germplasm because nutritional and agronomic attributes must also be considered.

The significant variety $\times$ fertilizer interaction further showed that varietal response was modified by nutrient management. Both varieties responded favourably to green manure, whereas WF showed a stronger response to NPK in terms of pest tolerance. This suggests that nutritional status may modify varietal susceptibility and that fertilizer recommendations for *Cylas* management should account for genotype-specific responses. However, biochemical and morphological resistance traits were not measured, so possible mechanisms involving periderm characteristics, secondary metabolites or resource allocation remain hypotheses.

Land configuration alone did not significantly affect *Cylas* incidence among flat, mound and ridge systems, indicating that physical modification of the soil surface was insufficient for consistent suppression. Nevertheless, *Cylas* biology provides a basis for potential interactions between soil configuration and pest development. Adults oviposit on vines and stems, larvae develop within storage roots, and pupation occurs in surrounding soil (Ames *et al.*, 2018; Rukarwa *et al.*, 2020). Changes in soil aeration, drainage and the environment surrounding storage roots may therefore influence soil-associated pest stages (Kumar *et al.*, 2019; Nyasani *et al.*, 2021; Ilozobhie *et al.*, 2024), while soil modification may alter relationships among vine nodes, root development and

larval establishment (Okonya *et al.*, 2017; Ebregt *et al.*, 2018). However, the absence of a significant main effect indicates that these influences did not produce consistent differences across configurations. Land configuration should therefore be regarded as a complementary component of *Cylas* management alongside suitable varieties, fertility management, field sanitation, clean planting material, crop rotation and timely planting and harvesting (Yada *et al.*, 2023).

Fertilizer management produced pronounced differences in infected and unmarketable roots. The unfertilized control recorded the highest infected-root count (15.50 roots/plot), whereas *Hyptis suaveolens* green manure recorded the lowest (3.61 roots/plot). Unmarketable roots similarly declined from 23.11 roots/plot in the control to 6.20 roots/plot under green manure. These reductions indicate that appropriate nutrient management was associated with lower *Cylas*-related losses and improved root quality, although unmarketable roots may arise from causes other than weevil damage and therefore cannot be attributed exclusively to *Cylas* suppression.

The particularly low infestation under green manure relative to the control, NPK and poultry manure suggests a strong treatment-associated response. Organic nutrient management can modify soil fertility, plant growth and the crop microenvironment, potentially influencing plant-pest interactions (Adams *et al.*, 2024). However, the present study did not measure insecticidal, repellent or biofumigation activity of *H. suaveolens*. Thus, the result demonstrates an association between green-manure application and reduced infestation rather than a confirmed direct pesticidal effect. This distinction is important because *Cylas* larvae feed within storage roots and are consequently difficult to detect and control after establishment (Yada *et al.*, 2023).

The three-year soil-management results provide an important context for the fertilizer responses. The initially degraded acidic Alfisol improved substantially in pH, organic carbon, total nitrogen, available phosphorus, exchangeable potassium and effective cation exchange capacity. Soil pH increased from 4.50 to 6.20, organic carbon from 0.31% to 1.44% (+364.5%), total nitrogen from 0.011% to 0.091% (+727.3%), available phosphorus from 4.40 to 7.04 mg kg⁻¹ (+60.0%), exchangeable potassium from 0.51 to 1.52 cmol kg⁻¹ (+198.0%), and ECEC from 6.54 to 8.54 cmol kg⁻¹ (+30.6%). These changes indicate substantial improvement in soil fertility and nutrient-retention capacity following three years of management.

Soil acidity can constrain nutrient availability and biological activity in tropical soils (Ch'ng *et al.*, 2022), while increased organic carbon and nitrogen contribute to nutrient cycling, soil structure and water retention (Kebede, 2021). Improved fertility may consequently strengthen crop growth and resilience to pest injury (Mwesige *et al.*, 2023). The interaction between land configuration and fertilizer management further suggests that physical and nutritional management may operate complementarily, with organic

amendments improving soil structure and biological activity while mounds and ridges can improve drainage and aeration. Nevertheless, soil biological populations, plant defence responses and *Cylas* survival were not directly measured. Therefore, proposed mechanisms involving altered pupal survival, microbial antagonism or adult emergence remain hypotheses requiring direct investigation (Liu *et al.*, 2020; Ilozobhie *et al.*, 2024).

The stronger suppression associated with green manure and poultry manure suggests that organic amendments may provide benefits beyond nutrient supply. By increasing organic matter, nutrient cycling and rhizosphere biological activity, organic inputs can improve soil conditions and potentially influence plant health and plant–herbivore interactions. Greater plant vigour may also improve tolerance of pest injury and sustain storage-root development. Organic inputs may influence plant defence pathways involving phenolics, terpenoids and other compounds associated with herbivore resistance (Ayobami *et al.*, 2021; Züst & Agrawal, 2021). The negative association between SPAD chlorophyll values and *Cylas* infestation is consistent with a plant–vigour mechanism whereby healthier plants may better withstand or compensate for herbivore injury (Huberty & Denno, 2019). Organic matter and habitat complexity generated by poultry and green manure may also stimulate microbial activity and beneficial soil organisms, potentially affecting soil-dwelling pest stages (Reddy *et al.*, 2018; Liu *et al.*, 2020). Decomposition of aromatic plant residues may release volatile compounds capable of influencing insect behaviour and development (Rahmawati *et al.*, 2023), while plant nutritional status can modify volatile organic compounds involved in herbivore host finding (Reddy & Erb, 2018). However, because volatile compounds, pest behaviour, larval mortality, entomopathogens and biological-control processes were not measured, the strong *H. suaveolens* response should be interpreted as treatment-associated suppression rather than proof of a specific insecticidal, repellent or biofumigation mechanism.

The treatment combinations demonstrated distinct variety × land configuration × fertilizer pathways for achieving high productivity. WF attained its highest yield of 41.53 t ha⁻¹ under mound configuration with NPK, whereas OF achieved 36.15 t ha⁻¹ under ridge configuration with poultry manure. These contrasting responses demonstrate that no single combination was universally optimal and emphasize the need to jointly consider genotype, land configuration and fertilizer source when developing recommendations. The negative correlations between *Cylas* infestation and marketable yield ($r = -0.301$) and fresh biomass ($r = -0.201$) further demonstrate the economic importance of infestation. Infestation was also positively associated with unmarketable roots, reinforcing its effects on both yield and root quality. Similar pest–yield relationships have been reported in sweet potato and other root and tuber crops exposed to chronic biotic stress (Okonya *et al.*, 2019; Nyasani *et al.*, 2021).

The positive associations of fresh biomass and chlorophyll status with marketable yield emphasize the importance of maintaining plant vigour under pest pressure. Greater biomass and photosynthetic capacity can support assimilate production and storage-root development, enabling plants to tolerate or compensate for pest injury (Huberty & Denno, 2019; Züst & Agrawal, 2021). Path analysis reinforced this interpretation by showing a direct negative effect of *Cylas* infestation on marketable yield and a positive direct effect of fresh biomass. Infestation also reduced yield indirectly through its negative association with fresh biomass. Thus, *Cylas* damage may reduce productivity through both direct

injury and disruption of plant growth and assimilate production, whereas vigorous growth may partially buffer yield losses.

The findings position varietal selection, fertility management and land configuration as complementary cultural components of *Cylas* management rather than standalone solutions. Variety and fertilizer source were stronger determinants of infestation than land configuration as main effects, while significant interactions demonstrated that management responses were context-dependent. An effective IPM framework should therefore combine suitable planting material, field sanitation, crop rotation, regular monitoring and conservation of biological control agents with appropriate soil fertility and land-management practices. Pheromone traps may support monitoring and, where appropriate, mass trapping (Kumar *et al.*, 2021), while judicious chemical intervention should be reserved for situations where pest pressure exceeds acceptable thresholds (Dara, 2019). Overall, integrating suitable varieties, appropriate nutrient sources and soil-health-improving practices offers a more sustainable strategy for reducing *Cylas*-associated losses while maintaining storage-root productivity. The strong response to organic amendments suggests benefits extending beyond nutrient supply, although the underlying biological and ecological mechanisms require further investigation to develop effective, context-specific management strategies.

Conclusion

This multi-season study demonstrates that integrated agronomic management can sustainably reduce *Cylas* weevil pressure while improving sweet potato productivity. Orange-fleshed varieties were 30.3% more infested than white-fleshed types, indicating varietal differences in susceptibility. *Hyptis suaveolens* green manure provided the strongest pest suppression and soil-fertility benefits, outperforming NPK, while land configuration alone had no significant main effect. However, raised configurations enhanced outcomes when combined with organic amendments. Mound + NPK minimized *Cylas* damage in white-fleshed varieties, whereas Ridge + poultry manure provided the best balance of reduced pest pressure and high marketable yield in orange-fleshed varieties. The negative association between *Cylas* infestation, yield and plant vigour reinforces the need for proactive management.

An effective Integrated Pest Management strategy should therefore combine raised land configurations, locally available organic amendments, variety-specific management, clean planting material and regular pest monitoring. Extension services should promote these practices through farmer training and demonstration plots, supported by improved access to inputs. Future research should clarify soil microbial and root-volatile mechanisms, evaluate long-term soil-health and yield stability, assess economic returns, and support breeding of varieties adapted to integrated *Cylas* management systems under degraded savanna conditions.

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