*The Bioscientist Journal Vol. 14 (2): 21 – 38, May 2026*
*Journal of the Faculty of Biosciences, Nnamdi Azikiwe University, Awka, Nigeria*
*Available online at http://www.bioscientistjournal.com*
DOI 10.54117/the_bioscientist.v14i2.214



OPEN ACCESS

*Full Length Research Article*

# Comparative Studies of Different Combinations of Bio-Enhancers (Cassava Peel and Poultry Manure) on the Growth of *Capsicum chinense* Jacq. (Scotch Bonnet pepper)

**[1,*]Amadi, N., [2]Yabrade, M. and [1]Nsan-nicholas, O. H.,**

[1]Department of Plant Science and Biotechnology, Faculty of Science, Rivers State University, Port Harcourt Nigeria
[2]Department of Marine Environment and Pollution Control Nigeria Maritime University, Okerenkoko Deltra State, Nigeria.
*Corresponding Author Email: noble.amadi1@ust.edu.ng * ORCID: https://orcid.org/0000-0002-8719-3049
***Article History**: Received: 30th October, 2025 Accepted: 23rd May, 2026*

**Abstract**

This study investigated the comparative effects of different combinations of cassava peel and poultry manure as bio-enhancers on the growth of *Capsicum chinense*. The experiment was conducted under greenhouse conditions using a Completely Randomized Design (CRD). The treatments comprising: $T_1$ (control), $T_2$ (cassava peel), $T_3$ (poultry manure), $T_4$ (50% cassava peel + 50% poultry manure), $T_5$ (75% cassava peel + 25% poultry manure), and $T_6$ (25% cassava peel + 75% poultry manure), were assessed for their influence on plant morphological at 2 and 4 weeks after planting (WAP), alongside soil nutrient parameters. The morphological trait result revealed that at 4 weeks, the highest plant height was recorded in $T_3$ (9.3 ± 0.5 cm) and $T_4$ (8.0 ± 0.01 cm), while $T_2$ showed the lowest values (1.340±0.75; 2.36±0.5) for 2weeks and 4 weeks. Leaf was highest at $T_2$ (22.36 ± 0.25) and $T_3$ (19 ± 0.5), whereas the control produced significantly fewer leaves (6.0±0.007). Stem girth increased substantially in $T_3$ (9.4 ± 0.1 mm) and $T_6$

(9.0 ± 0.001 mm), outperforming the control (7.0 ± 0.065 mm). Similarly, leaf area was maximized in $T_4$ (56.06 ± 1.03 cm²) and $T_6$ (49.0 ± 0.09 cm²), compared with the control (28 ± 0.5 cm²). A strong positive correlation was observed between nitrogen and phosphorus (r = 0.785, p = 0.064) and between potassium and sodium (r = 0.907, p = 0.0125), indicating complementary nutrient interactions in the soil. Multivariate analyses supported these results. Cluster analysis grouped $T_4$, $T_6$, and $T_3$ (4 WAP) as morphologically similar and superior, while PCA separated $T_3$, $T_4$, and $T_5$ from the control, confirming treatment differentiation. The findings suggest that the synergistic use of cassava peel and poultry manure can improve soil fertility and promote vigorous growth of *Capsicum chinense*, providing a sustainable and eco-friendly alternative.

**Keyword**: Cassava peel, Poultry manure, *Capsicum chinense*, Organic amendments, Soil fertility, Morphological traits, Principal Component Analysis (PCA).

## Introduction

The continuous decline in soil fertility caused by intensive cultivation, erosion, and over-dependence on synthetic fertilizers has necessitated the search for eco-friendly and cost-effective alternatives to enhance crop productivity. Organic amendments such as poultry manure and agro-wastes like cassava peels are known to improve soil structure, increase nutrient availability, and support microbial activity beneficial to plant growth (for example, poultry manure improved organic carbon, available phosphorus and total nitrogen in degraded Alfisols) (Adeleye *et al.,* 2010; Stoleru *et al*., 2023). Cassava peel, a by-product of cassava processing, is rich in organic matter and carbohydrates, while poultry manure provides essential macro- and micronutrients such as nitrogen, phosphorus, and potassium. Combining these organic materials may offer synergistic effects, improving nutrient release and soil microbial activity (for example, combinations of cassava peels and poultry manure significantly increased soil N, P, K, Mg and Ca in experiments) (Stoleru, *et al*. 2023).

*Capsicum chinense*, commonly known as Scotch Bonnet pepper, is a high-value horticultural crop widely cultivated for its pungency, nutritional, and economic importance. However, its growth and yield potential are often limited by nutrient deficiencies, particularly in degraded tropical soils. For example, while some studies find soil type a negligible effect on vitamin/carotenoid accumulation in *C. chinense* fruits, nutrient-rich soils nonetheless remain critical for achieving optimum yield and quality (Avasiloaiei *et al*., 2025; Jiang, *et al*., 2025).

This study was therefore designed to evaluate the comparative influence of cassava peel and poultry manure combinations on the growth performance of *Capsicum chinense* using hypothetical data to demonstrate their potential impact on sustainable agriculture (Das *et al*., 2021; Sini *et al*., 2024).

## Materials And Methods

### Study Area

The study was carried out at the Rivers State University Botanical Farm, located at latitude 4°47'51.96" N and longitude 6°58'50.93" E, within the Niger Delta region of Nigeria. The area lies within the humid tropical zone and is well known for its suitability for diverse agricultural practices. The region experiences two distinct seasons: the wet season (April to September) and the dry season (October to March). Annual

rainfall ranges between 2,400 mm and 4,000 mm**,** providing ample soil moisture that supports vigorous plant growth during the rainy months. The high humidity levels characteristic of the wet season contribute significantly to the productivity of farmlands in the study area. Conversely, the dry season is marked by reduced rainfall and elevated temperatures, creating contrasting climatic conditions that influence crop growth cycles and determine planting and harvesting periods. The soils of the area are generally well-drained and fertile, typical of the Niger Delta, making the location suitable for agricultural research and experimental cultivation.

**Sources of Materials and Processing**

Cassava peels and poultry manure (Plates 1and 2) used in this study were collected from Omuoda, Aluu, in Ikwerre Local Government Area of Rivers State. The community is recognized for its intensive cassava production. The cassava peels were obtained as by-products following the processing of cassava tubers for consumption. To enhance its storability, the peels were sun-dried for one week**.** After drying, they were milled into a fine powder to ensure uniformity and ease of handling. On the other hand, the freshly collected poultry droppings were air-dried for several hours to reduce moisture content and minimize the proliferation of harmful pathogens. Following drying, the manure was sieved manually to remove coarse particles, ensuring a fine and homogeneous texture suitable for use as an organic soil amendment. The processed cassava peel powder and manure were subsequently taken to the laboratory for nutrient composition analysis as shown in Table 1.



**Plate 1: Cassava Peels during Processing at Omuoda, Aluu.**



**Plate 2: Poultry Manure at a Local Poultry**

**Experimental Design and Treatments**

The study was conducted in a greenhouse environment using a Complete Randomized Design (CRD) with six treatments option replicated six times. Each planting bag was filled with 2 kg of topsoil after baseline analysis. They were prepared for use in planting, with some of them mixed with respective bio-enhancer treatments as shown in Table 1. Then, Healthy *Capsicum chinense* two seedlings were transplanted into bags and maintained under uniform irrigation and management conditions.

**Table 1: Treatment application**

| Treatment | Composition (%) |
|---|---|
| $T_1$ | Control (no amendment) |
| $T_2$ | 100% Cassava peel |
| $T_3$ | 100% Poultry manure |
| $T_4$ | 50% Cassava peel + 50% Poultry manure |
| $T_5$ | 75% Cassava peel + 25% Poultry manure |
| $T_6$ | 25% Cassava peel + 75% Poultry manure |

The experiment was monitored for a period of four weeks. At the end of the experiment, soil samples were collected from each plot and treatment option. The samples were properly labeled and transported to the laboratory for the determination and analysis of their chemical properties.

**Growth Parameters Measured**

At 2-week intervals, the following parameters were recorded from 2 to 4 weeks after transplanting (WAT): plant height (cm), Number of leaves, Stem girth (mm) and Leaf area ($cm^2$).

**Plant Height Measurement**: Plant height was measured from the soil surface at the base of each plant to the tip of the apical shoot. A calibrated meter rule/tape was used depending on plant size. All measurements were taken in the morning when plants were turgid to ensure consistency.

**Stem Girth (Stem Diameter) Measurement**: Stem girth was determined at approximately 1–2 cm above the soil surface to avoid irregularities near the root collar. This was done for all treatment options and replications. A digital Vernier caliper was used to obtain precise measurements. Stem diameter was recorded to the nearest 0.01 mm. Measurements were taken carefully to avoid compressing the stem.

**Number of Leaves**: The number of leaves per plant was determined through manual counting. Only fully expanded and healthy leave**s** were included, while senescent, damaged, or newly emerging leaves were excluded to maintain consistency. Leaf count was performed at specified intervals throughout the study period and this process was done for all treatment options and replications.

**Leaf area**: Leaf area was determined using the non-destructive method described by Carleton and Foote (1965), where leaf area (LA) was estimated as: Leaf Area=L×W×C where $L$ = leaf length (cm), $W$ = maximum leaf width (cm), and $C$ = correction factor (0.75 for *Capsicum* species). This was done for all treatment options and replications

**Determination of Soil Chemical Parameter**

**Determination of Soil pH:** Soil pH was determined using the soil water suspension method as described by Jackson (1958). A 1:2.5 soil-to-water ratio was prepared by mixing 10 g of air-dried soil with 25 mL of distilled water. The mixture was stirred and allowed to equilibrate for 30 minutes. The pH was then measured using a standardized digital pH meter, previously calibrated with buffer solutions of pH 4.0, 7.0, and 9.0.

**Determination of Total Nitrogen (N):** Total nitrogen was determined using the Kjeldahl digestion method following Bremner (1965). Soil samples (1 g) were digested with concentrated sulfuric acid ($H_2SO_4$) and a digestion catalyst ($K_2SO_4$ + $CuSO_4$). The digested solution was distilled using a micro-Kjeldahl apparatus and the liberated ammonia ($NH_3$) was collected in boric acid solution. Titration with standardized HCl was used to quantify nitrogen content.

**Determination of Available Phosphorus (P):** Available phosphorus was determined using the Olsen method for neutral–alkaline soils or the Bray-1 method for acidic soils (Olsen *et al*., 1954). Soil samples were extracted with 0.5 M $NaHCO_3$ (pH 8.5). The concentration of P in the extract was read using a spectrophotometer at 882 nm after development of the blue molybdate complex.

**Determination of Exchangeable Potassium (K) and Sodium (Na):** Exchangeable K and Na were determined using the ammonium acetate extraction method described by Thomas (1982). Soil samples were extracted with 1 M ammonium acetate ($NH_4OAc$) at pH 7.0. The filtrate was analyzed using a flame photometer, calibrated with standard K and Na solutions.

**Determination of Exchangeable Magnesium (Mg):** Exchangeable Mg was also determined from the $NH_4OAc$ extract, following procedures outlined by Jackson (1958) and Thomas (1982). Instead of flame photometry (used for K and Na), Mg concentration was quantified using an Atomic Absorption Spectrophotometer (AAS) at the appropriate wavelength (285.2 nm).

**Data Analysis**

The data generated from the field experiment were subjected to Analysis of Variance (ANOVA) using SAS to determine the significance of treatment effects. Mean separation was carried out using Duncan's

Multiple Range Test (DMRT) at the 5% probability level. In addition, correlation analysis was performed to evaluate the relationships among the measured soil chemical properties. Principal Component Analysis (PCA) and dendrogram cluster analysis were also conducted to compare the impact and similarity of the different treatment options on the soil properties and to identify patterns of variation among treatments.

## Results

### Baseline analysis for soil and treatments

The analysis of the soil chemical parameters showed considerable variation in nutrient composition. Total nitrogen (N) content was relatively high at 75.6 mg/L. Phosphorus (P) concentration was low, measuring 1.0 mg/L. Potassium (K) concentration was moderate at 40.1 mg/L, whereas magnesium (Mg) exhibited a notably high concentration of 210.4 mg/L. The soil pH was recorded as 6.0, while Sodium (Na) concentration was low at 2.7 mg/L (Table 2).

**Table 2 Soil Chemical properties before treatment application**

| S/N | Sample identify | N (mg/L) | Phosphorus (mg/L) | K (mg/L) | Mg (mg/L) | pH | Na (mg/L) |
|---|---|---|---|---|---|---|---|
| 1 | Soil chemical | 75.6 | 1.0 | 40.1 | 210.4 | 6 | 2.7 |

At baseline (Table 3), cassava peel recorded a relatively low nitrate concentration of 1.30 mg/L, moderate phosphorus content at 2.97 mg/L, and a very high potassium level of 248.3 mg/L, Magnesium concentration was 109.13 mg/L, also comparatively high. The material exhibited a slightly acidic pH of 5.40. Sodium concentration was remarkably high at 544 mg/L, In contrast, poultry manure had a higher Nitrogen content of 4.70 mg/L, but a lower phosphorus concentration (1.69 mg/L) compared to cassava peel. Potassium concentration was low (2.5 mg/L), and magnesium was minimal at 0.25 mg/L. Poultry manure showed a slightly acidic to near-neutral pH of 6.2, while sodium concentration was 32 mg/L, considerably lower than that of cassava peel (Table 3).

**Table 3. Baseline analysis of cassava peel and poultry manure**

| **S/N** | **Sample identify** | **N (mg/L)** | **Phosphorus (mg/L)** | **K (mg/L)** | **Mg (mg/L)** | **pH (mg/L)** | **Na (mg/L)** |
|---|---|---|---|---|---|---|---|
| 1 | Cassava peel | 1.30 | 2.97 | 248.3 | 109.134 | 5.40 | 544 |
| 2 | Poultry manure | 4 70 | 1.69 | 2.5 | 0.25 | 6.2 | 32 |

### Effect of Organic Amendments on Plant Morphological Parameters for Plant Height (cm), Number of Leaves, Stem Girth (mm), and Leaf Area (cm²).

At 2 weeks after planting (WAP), seedlings in the control plots ($T_1$) exhibited a mean plant height of 4.0 ± 0.6 cm, which was significantly lower ($p < 0.05$) than those grown in soils amended with organic materials. By 4 WAP, plant height increased markedly across all treatments. The tallest plants were observed in $T_4$ (50% Cassava peel + 50% Poultry manure) with 9.3 ± 0.5 cm and $T_6$ (25% Cassava peel + 75% Poultry manure) with 7.9 ± 0.5 cm, both of which were significantly ($p < 0.05$) higher than the control (5.33 ± 0.5 cm) and the 100% cassava peel treatment ($T_2$, 2.36 ± 0.5 cm). The least height recorded in the cassava-only treatment ($T_2$) indicates that cassava peel alone was less effective in promoting stem elongation. The Least Significant Difference (LSD) (0.34 cm) value confirmed significant differences among treatment means. Similarly, results revealed that the number of leaves varied considerably among treatments. At 2 WAP, leaf number ranged from 3.0 ± 0.02 in the control to 13.0 ± 0.15 in the poultry-manure-amended soil ($T_3$). By 4 WAP, the number of leaves increased significantly ($p < 0.05$) across all treatments, with $T_4$ (50% Cassava + 50% Poultry) recording the highest leaf number (19.0 ± 0.5) followed by $T_6$ (25% Cassava + 75% Poultry) with 8.07 ± 0.01. The least number of leaves occurred in cassava-only treatments ($T_2$ and $T_5$), both below seven leaves. Generally, treatments containing poultry manure either alone or in combination with cassava peel produced significantly higher leaf numbers than cassava-only treatments, demonstrating the positive effect of poultry manure on vegetative development. The variation among treatment means was significant as indicated by the LSD value (0.82) (**Table 4**). The stem girth of the seedlings also responded positively to the organic amendments. At 2 WAP, stem girth ranged between 4.28 ± 0.2 mm in the control and 5.9 ± 0.5 mm in poultry-manure-treated soil. By 4 WAP, a significant ($p < 0.05$) increase was observed across all treatments, with the thickest stems recorded in $T_4$ (9.4 ± 0.1 mm) and $T_6$ (9.0 ± 0.001 mm). These were statistically superior to the control (7.0 ± 0.065 mm) and cassava-only treatment (6.23 ± 0.21 mm). The LSD (0.66 mm) confirmed the significance of these differences, suggesting that poultry manure, either used alone or in combination with cassava peel, enhanced stem development and structural strength. Leaf area also increased progressively with both plant age and manure application rate. At 2 WAP, the control recorded the smallest leaf area (25.9 ± 0.05 cm²), whereas the largest was observed in $T_6$ (56.06 ± 1.03 cm²). By 4 WAP, leaf area remained highest in poultry-based treatments $T_4$ (52.0 ± 0.25 cm²) and $T_6$ (49.0 ± 0.09 cm²) which were significantly ($p < 0.05$) greater than the control (28 ± 0.5 cm²) and the cassava-only treatment (32.4 ± 0.3 cm²). The LSD (0.94 cm²) further confirmed highly significant differences among treatments (**Table 4**).

**Table 4: Effect of Organic Amendments on Plant Morphological Parameters**

| Morphology | Weeks after planting | $T_1$ (Control) | $T_2$ (Cassava peel) 100% | $T_3$ (Poultry manure) 100% | $T_4$ (50% Cassava + 50% Poultry) | $T_5$ (75% Cassava + 25% Poultry) | T6 (25% Cassava + 75% Poultry) | LSD |
|---|---|---|---|---|---|---|---|---|
| Plant height | 2 weeks | $4.0±0.6^b$ | $1.340±0.75^d$ | $6.52±0.44^a$ | $2.0±0.09^c$ | $1.2±0.3^d$ | $1.56±0.1^d$ | 0.34 |
| | 4 weeks | $5.33±0.5^c$ | $2.36±0.5^d$ | $9.3±0.5^a$ | $8.0±0.01^a$ | $5.5±0.91^c$ | $7.9±0.5^b$ | 114 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Number of Leaves* | 2 weeks | 3.0±0.02$^{c}$ | 13±0.15$^{a}$ | 12.0±0.44$^{b}$ | 2.33±0.58$^{c}$ | 2.66±0.5$^{c}$ | 2.89±0.62$^{c}$ | 0.82 |
| | 4 weeks | 6.0±0.007$^{c}$ | 2236±0.25$^{a}$ | 19±0.5$^{b}$ | 7.0±1.73$^{c}$ | 6.33±0.57$^{c}$ | 8.07±0.01$^{bc}$ | 2.22 |
| *Stem Girth (mm)* | 2 weeks | 4.28±0.2$^{c}$ | 5.9±0.5$^{b}$ | 6.45.0±0.4$^{b}$ | 7.83±0.8$^{a}$ | 6.6±0.5$^{b}$ | 7.8±0.2$^{a}$ | 0.66 |
| | 4 weeks | 7.0±0.065$^{c}$ | 6.23±0.21$^{c}$ | 9.4±0.1$^{a}$ | 8.06±1.3$^{b}$ | 6.98±0.7$^{c}$ | 9.0±0.001$^{a}$ | 1.28 |
| *Leaf Area ($cm^2$)* | 2 weeks | 25.9±0.05$^{d}$ | 32.4±0.3$^{c}$ | 35.0±0.24$^{c}$ | 52±0.252$^{a}$ | 34±0.8$^{c}$ | 44±0.2$^{b}$ | 0.94 |
| | 4 weeks | 28±0.5$^{d}$ | 36.3±0.2$^{c}$ | 39.8±0.9$^{c}$ | 56.06±1.03$^{a}$ | 36.9±0.2$^{c}$ | 49.0±0.09$^{b}$ | 1.71 |

Note: Mean values with different superscript alphabets across each row significantly difference at $P<0.05$.

**Effect of amendment on soil chemical properties**

The application of cassava peel and poultry manure, either singly or in combination, significantly influenced the soil's macronutrient composition and pH compared with the control treatment ($p < 0.05$) (Table 5). Soil potassium (K) concentration varied markedly among treatments. The highest K content (248.3 ± 0.54 mg $kg^{-1}$) was recorded in the cassava peel only–amended soil ($T_2$), which was significantly ($p < 0.05$) higher than all other treatments. Moderate K levels were obtained in the combined treatments $T_4$ (50% Cassava + 50% Poultry), $T_5$ (75% Cassava + 25% Poultry), and $T_6$ (25% Cassava + 75% Poultry) with respective values of 44 ± 3 mg $kg^{-1}$, 42.8 ± 1.00 mg $kg^{-1}$, and 41.8 ± 0.25 mg $kg^{-1}$. The lowest K value (2.5 ± 0.12 mg $kg^{-1}$) occurred in the poultry manure only treatment ($T_3$). The LSD (1.33) confirmed significant differences among treatment means, indicating that cassava peel contributed more strongly to soil potassium enrichment than poultry

Magnesium (Mg) concentration also differed significantly ($p < 0.05$) among treatments. The highest Mg value (162.33 ± 12 mg $kg^{-1}$) was observed in $T_4$ (50% Cassava + 50% Poultry), followed by $T_6$ (25% Cassava + 75% Poultry) and $T_5$ (75% Cassava + 25% Poultry), with values of 142.33 ± 4.3 mg $kg^{-1}$ and 122 ± 0.22 mg $kg^{-1}$, respectively. The control (112.33 ± 0.57 mg $kg^{-1}$) and cassava-only treatment (109.12 ± 2.05 mg $kg^{-1}$) recorded moderate Mg levels, while the poultry-only treatment ($T_3$) had the least Mg (0.25 ± 0.04 mg $kg^{-1}$). The LSD (1.08) confirmed a highly significant variation, suggesting that combined organic treatments enhanced Mg availability in the soil more effectively than single amendments.

Soil nitrogen (N) content was significantly affected by the organic amendments ($p < 0.05$). The highest N concentrations were obtained in $T_4$ (23.86 ± 0.2 mg $kg^{-1}$) and $T_5$ (33.23 ± 0.02 mg $kg^{-1}$), which were statistically similar but superior to other treatments. $T_6$ (22.83 ± 0.05 mg $kg^{-1}$) also recorded elevated N values compared to the control (19.45 ± 0.05 mg $kg^{-1}$). Conversely, the cassava-only treatment ($T_2$) recorded the lowest nitrogen content (1.30 ± 0.54 mg $kg^{-1}$), indicating limited N mineralization from cassava peel alone. The LSD (0.14) confirmed the high level of treatment effect, emphasizing that poultry manure substantially improved nitrogen enrichment when used either alone or in mixtures.

Sodium (Na) concentration ranged from 32.66 ± 1.14 mg $kg^{-1}$ in $T_6$ (25% Cassava + 75% Poultry) to 54 ± 0.84 mg $kg^{-1}$ in $T_2$ (Cassava peel 100%). Although $T_2$ recorded the highest Na level, differences among treatments were relatively small. The control (38.26 ± 2 mg $kg^{-1}$) and most combined

treatments ($T_4$, $T_5$, $T_6$) had statistically similar Na contents, suggesting that the amendments had minimal effect on soil sodium. Nonetheless, the LSD (1.14) confirmed significant but mild variation between means.

Phosphorus (P) levels were significantly influenced ($p < 0.05$) by the treatments. The highest P value (8 ± 0.2 mg $kg^{-1}$) occurred in $T_3$ (Poultry manure 100%), followed by $T_4$ (6.86 ± 0.02 mg $kg^{-1}$), $T_5$ (6.43 ± 0.005 mg $kg^{-1}$), and $T_6$ (5.91 ± 0.04 mg $kg^{-1}$). The control (3.15 ± 3 mg $kg^{-1}$) and cassava-only treatment (2.8 ± 0.52 mg $kg^{-1}$) recorded the lowest phosphorus concentrations. The LSD (0.23) confirmed significant treatment effects, highlighting the efficiency of poultry manure in enhancing soil phosphorus availability.

Soil pH values ranged from 6.0 ± 0.005 in the cassava peel and poultry manure only treatments to 8.43 ± 2 in the control. The combined treatments $T_4$ (6.7 ± 0.4), $T_5$ (8.32 ± 0.12), and $T_6$ (8.33 ± 0.11) were slightly alkaline but remained within the favorable range for nutrient uptake. The LSD (0.20) confirmed significant differences among treatment means. These results suggest that organic amendments, particularly poultry manure, moderated soil acidity and promoted conditions conducive to nutrient mineralization and plant growth.

**Table 5: Effect of amendment on soil chemical properties**

| Chemical properties | $T_1$ (Control) | $T_2$ (Cassava peel) | $T_3$ (Poultry manure) | $T_4$ (50% Cassava + 50% Poultry) | $T_5$ (75% Cassava + 25% Poultry) | $T_5$ (25% Cassava + 75% Poultry) | LSD |
|---|---|---|---|---|---|---|---|
| k | 32.33±5$^{c}$ | 248.3±0.54$^{a}$ | 2.5±0.12 | 44±3$^{b}$ | 42.8±1.00$^{b}$ | 41.8±0.245$^{b}$ | 1.33 |
| Mg | 112.33±0.57$^{c}$ | 109.12±2.05$^{c}$ | 0.25±0.04$^{d}$ | 162.33±12$^{a}$ | 122±0.22$^{b}$ | 142.33±4.3$^{b}$ | 1.08 |
| N | 19.45±0.05$^{c}$ | 1.30±0.54$^{f}$ | 5.9±0.02$^{d}$ | 23.86±0.2$^{a}$ | 33.23±0.02$^{a}$ | 22.83±0.05$^{b}$ | 0.14 |
| Na | 38.26±2$^{b}$ | 54±0.84$^{a}$ | 38±2$^{b}$ | 33.54±5$^{b}$ | 37.00±0.057$^{b}$ | 32.66±1.14$^{b}$ | 1.14 |
| P | 3.145±3$^{c}$ | 2.8±0.52$^{c}$ | 8±0.2$^{a}$ | 6.86±0.02$^{b}$ | 6.433±0.005$^{b}$ | 5.91±0.04$^{b}$ | 0.23 |
| pH | 8.43±2$^{a}$ | 6±0.005$^{b}$ | 6±0.092$^{b}$ | 6.7±0.4$^{b}$ | 8.32±0.12$^{a}$ | 8.33±0.112$^{a}$ | 0.20 |

Note: Mean values with different superscript alphabets across each row significantly difference at $P<0.05$.

**Correlation among Soil Chemical Properties**

The correlation analysis among the soil chemical properties revealed varying degrees of positive and negative relationships between the parameters. Potassium (K) showed a very strong positive correlation with sodium (Na) ($r = 0.90730$). However, K exhibited negative correlations with nitrogen (N) ($r = -0.54565$), phosphorus (P) ($r = -0.67610$), and soil pH ($r = -0.42714$). A weak positive correlation was observed between K and magnesium (Mg) ($r = 0.18013$).

Magnesium (Mg) showed a moderate positive correlation with nitrogen (N) ($r =$

0.58813) and soil pH (r = 0.47640), while weak negative correlations were recorded with sodium (Na) (r = -0.19222) and phosphorus (P) (r = -0.30667).
Nitrogen (N) exhibited a strong positive correlation with soil pH (r = 0.78499). Conversely, nitrogen showed a strong negative correlation with sodium (Na) (r = -0.71686), while a weak positive relationship was observed with phosphorus (P) (r = 0.28386). Sodium (Na) demonstrated strong negative correlations with phosphorus (P) (r = -0.65393) and soil pH (r = -0.52610). Phosphorus (P) showed a weak negative correlation with soil pH (r = -0.14735), suggesting minimal association between these two parameters.

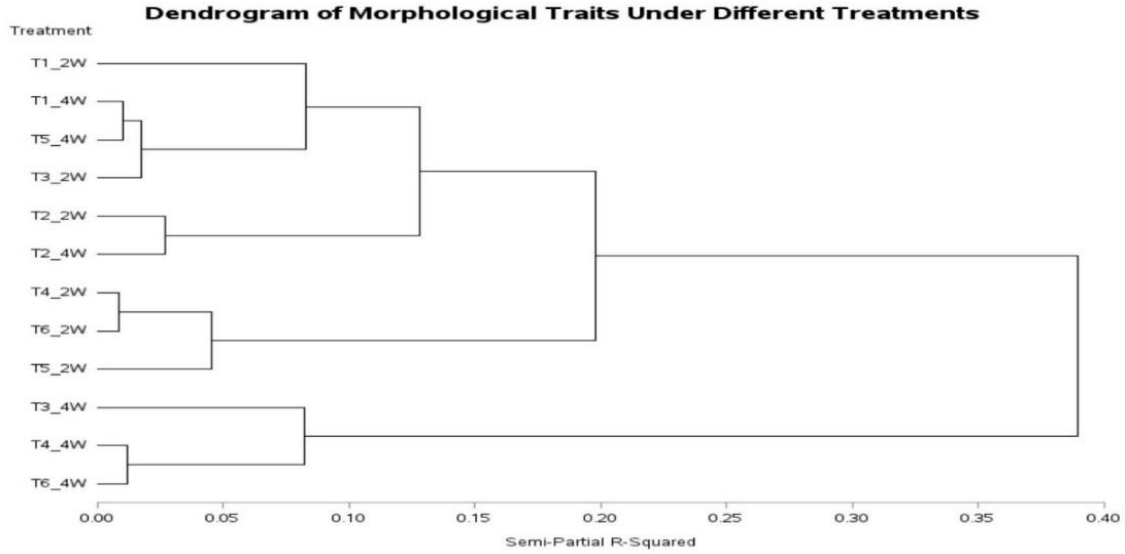
**Table 6: The correlation matrix of varying degrees of association among soil macronutrients and pH under different organic amendment treatments.**

| | K | Mg | N | Na | P | pH |
|---|---|---|---|---|---|---|
| K | 1.00000 | | | | | |
| Mg | 0.18013 | 1.00000 | | | | |
| N | -0.54565 | 0.58813 | 1.00000 | | | |
| Na | 0.90730 | -0.19222 | -0.71686 | 1.00000 | | |
| P | -0.67610 | -0.30667 | 0.28386 | -0.65393 | 1.00000 | |
| pH | -0.42714 | 0.47640 | 0.78499 | -0.52610 | -0.14735 | 1.00000 |

**Dendrogram Ward's Minimum Variance Cluster Analysis**

The dendrogram of morphological traits under different treatments, obtained using Ward's Minimum Variance Method, reveals the hierarchical relationships among the treatments based on their morphological similarity. The treatments were grouped based on the semi-partial R-squared distance,

indicating the degree of dissimilarity between clusters. At approximately 0.20 rescaled semi-partial $R^2$, three distinct clusters can be identified: Cluster I: T1_2W, T1_4W, T5_4W, T3_2W, T2_2W, and T2_4W exhibited close similarity in their morphological characteristics, indicating comparable growth responses during the 2nd and 4th weeks. While in cluster II, showed that T4_2W, T6_2W, and T5_2W treatments had moderate similarity. Perhaps, cluster III with T3_4W, T4_4W, and T6_4W treatments are distinctly separated from the others, indicating pronounced differences in morphological traits, especially at the 4th week of treatment.



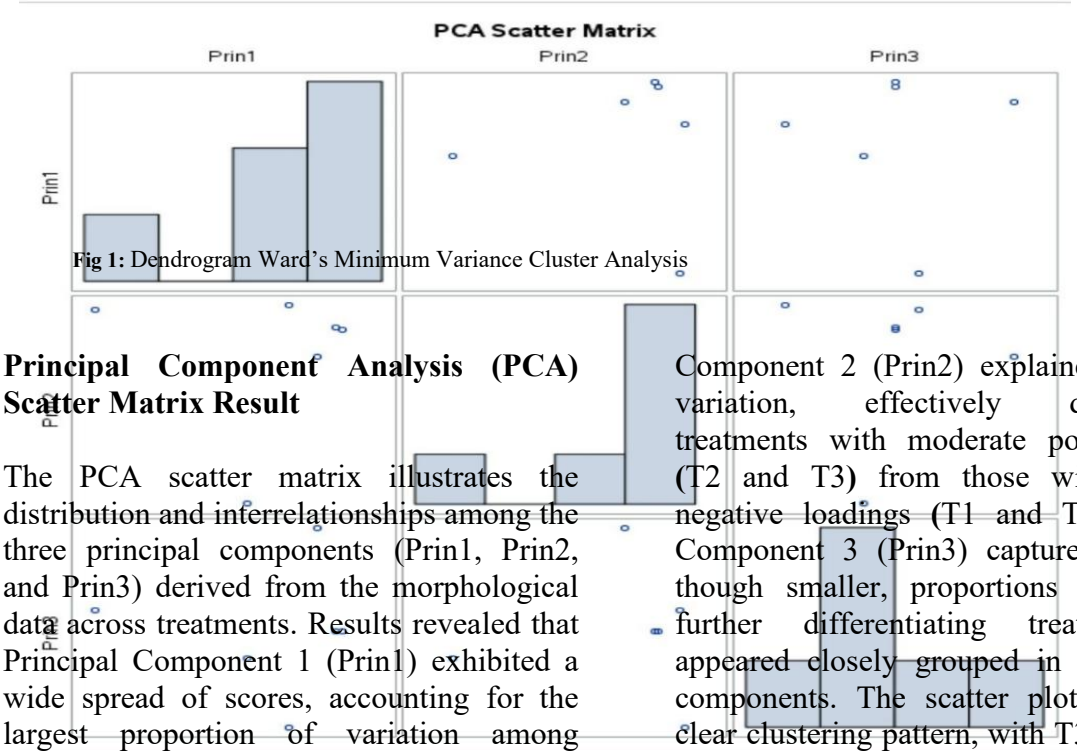



**Fig 1:** Dendrogram Ward's Minimum Variance Cluster Analysis

**Principal Component Analysis (PCA) Scatter Matrix Result**

The PCA scatter matrix illustrates the distribution and interrelationships among the three principal components (Prin1, Prin2, and Prin3) derived from the morphological data across treatments. Results revealed that Principal Component 1 (Prin1) exhibited a wide spread of scores, accounting for the largest proportion of variation among treatments. Treatments T3, T4, and T5 were positioned towards higher Prin1 values, whereas T1 was distinctly separated with lower scores, reflecting divergent morphological characteristics. Principal Component 2 (Prin2) explained secondary variation, effectively distinguishing treatments with moderate positive scores (T2 and T3) from those with lower or negative loadings (T1 and T4). Principal Component 3 (Prin3) captured additional, though smaller, proportions of variation, further differentiating treatments that appeared closely grouped in the first two components. The scatter plots revealed a clear clustering pattern, with T3, T4, and T5 forming a compact cluster indicative of strong morphological similarity, while T1 remained isolated, confirming its distinct response. Treatments T2 and T6 occupied intermediate positions.

**Fig 2:** The PCA scatter matrix illustrates the distribution and interrelationships among the three principal components (Prin1, Prin2, and Prin3) derived from the morphological data across treatments.

## Discussion

The present study demonstrated that the application of organic amendments, particularly poultry manure and its combinations with cassava peel, significantly enhanced the morphological growth parameters of the test plants compared to the unamended control. The marked increases in plant height, number of leaves, stem girth, and leaf area across treatments indicate that nutrient availability and soil fertility were greatly improved through organic matter incorporation. At the early growth stage (2 WAP), seedlings in the control plots exhibited limited growth performance, as reflected in their shorter height and fewer leaves. This observation which suggests nutrient deficiency typical of unamended soils, may have restricted vegetative development. Similar result was also reported by Ayeni *et al*., (2012) and Ndukwe *et al*., (2020). In contrast, the treatments containing poultry manure ($T_3$, $T_4$, and $T_6$) showed optimal morphological responses, highlighting the manure's high nutrient content especially nitrogen, phosphorus, and potassium. This finding is understandable since the added organic could be responsible for higher morphological growth because of the presence of essential growth nutrient in the amendment used. This result is in agreement with Adeleye *et al*., (2010) and Egbuchua and Enujeke, (2013), that exposing plant to essential nutrients can enhance optimal plant. By 4 WAP, plant height and leaf number increased substantially in all organically amended soils, with the best performance observed in the 50% Cassava peel + 50% Poultry manure ($T_4$) and 25% Cassava peel + 75% Poultry manure ($T_6$) treatments. This synergistic effect between cassava peel and poultry manure may be attributed to improved soil structure, increased microbial activity, and gradual nutrient mineralization that ensured a sustained nutrient supply to the plants. Similar observations were reported by Iren *et al*. (2016), and Adekiya *et al.,* (2019) who found that combining organic residues with animal manures enhanced nutrient release patterns and improved plant growth compared to single organic inputs. The poor growth recorded in the cassava-only treatments ($T_2$ and $T_5$) underscores the low nutrient density and slower decomposition rate of cassava peels, which alone may not provide sufficient immediate nutrients to support vigorous early growth (Odedina *et al.,* 2003; Akanbi *et al.,* 2007). However, when blended with nutrient-rich poultry manure, the resulting mixture enhances both the organic matter content and nutrient balance, thereby promoting plant vigor and productivity.

Stem girth and leaf area also followed a similar pattern, with significant increases in the poultry-based treatments at both growth stages. The observed improvement in stem thickness suggests enhanced photosynthetic response and mechanical support due to better nutrient uptake while larger leaf area in these treatments further indicates improved photosynthetic efficiency and biomass accumulation, which are crucial determinants of plant productivity. Similar result was reported by Makinde *et al*., (2011) and Aliyu *et al*., (2014). The significant differences indicated by LSD values across all morphological parameters reaffirm the positive and consistent influence of poultry manure on plant growth. This finding aligns with previous studies that reported the superior effects of poultry manure compared to other organic residues due to its balanced nutrient composition and faster mineralization rate (Agbede *et al*., 2008; Ayeni *et al*., 2010).

**Effect of amendment on soil chemical properties**

The application of cassava peel and poultry manure, both alone and in combination, significantly improved soil macronutrient composition and pH compared with the un-amended control. This finding is consistent with prior work showing that organic amendments derived from crop residues and animal manures can enhance nutrient availability and raise soil pH in acidic tropical soils. Similar result was reported by Stoleru, *et al*. (2023). The highest K content recorded in the cassava-peel only treatment ($T_2$), which was significantly greater than all other treatments. This could be attributed to the concentration of K in the cassava peel. Moderate K levels occurred in the mixed treatments ($T_4$, $T_5$, $T_6$) with values respectively. The poultry-only treatment ($T_3$) had the lowest K concentration. This pattern suggests that cassava peel contributes strongly to soil K enrichment relative to poultry manure. A similar observation was made in a study of cassava peel and poultry manure-based compost where cassava peel supplied higher K than some animal-derived manures. The high K in $T_2$ may be due to the release of exchangeable K from the decomposition of cassava peels, which are known to have appreciable K content. The much greater K concentration in the cassava-only treatment indicates that this residue is an excellent source of exchangeable K for soils. This aligns with previous by Agbor *et al*. (2015) whose studies showed that cassava peels contributed notably to K pools.

Magnesium (Mg) also differed significantly among treatments ($p < 0.05$). The highest Mg was observed in $T_4$ (50% Cassava + 50% Poultry), followed by $T_6$ (25% Cassava + 75% Poultry) and $T_5$ (75% Cassava + 25% Poultry). The control and cassava-only treatment had moderate Mg levels, while the poultry-only treatment ($T_3$) had the least This indicates highly significant variation. The superior performance of combined organic treatments suggests synergistic effects of cassava peel + poultry manure on Mg availability. The highest N concentrations were noted in $T_5$ and $T_4$ which did not differ statistically, but both exceeded other treatments. $T_6$ also recorded elevated N compared with the control. This is consistent with studies showing that poultry manure has a high N content and that combinations with crop-residue amendments improve total soil N. For instance, research showed that poultry manure and cassava peel-based compost significantly increased total N compared to control. Similar result was reported by Agbor *et al*., (2015). The highest Mg and N concentrations were recorded in treatments

combining cassava peel and poultry manure, rather than in single amendments alone. This suggests that cassava peel providing K and perhaps carbon substrate, while poultry manure provides N and base cations, enhancing overall nutrient release and retention. The combination increase supports that combined organic amendments improve exchangeable bases (including Mg) and cation-exchange capacity more than single materials.

**Correlation among Soil Chemical Properties**

The correlation analysis of the soil chemical properties revealed important interactions among the nutrients and soil pH, indicating possible similarities or differences in their sources, mobility, and availability within the soil environment. The very strong positive correlation observed between potassium (K) and sodium (Na) level indicates that soils with higher K concentrations also tended to have elevated Na levels. This relationship may be attributed to the exchangeable cations within the soil colloidal complex - released during the decomposition of cassava peels, with records of high levels of both elements. Similar findings have been reported by Adesodun *et al*. (2015), who observed that organic residues rich in K often enhance Na mobility through increased cation exchange and soil organic matter decomposition. This result also agrees with Osemwota (2010), who also suggests that both elements may originate from similar parent materials or may be influenced by similar soil processes such as mineral weathering and ion exchange. This relationship may also indicate that soils with high sodium accumulation tend to retain higher potassium levels due to similarities in their ionic behavior.

Potassium exhibited negative correlations with nitrogen (N), phosphorus (P), and soil pH, indicating that increasing potassium concentration may be associated with reduced availability of these nutrients and lower soil alkalinity. This finding aligns with Osemwota (2010), who reported that excessive K enrichment can inhibit N and P uptake by affecting nutrient balance and microbial mineralization processes. Magnesium (Mg) displayed positive relationships with N and pH, implying that Mg availability may enhance nitrogen transformation and stabilize soil reaction. The strong negative relationship between K and P may suggest nutrient antagonism or differential uptake and fixation mechanisms within the soil. Magnesium (Mg) showed a moderate positive correlation with nitrogen (N), suggesting that soils with higher magnesium content may support greater nitrogen availability, possibly because both nutrients are associated with organic matter accumulation and improved soil fertility. The positive relationship between Mg and soil pH further indicates that magnesium may contribute to reducing soil acidity, thereby enhancing nutrient availability and improving soil conditions for plant growth. However, Mg showed weak negative correlations with Na and P, indicating limited antagonistic interactions among these nutrients. This aligns with the findings of Agbede (2017), who reported that Mg contributes to improved soil structure and microbial activity, thereby promoting nitrogen mineralization. Conversely, its weak negative correlations with Na and P reflect mild nutrient competition effects under organic amendment influence. Nitrogen exhibited a strong positive correlation with phosphorus suggesting a synergistic relationship often associated with the concurrent mineralization of poultry manure-derived organic matter. According to Eghball (2002), organic manures release N and P in complementary patterns, supporting the

observed association. The negative correlations of N with Na and K indicate potential ionic imbalance at higher salt levels, which could inhibit N uptake or transformation processes (Tisdale *et al*., 1993).

Nitrogen displayed a strong positive correlation with soil pH. This variation could be attributed to the fact that nitrogen availability increases under less acidic soil conditions. This relationship may be attributed to enhanced microbial activity and mineralization processes at relatively higher pH levels, which promote nitrogen transformation and availability.

In contrast, the strong negative correlation between N and Na suggests that elevated sodium concentrations may adversely affect nitrogen availability, possibly due to salinity effects that suppress microbial activity and nutrient uptake. This result agrees with Adekiya *et al*., (2019) suggesting that the strong negative correlations with phosphorus (P) and soil pH, indicating that increasing sodium concentration may contribute to nutrient imbalance and soil degradation. High sodium levels are often associated with poor soil structure and reduced nutrient availability, which could explain the reduction in phosphorus concentration and soil pH observed in the study. Excess sodium may also increase soil salinity, thereby limiting nutrient uptake efficiency by plants. Phosphorus (P) exhibited a weak negative correlation with soil pH, suggesting that soil pH had minimal influence on phosphorus availability within the study area. This weak relationship may indicate that other factors such as soil texture, organic matter content, and phosphorus fixation processes play more dominant roles in determining phosphorus dynamics in the soil.

**Principal Component Analysis (PCA) Scatter Matrix Result**

PCA scatter distribution demonstrated clear clustering patterns. $T_3$, $T_4$, and $T_5$ formed a compact cluster, signifying strong morphological similarity and consistent growth enhancement under moderate to high organic amendment rates. Conversely, $T_1$ remained isolated, confirming its distinct response under nutrient-limited conditions. T2 and T6 occupied intermediate positions, suggesting moderate improvement in morphological traits relative to the control. These results collectively indicate that organic amendments, particularly cassava peel and poultry manure combinations, exerted significant influence on morphological trait expression. Similar findings were reported by Adekiya *et al.* (2019), who observed that organic nutrient inputs enhance plant vigor, promote balanced growth, and create distinct morphological groupings in multivariate analyses.

**Conclusion**

This study demonstrated that the combined use of cassava peel and poultry manure significantly enhances the growth performance of *Capsicum chinense*. The integration of cassava peel and poultry manure improved soil nutrient status, moderated pH, and significantly enhanced plant growth and morphological development compared with single amendments. These findings highlight the agronomic potential of combined organic residues as sustainable soil fertility enhancers capable of improving both soil quality and crop productivity. Therefore, the combination of cassava peel and poultry manure is recommended as a sustainable bio-enhancer for *Capsicum chinense* production, reducing reliance on costly inorganic fertilizers and promoting waste recycling in agriculture.

**Acknowledgements**
The authors express their sincere appreciation to the staff and management of the laboratory and field unit where this research was conducted for their technical assistance and support during the experiment. Gratitude is also extended to colleagues and friends who contributed valuable suggestions and encouragement throughout the study.

**Conflict of Interest**
The authors declare that there is no conflict of interest regarding the publication of this research work.

**Funding**
This research received no external funding and was solely supported by the authors.

**Author's Contribution**
All authors contributed significantly to the conception and design of the study. Data collection, laboratory analysis, statistical analysis, interpretation of results, and manuscript preparation were jointly carried out by the authors. All authors read and approved the final manuscript before submission.

**References**

Adekiya, A. O., Agbede, T. M. and Olayanju, A. (2019). Effect of organic amendments on soil chemical properties and yield of maize. *Archives of Agronomy and Soil Science, 65*(6), 807–820.

Adeleye, E. O., Ayeni, L. S. and Ojeniyi, S. O. (2010). Effect of poultry manure on soil physico- chemical properties, leaf nutrient contents and yield of yam (*Dioscorea rotundata*) in southwest Nigeria. *Journal of American Science, 6*(10), 871–878.

Agbede, T. M., Ojeniyi, S. O. and Adeyemo, A. J. (2008). Effect of poultry manure on soil physical and chemical properties, growth and grain yield of sorghum. *Journal of Applied Science Research, 4*(12), 1959–1963.

Adesodun, J. K., Adeyemi, E. F. and Oyegoke, C. O. (2015). Composting of cassava peel with poultry manure and the use for improving soil properties and maize yield. *Bioresource Technology, 96*(13), 153–158.

Agbede, T. M. (2017). *Understanding Soil and Plant Nutrition.* Akure: Laflink Printing Press.

Akanbi, W. B., Adeboye, C. O., Togun, A. O., Ogunrinde, J. O. and Adeyeye, S. A. (2007). Growth, herbage and seed yield and quality of roselle (*Hibiscus sabdariffa* L.) as influenced by poultry manure and nitrogen fertilizer. *World Journal of Agricultural Sciences, 3*(5), 617–622.

Aliyu, L., Yusuf, M. and Ahmad, A. (2014). Effect of organic and inorganic fertilizers on the growth and yield of okra. *International Journal of Agronomy and Agricultural Research, 4*(3), 26–33.

Ayeni, L. S., Adetunji, M. T. and Ojeniyi, S. O. (2012). Integrated application of poultry manure and mineral fertilizer on soil chemical properties, nutrient uptake and yield of maize (*Zea mays*). *Nigerian Journal of Soil Science, 22*, 10–20.

Avasiloaiei, D. I., Calara, M., Brezeanu, P. M., Bălăiță, C., Brumă, I. S. and

Brezeanu, C. (2025). *Capsicum chinense Jacq. Response to Pyrolysis- Derived Amendments and Sustainable Fertilizers in Containerized Greenhouse Systems.* Agronomy, 15, 2125.

Brady, N. C. and Weil, R. R. (2017). *The Nature and Properties of Soils* (15th ed.). Pearson Education.

Bremner, J. M. (1965). *Nitrogen availability indexes*. In: Black et al. (Eds.) Methods of Soil Analysis.

Das, S., Sarkar, S., Das, M., Banik, P. and Bhattacharya, S. S. (2021). Influence of soil quality factors on capsaicin biosynthesis, pungency, yield, and produce quality of chili: An insight on Csy1, Pun1, and Pun1² signaling responses. *Plant Physiology and Biochemistry*, 166, 427-436

Egbuchua, C. N. and Enujeke, E. C. (2013). Growth and yield responses of cucumber (*Cucumis sativus* L.) to organic manure types in Asaba area of Delta State, Nigeria. *Journal of Agriculture and Food Sciences, 1*(1), 58–64.

Eghball, B. (2002). *Soil properties as influenced by phosphorus- and nitrogen-based manure and compost applications. Agronomy Journal*, 94(1), 128-135.

Iren, O. B., Asawalam, D. O. and Ezeugwu, C. O. (2016). Effect of organic waste materials on soil chemical properties and maize yield in Abia State, Nigeria. *Nigerian Journal of Soil Science, 26*(2), 233–242.

Jackson, M. L. (1958). *Soil Chemical Analysis*.

Makinde, E. A., Ayoola, O. T. and Akande, M. O. (2011). Effects of organic, organomineral and NPK fertilizer treatments on the nutrient uptake of *Amaranthus cruentus*. *Proceedings of the 35th Annual Conference of the Soil Science Society of Nigeria*, 91–98.

Ndukwe, O. O., Obalum, S. E. and Oguegbuna, V. O. (2020). Comparative effectiveness of organic and inorganic fertilizers on the growth of maize in a degraded tropical soil. *Tropical Agriculture, 97*(2), 104–115.

Odedina, S. A., Odedina, J. N., Ayeni, L. S., Arowojolu, S. A., Adeyeye, S. A. and Ojeniyi, S. O. (2003). Effects of types of ash on soil fertility, nutrient availability and yield of yam (*Dioscorea rotundata*). *Nigerian Journal of Soil Science, 13*, 61–67.

Olsen, S. R., Cole, C. V., Watanabe, F. S. and Dean, L. A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate.

Olayinka, A., Adebayo, A. and Oyegoke, C. O. (2011). Influence of cassava peel compost and poultry manure on nutrient dynamics in soil. *African Journal of Agricultural Research, 6*(3), 491–498.

Osemwota, I. O. (2010). Effect of organic and inorganic amendments on soil properties and yield of maize in a degraded ultisol. *World Journal of Agricultural Sciences, 6*(2), 153–158.

Obi, M. E. and Ebo, P. O. (1995). The effects of organic and inorganic amendments on soil physical properties and maize production in a severely degraded sandy soil in southern Nigeria. *Bioresource Technology, 51*(2–3), 117–123.

Sini, H. N., Barzegar, R., Mashaee, S. S., Ghahsare, M. G., Mousavi-Fard, S. and Mozafarian, M. (2024). *Effects of biofertiliser on the production of bell pepper (Capsicum annuum L.) in greenhouse. Journal of Agriculture and Food Research*, 16, (10) 10-60.

Stoleru, V., Mangalagiu, I., Amăriucăi-Mantu, D., Teliban, G.-C., Cojocaru, A., Rusu, O.-R., Burducea, M., Mihalache, G., Rosca, M., Caruso, G., Sekara, A. and Jităreanu, G. **(**2023**).** Enhancing the nutritional value of sweet pepper through sustainable fertilization management. *Frontiers in Nutrition*, 10, (126) 49-99.

Tisdale, S. L., Nelson, W. L., Beaton, J. D. and Havlin, J. L. (1993). *Soil Fertility and Fertilizers* (5th ed.). Macmillan.

Thomas, G. W. (1982). *Exchangeable cations*. In: Methods of Soil Analysis, Part 2.

Wong, V. N. L., Dalal, R. C. and Greene, R. S. B. (2009). Carbon dynamics of sodic and saline soils following gypsum and organic material additions: Laboratory incubation study. *Geoderma, 152*(1–2), 68–75.