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Effects of Poultry Manure, NPK Fertilizer and their Integrated Application on Soil Fertility and Cucumber (*Cucumis sativus* L.) Yield in Awka, Southeastern Nigeria

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ABSTRACT

Objective: This study investigated the effects of poultry manure, NPK 20:10:10 fertilizer, and their integrated application on soil physicochemical properties, growth, and yield of cucumber (*Cucumis sativus* L.) in Awka, Southeastern Nigeria, where soil fertility decline limits crop productivity.

Materials and Methods: The experiment was conducted during the 2025 cropping season at the Teaching and Research Farm, Faculty of Agriculture, Nnamdi Azikiwe University (UNIZIK). The study site is located within a humid tropical agroecological zone characterized by an annual rainfall ranging from 1,800 to 2,500 mm and mean temperatures between 26 and 30 °C. The experimental layout followed a Randomized Complete Block Design (RCBD), comprising four treatments replicated four times. The treatments comprised: T_0 (control), T_1 (poultry manure at 10 t ha^{-1}), T_2 (poultry manure at 5 t ha^{-1} combined with NPK 20:10:10 at 150 kg ha^{-1}) and T_3 (NPK 20:10:10 at 300 kg ha^{-1}). Soil physicochemical properties, vegetative growth parameters, and yield attributes were evaluated. The trial was conducted over a period of approximately 10 weeks, encompassing the nursery stage through to harvest. Baseline soil analysis indicated low Organic Carbon (OC), Total Nitrogen (TN) and available Phosphorus (P), reflecting poor inherent soil fertility.

Results: Application of soil amendments significantly improved soil pH, organic carbon, nutrient availability and Effective Cation Exchange Capacity (ECEC) compared with the control (T_0). The integrated treatment (T_2) produced the most balanced improvement in soil physicochemical properties. Cucumber growth and yield responded positively to enhanced soil fertility, with T_2 recording superior vine length, leaf development and fruit yield. Treatment T_1 notably improved soil Aggregate Stability (AS), potassium (K^+), pH, and OC, whereas T_3 enhanced Soil Hydraulic Conductivity (SHC), Available Phosphorus (AP), Bulk Density (BD), calcium (Ca^{2+}), ECEC, TN, and K availability.

Conclusion: The findings demonstrate that integrating organic and inorganic nutrient sources enhance nutrient synchrony, improve soil quality, and increase cucumber productivity in sandy loam soils. Integrated nutrient management is therefore recommended as a sustainable strategy for cucumber cultivation in Southeastern Nigeria.

INTRODUCTION

Cucumber (*Cucumis sativus* L.) is a widely cultivated vegetable crop in tropical and subtropical regions and is valued for its nutritional, economic and health benefits[1,2].

The fruit is a rich source of water, vitamins and essential minerals, thereby contributing significantly to human nutrition and income generation among smallholder farmers in Nigeria[3]. In recent years, cucumber production has expanded rapidly in Southeastern Nigeria due to increasing market demand and the crop's adaptability to diverse soil types and climatic conditions[3]. However, sustained productivity is increasingly constrained by declining soil fertility, nutrient depletion, and suboptimal soil management practices[4].

In Southeastern Nigeria, continuous cropping without adequate nutrient replenishment has led to the deterioration of soil physical and chemical properties, resulting in reduced crop yield potential[6,7]. Organic soil amendments, particularly poultry manure and other animal by-products, have been identified as sustainable options for improving soil fertility, enhancing nutrient cycling and increasing crop productivity[8]. Poultry manure supplies appreciable amounts of nitrogen, phosphorus and potassium, while also improving soil structure, moisture retention and microbial activity[9]. Previous studies in the region have demonstrated that poultry manure application enhance cucumber growth, nutrient uptake and yield performance when compared with the sole use of inorganic fertilizers[4,10,11].

Despite these advantages, the sole application of poultry manure may not adequately satisfy the immediate nutrient requirements of cucumber because of the slow mineralization of organic nutrients. Consequently, the integration of poultry manure with moderate rates of mineral fertilizers such as NPK has been recommended to combine the rapid nutrient availability of inorganic fertilizers with the long-term soil quality benefits of organic inputs[12]. Integrated nutrient management practices have been reported to improve soil organic matter content, reduce bulk density, enhance nutrient-use efficiency, and increase cucumber yield and fruit quality in humid tropical environments[13].

However, field-based evidence on the combined effects of poultry manure and NPK fertilizer on soil physicochemical properties and cucumber productivity under the sandy loam soils of Awka, Southeastern Nigeria, remains limited. Therefore, this study evaluated the effects of poultry manure, NPK 20:10:10 fertilizer and their integrated application on soil properties, as well as the growth and yield of cucumber. The findings are expected to contribute to the development of balanced and sustainable nutrient management strategies for cucumber production in the humid tropics.

MATERIALS AND METHODS

Description of the experimental site: The field experiment was conducted at the Teaching and Research Farm of the Faculty of Agriculture, Nnamdi Azikiwe University, Awka, Anambra State, Southeastern Nigeria. The site lies within the humid tropical climatic zone at latitude 6°14' 48"N and longitude 7°07' 09"E. The area receives an annual rainfall of approximately 1,800-2,500 mm, with mean daily temperatures ranging from 26-30°C and relative humidity of 70-80%[14]. The soil is predominantly sandy loam to sandy clay loam and is classified as a Typic Paleustult according to the USDA Soil Taxonomy[15].

Experimental design and treatments: The experiment was laid out in a Randomized Complete Block Design (RCBD) comprising four treatments and four replications (Table 1). The treatments were: T_0 (control); T_1 (poultry manure at 10 t ha^{-1}); T_2 (poultry manure at 5 t ha^{-1} combined with NPK fertilizer (20:10:10) at 150 kg ha^{-1}) and T_3 (NPK fertilizer (20:10:10) at 300 kg ha^{-1}).

Each plot measured 3×3 m, with 1 m spacing between plots and blocks, resulting in a total of 16 plots and a net experimental area of 240 m² (17×14 m). Experimental beds were raised to a height of approximately 57 cm and manually levelled to reduce the risk of water erosion. Poultry manure was aerobically cured in jute bags for four weeks prior to application to minimize ammonia volatilization and reduce pathogen load. The manure was incorporated into the soil two weeks before planting to allow for decomposition and nutrient release, while NPK fertilizer (20:10:10) was applied by side placement at two weeks after transplanting (2 WAT) to minimize nutrient losses[16].

Soil sampling and laboratory analyses: Prior to land preparation, composite soil samples were randomly collected from the 0-20 soil cm soil depth across the experimental site using a soil auger. The samples were composited, air-dried, and passed through a 2 mm mesh sieve in preparation for laboratory analyses, with the exception of those designated for bulk density determination. Representative samples of poultry manure and NPK fertilizer (20:10:10) were also collected and analyzed (Table 2).

Table 1: Field layout (RCBD, 4 treatments×4 replications)

Block 1			
Plot 1	Plot 2	Plot 3	Plot 4
T_0	T_1	T_2	T_3
Block 2			
Plot 5	Plot 6	Plot 7	Plot 8
T_3	T_0	T_1	T_2
Block 3			
Plot 9	Plot 10	Plot 11	Plot 12
T_2	T_3	T_0	T_1
Block 4			
Plot 13	Plot 14	Plot 15	Plot 16
T_1	T_2	T_3	T_0

Block: Replication, T_0: Control (no amendment), T_1: Poultry manure (PM) at 10 t ha^{-1}, T_2: PM at 5 t ha^{-1} + NPK 20:10:10 at 150 kg ha^{-1}, T_3: NPK^{+} 20:10:10 at 300 kg ha^{-1}

Table 2: Chemical composition of poultry manure (PM) and NPK 20:10:10 fertilizer used in the experiment

Parameters	Unit	Poultry manure	NPK 20:10:10 fertilizer
pH	-	8.87	-
Nitrogen	%	3.20	20
Phosphorus	%	2.30	10
Exchangeable K^+	Cmol (+) kg^{-1}	1.38	10
Exchangeable Ca^{2+}	Cmol (+) kg^{-1}	0.84	-
Exchangeable Mg^{2+}	Cmol (+) kg^{-1}	0.49	-
Exchangeable Na^+	Cmol (+) kg^{-1}	0.30	-
Organic carbon (OC)	%	21.30	-
C:N ratio	-	6.66	-

Field data (2025)

Particle size distribution was determined using the hydrometer method[17]. Soil moisture content was determined following the method described by Obi[18], hydraulic conductivity was determined by the constant head method and aggregate stability by the wet sieving method[19,20]. Soil pH was measured in a 1:2.5 soil-to-water suspension using a glass electrode pH meter[21]. Organic carbon was determined by the Walkley-Black wet oxidation method, total nitrogen by the Kjeldahl digestion method and available phosphorus using the Bray-1 extraction method[22-24]. Exchangeable Ca, Mg, K, and Na were extracted with ammonium acetate and quantified using atomic absorption spectrophotometry, while exchangeable acidity (Al^{3+}+H^+) was determined by titration[21,25].

Bulk density was determined using the core method[26]. Total porosity, Effective Cation Exchange Capacity (ECEC), and base saturation were calculated using the following expressions:

(a) $$\text{Total porosity}(\%) = \left(1 - \frac{BD}{PD}\right) \times 100 \quad (1)$$

Where:

BD : Bulk density (Mg/m^3)

PD : Particle density (usually assumed to be 2.65 g/cm^3 for mineral soils)

(b) $$ECEC = Ca^{2+} + Mg^{2+} + K^+ + Na^+ + Al^{3+} + H^+ \quad (2)$$

(C) $$\text{Base saturation}(\%) = \frac{Ca^{2+} + Mg^{2+} + K^+ + Na^+}{ECEC} \times 100 \quad (3)$$

Source of planting material: The cucumber variety used in this study was *Cucumis sativus* L. (cv. Cu 999), obtained from the Agricultural Development Programme (ADP) office in Awka, Anambra State, Nigeria. This variety is early maturing, high yielding and characterized by moderate vine growth, attributes that make it well adapted to the humid tropical conditions of southeastern Nigeria.

Seed viability test and nursery establishment: Prior to sowing, a germination test was conducted to determine seed viability. Fifty seeds were randomly selected and evenly distributed into five Petri dishes (10 seeds per dish) lined with Whatman filter paper. The filter papers were moistened with distilled water and the dishes were incubated at room temperature for a period of 4-7 days, during which germination was monitored and recorded.

Germination percentage was calculated as:

$$\frac{\text{Number of germinated seeds}}{\text{Number of seeds sown}} \times 100 \quad (4)$$

Seeds were raised in a nursery using perforated polybags filled with topsoil. Two seeds were sown per polybag and lightly covered with soil. The seedlings were watered daily, and thinning was performed after emergence to retain one healthy seedling per polybag.

Transplanting and field establishment: Seedlings were transplanted to the field at 2 WAP in the nursery, when they had developed 2-3 true leaves. Transplanting of seedlings was carried out in the early morning to minimize transplant shock. The seedlings were arranged at a spacing of 50×50 cm, resulting in 25 plants per plot, equivalent to approximately 40,000 plants ha^{-1}. Missing stands were replaced one week after transplanting (WAT) to ensure a uniform plant population.

Staking and fertilizer application: Staking was performed at 3 WAT using bamboo sticks and twine to support the vines such that they can carry the pods when it eventually gets to that stage, improve aeration, reduce disease incidence, and prevent fruit contact with the soil surface. NPK fertilizer (20:10:10) was applied 2 WAT according to the respective treatment combinations. Fertilizer was applied using the ring method, approximately 5 cm away from the plant base, and lightly incorporated into the soil to enhance nutrient uptake. Poultry manure and integrated treatments were applied strictly following the experimental treatment structure.

Weed, water and crop protection management: Weed control was carried out manually using a hoe at 2, 4 and 6 WAT to minimize competition for nutrients, water and light. Supplemental irrigation was provided during periods of insufficient rainfall to maintain optimal soil moisture. Standard crop protection practices were employed throughout the growing period to minimize pest and disease incidence[27].

Flowering and harvesting: Cucumber plants reached 50% flowering at approximately 5-6 WAT, depending on treatment. Harvesting commenced at 7-8 WAT, when fruits reached marketable maturity and was done at 1-3 days to encourage continuous fruit production.

Data collection: Growth parameters, including vine length (cm), number of leaves per plant and Leaf Area Index (LAI), were measured at 50% flowering (5-6 WAT). Vine length was measured at 2, 4 and 6 WAT u
sing a measuring tape. Leaf area index was calculated as:

$$LAI = \text{Leaf length} \times \text{leaf width} \times 0.85$$

as described by Blanco and Folegatti[28]. Yield parameters measured at harvest included the number of fruits per plant. Total yield per treatment was calculated and expressed on a hectare basis.

Statistical analysis: Data were subjected to analysis of variance (ANOVA) using IBM SPSS Statistics software (version 29)[29]. Treatment means were separated using the Least Significant Difference (LSD) test at the 5% probability level ($p \leq 0.05$), following the procedure described by Steel and Torrie[30]. Data visualizations, including bar charts, histograms, boxplots, and violin plots, were generated using R Studio package version, v 4.3.1.

RESULTS AND DISCUSSION

Baseline soil conditions and implications for cucumber production: The pre-experimental soil properties are summarized in Table 3 and Fig. 1. The soil was classified as sandy loam, a texture generally favorable for cucumber cultivation due to its good drainage characteristics and low mechanical resistance to root penetration. Despite this textural advantage, the soil exhibited a high bulk density (1.90 Mg m^{-3}) and low total porosity (28.04%), indicative

Table 3: Physicochemical properties of the soil before treatment application

Parameters	Unit	Value
Sand	%	68.00
Silt	%	22.00
Clay	%	10.00
Textural class	-	Sandy loam
Bulk density (BD)	Mg m^{-3}	1.90
Moisture content (MC)	%	15.15
Total porosity (TP)	%	28.04
Saturated hydraulic conductivity (SHC)	cm/hr	0.03
Aggregate stability (AS)	%	18.71
Soil pH	-	5.98
Organic carbon (OC)	%	1.21
Total nitrogen (TN)	%	0.104
Available phosphorus (P)	(mg kg^{-1})	5.21
Exchangeable Ca^2	Cmol (+) kg^{-1}	2.60
Exchangeable Mg^2	Cmol (+) kg^{-1}	1.20
Exchangeable K^+	Cmol (+) kg^{-1}	0.28
Exchangeable Na^+	Cmol (+) kg^{-1}	0.21
Exchangeable H^+	Cmol (+) kg^{-1}	0.40
Exchangeable Al^{3+}	Cmol (+) kg^{-1}	0.80
Effective cation exchange capacity (ECEC)	Cmol (+) kg^{-1}	5.49
Base saturation (BS)	%	78.14

Field data (2025)

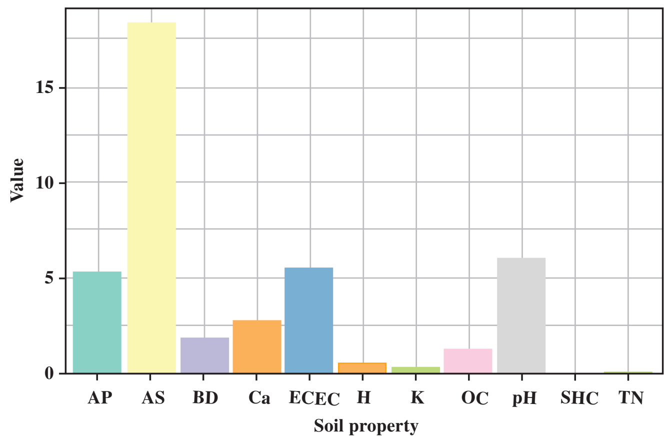

Fig. 1: Bar plots showing baseline soil information before the experiment
AP: Available phosphorus, AS: Aggregate stability, BD: Bulk density, ECEC: Effective cation exchange capacity, OC: Organic carbon, SHC: Saturated hydraulic conductivity and TN: Total nitrogen

of compaction and restricted aeration. Such conditions are known to limit root elongation, reduce oxygen diffusion and constrain nutrient and water uptake in shallow-rooted vegetable crops such as cucumber[31].

The low hydraulic conductivity (0.03 cm h^{-1}) suggests restricted water movement within the soil profile, which may predispose the root zone to transient waterlogging following rainfall events, while the low moisture content (25.15%) indicates limited water retention capacity. These physical constraints may adversely affect physiological processes, vegetative growth and fruit development in cucumber[5].

Soil reaction was moderately acidic (pH 5.98), which falls within the acceptable range for cucumber cultivation. However, the presence of exchangeable Al^{3+} (0.80 cmol(+) kg^{-1}) represents a potential risk of aluminum toxicity under intensified cultivation. High Al^{3+} levels can impair root growth, restrict nutrient uptake and reduce crop performance in acidic soils[32].

The soil was also characterized by moderate organic carbon (1.21%), total nitrogen (0.104%) and available phosphorus (5.21 mg kg^{-1}), which are within the critical thresholds (0.75 % - 2.0 % OC, 0.015 % - 0.02), for optimal cucumber growth[33]. These values are limited to sustainable production due to poor inherent fertility and low nutrient reserves of soils in the region, further confirmed by the relatively low effective cation exchange capacity [5.49 cmol(+) kg^{-1}]. Such characteristics are typical of the highly weathered Ultisols of southeastern Nigeria, where continuous cultivation, intense rainfall and limited organic inputs accelerate nutrient depletion and structural degradation[7]. Collectively, these baseline soil conditions highlight the necessity for fertility amendments to enhance both the physical and chemical properties of the soil, thereby supporting sustainable cucumber production.

Quality of poultry manure and NPK fertilizer (20:10:10) used in the experiment: The chemical composition of the poultry manure and inorganic fertilizer utilized in this experiment is presented in Table 2. The poultry manure was alkaline (pH 8.87), suggesting its potential to ameliorate soil acidity and reduce exchangeable Al^{3+} in the moderately acidic baseline soil. This liming effect is agronomically significant in acidic tropical soils, where aluminum toxicity can constrain root growth and nutrient uptake. Poultry manure also supplied appreciable amounts of essential plant nutrients, including nitrogen (3.20%), phosphorus (2.30%), calcium, magnesium and sodium cations, which were deficient or marginal in the pre-experimental soil (Table 3). Additionally, the manure exhibited a high organic carbon content (21.30%) and a low C:N ratio (6.66), indicative of rapid mineralization and early nutrient release. Such nutrient release dynamics are particularly advantageous for short-duration crops like cucumber, which require an adequate and timely supply of nutrients during early vegetative growth and fruiting stages[34]. Furthermore, the high organic matter content of poultry manure is expected to enhance soil structure, microbial activity and nutrient retention.

In contrast, the NPK (20:10:10) fertilizer provided readily available macronutrients, particularly nitrogen, phosphorus and potassium, which are essential for rapid vegetative growth, flowering, and fruit development. However, unlike poultry manure, mineral fertilizer does not contribute directly to soil organic matter accumulation or the improvement of soil physical properties. The contrasting nutrient release patterns and soil-conditioning effects of poultry manure and NPK fertilizer (20:10:10) emphasize their complementary roles in integrated soil fertility management. Consequently, combining organic and inorganic nutrient sources offers a strategy for synchronizing nutrient supply with crop demand while simultaneously enhancing soil quality[35].

Effects of amendments on soil physical properties: The effects of poultry manure, NPK 20:10:10 fertilizer and their integrated application on soil physical properties after cucumber harvest are presented in Table 4. Compared to the control, treatments receiving poultry manure, either alone or in combination with NPK fertilizer (20:10:10), resulted in substantial improvements in soil physical condition. The sole application of poultry manure (T_1) significantly reduced bulk density (1.33 Mg m^{-3}) and increased total porosity (49.81%), reflecting enhanced soil aggregation and structural stability. These improvements are attributed to the addition of organic matter, which acts as a binding agent, promotes stable aggregate formation and improves pore continuity within the soil matrix[36].

Saturated hydraulic conductivity was highest under the combined treatment (T_2), indicating improved water movement through the soil profile. Enhanced hydraulic conductivity is particularly important for cucumber cultivation, as the crop requires well-drained soils to prevent root hypoxia and minimize the risk of soil-borne diseases. The integrated application of poultry manure and NPK fertilizer (20:10:10) produced the most balanced improvements in moisture content, bulk density, porosity, and aggregate stability, demonstrating a synergistic interaction between organic matter inputs and mineral nutrient supply.

Statistical analysis revealed that bulk density (0.12*), saturated hydraulic conductivity (0.0128*) and aggregate stability (2.908*) responded significantly to amendment application at $p \leq 0.05$, whereas soil moisture content, total porosity and particle size distribution did not differ significantly among treatments (Table 4). The sole application of NPK fertilizer (T_3) showed limited improvement in soil physical indices, highlighting the inability of mineral fertilizers alone to enhance soil

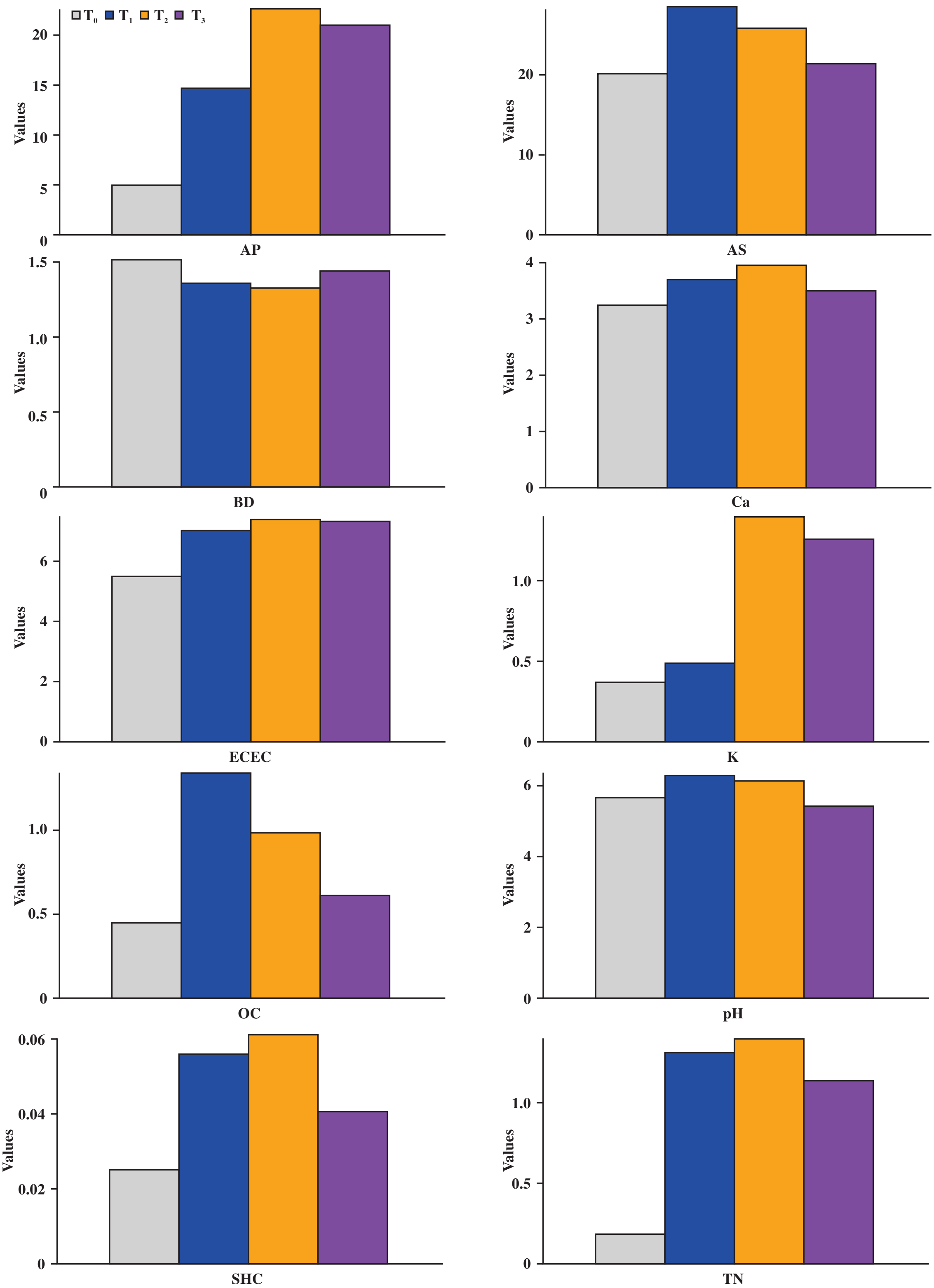

Fig. 2: Histogram showing the effects of Treatments on selected Soil Properties

T_0: Control (no amendment), T_1: Poultry manure (PM) at 10 t ha^{-1}, T_2 = PM at 5 t ha^{-1} + NPK 20:10:10 at 150 kg ha^{-1}, T_3: NPK 20:10:10 at 300 kg ha^{-1}, AP = Available phosphorus, AS = Aggregate stability, BD = Bulk density, ECEC = Effective cation exchange capacity, OC = Organic carbon, SHC = Saturated hydraulic conductivity, TN = Total nitrogen.

structural properties. Figure 2 presents a histogram illustrating the effects of the amendments on the improvement of soil physical conditions.

Effects of amendments on soil chemical properties: The effects of poultry manure, NPK fertilizer (20:10:10) and their combined application on soil chemical properties

Table 4: Effects of poultry manure (PM), NPK 20:10:10 fertilizer and their combination on soil physical properties

Treatments	Moisture content (%)	Saturated hydraulic Conductivity (cm h^{-1})	Aggregate stability (%)	Bulk density (Mg m^{-3})	Total porosity (%)	Sand (%)	Silt (%)	Clay (%)
T_0	18.97	0.0236	19.50	1.51	43.02	51.22	35.60	13.18
T_1	19.42	0.0544	27.75	1.33	49.81	51.25	36.50	12.25
T_2	21.19	0.0591	25.22	1.36	34.37	50.70	34.72	14.58
T_3	19.16	0.0393	21.25	1.45	48.68	48.15	36.73	15.12
LSD	4.85	0.0128*	2.908*	0.12*	15.82	3.26	2.48	3.07

T_0: Control (no amendment), T_1: Poultry manure (PM) at 10 t ha^{-1}, T_2 = PM at 5 t ha^{-1} + NPK 20:10:10 at 150 kg ha^{-1}, T_3: NPK 20:10:10 at 300 kg ha^{-1}, LSD: Least significant difference at $p \leq 0.05$ and *statistically significant

Table 5: Effects of poultry manure, NPK 20:10:10 fertilizer and their combination on soil chemical properties

Treatments	pH	OC	TN	AP	Ca²	Mg²	K	Na	Al³	H	ECEC	BS
		---------(%)---------		(mg kg^{-1})	--Cmol (+) kg^{-1}						--------------------------------------	(%)
T_0	5.58	0.44	0.15	4.95	3.22	1.34	0.36	0.25	0.15	0.06	5.38	96.10
T_1	6.28	1.32	1.26	14.58	3.68	1.84	0.49	0.50	0.12	0.06	6.69	97.30
T_2	6.10	0.98	1.35	22.50	3.95	1.42	1.15	0.33	0.10	0.10	7.05	97.16
T_3	5.45	0.60	1.11	20.85	3.53	1.64	1.22	0.35	0.11	0.07	6.92	93.40
LSD	0.36*	0.44*	0.07*	4.00*	0.42*	0.50	0.17*	0.11	0.06	0.04	1.12*	11.10

T_0: Control (no amendment), T_1: Poultry manure (PM) at 10 t ha^{-1}, T_2 = PM at 5 t ha^{-1} + NPK 20:10:10 at 150 kg ha^{-1}, T_3: NPK 20:10:10 at 300 kg ha^{-1}, LSD: Least Significant Difference at $p \leq 0.05$, OC: organic carbon, TN: Total nitrogen, AP: Available phosphorus, ECEC: Exchangeable cation exchange capacity, BS: base saturation and *Statistically significant

Table 6: Effects of Poultry manure, NPK 20:10:10 fertilizer, and their combination on growth and yield parameters of cucumber (*Cucumis sativus* L.)

Treatments	Leaf Area (cm^2)	No. of leaves	No. of fruits per plant	Vine length (cm)
T_0	240.54	52.44	6.00	158.31
T_1	288.25	68.63	8.25	167.63
T_2	314.82	127.50	11.75	188.19
T_3	283.17	80.75	7.50	174.75
Grand Mean	281.7	82.30	8.38	172.22
LSD	37.46*	12.85*	2.0*	11.60*

T_0: Control (no amendment), T_1: Poultry manure (PM) at 10 t ha^{-1}, T_2 = PM at 5 t ha^{-1} + NPK 20:10:10 at 150 kg ha^{-1}, T_3: NPK 20:10:10 at 300 kg ha^{-1}, LSD: Least Significant Difference at $p \leq 0.05$ and *Statistically significant

following cucumber harvest are presented in Table 5. Soil pH increased significantly (0.36*), with the highest value observed under sole poultry manure application (T_1; pH 6.28) (Fig. 2). This increase reflects the alkaline nature of poultry manure and its contribution of base-forming cations, which neutralize soil acidity and reduce exchangeable A^{3+} in acidic tropical soils[37].

Organic carbon content increased markedly under poultry manure application, particularly in T_1 (1.32%), indicating enhanced accumulation of organic matter, improved nutrient retention and favorable conditions for microbial activity. Total nitrogen and available phosphorus were significantly higher in amended plots (0.07* and 4.00*, respectively), with the greatest increase was observed under the integrated treatment (T_2) (1.35 and 22.50 mg kg^{-1}, respectively). These improvements reflect both direct nutrient inputs and enhanced nutrient-use efficiency associated with organic-mineral interactions, which stimulate microbial activity and nutrient mineralization[38]. Additionally, the release of organic acids during manure decomposition may have reduced phosphorus fixation, thereby increasing phosphorus availability[39].

Exchangeable potassium (K^+) was highest under the sole NPK fertilizer treatment (T_3) (1.22 Cmol (+) kg^{-1}), highlighting the effectiveness of mineral fertilizer in supplying readily available potassium to meet the high K demand of cucumber during fruit development. In contrast, Effective Cation Exchange Capacity (ECEC) was highest under the integrated treatment (T_2) (7.05 Cmol (+) kg^{-1}), indicating improved soil buffering capacity and sustained nutrient availability resulting from the combined effects of organic matter addition and mineral nutrient supply[38]. The increased ECEC in T_1 and T_2 could be attributed to humified organic fractions providing additional exchange sites, thereby enhancing nutrient retention. Overall, the integrated application of poultry manure and NPK fertilizer (20:10:10) corrected the major chemical limitations of the soil more effectively than either of hte amendment applied alone (Fig. 2). Statistical analysis indicated that soil pH, organic carbon, total nitrogen, available phosphorus, exchangeable calcium, potassium, and ECEC were significantly influenced by the amendment application at $p \leq 0.05$. Conversely, exchangeable magnesium, sodium, exchangeable acidity, and base saturation did not differ significantly among treatments.

Effects of amendments on cucumber growth and yield: The effects of Poultry Manure (PM), NPK fertilizer (20:10:10) and their combined application on cucumber growth and yield parameters are presented in Table 6. The integrated application of poultry manure and NPK fertilizer (T_2) significantly enhanced both vegetative growth and yield performance, reflecting improved nutrient synchrony and a balanced nutrient supply to the crop (Fig. 3-7). The superior vine elongation observed under T_2 (Fig. 3) indicates enhanced vegetative growth resulting from improved soil physical conditions and sustained nutrient availability provided by the combined organic and inorganic inputs. The improved soil structure and nutrient retention under this treatment likely promoted root development and efficient nutrient uptake, which are essential for vigorous vine growth. This treatment also produced the highest number of leaves and Leaf Area Index (LAI) (Fig. 4 and 5), as well as the greatest fruit

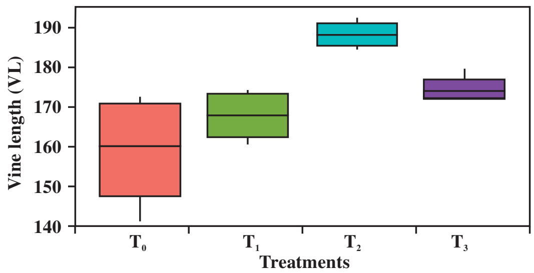

Fig. 3: Boxplot showing the effects of treatment on Vine length
T_0: Control (no amendment), T_1: Poultry manure (PM) at 10 t ha^{-1}, T_2: PM at 5 t ha^{-1} + NPK 20:10:10 at 150 kg ha^{-1}, T_3: NPK 20:10:10 at 300 kg ha^{-1},

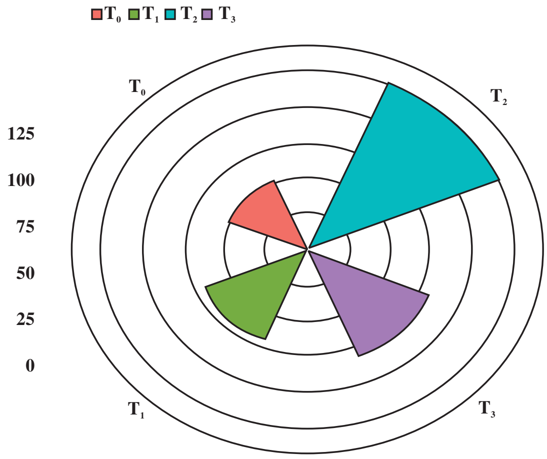

Fig. 4: Mean circular bar chart showing the effects of treatment on Number of leaves
T_0: Control (no amendment), T_1: Poultry manure (PM) at 10 t ha^{-1}, T_2 = PM at 5 t ha^{-1} + NPK 20:10:10 at 150 kg ha^{-1}, T_3: NPK 20:10:10 at 300 kg ha^{-1}

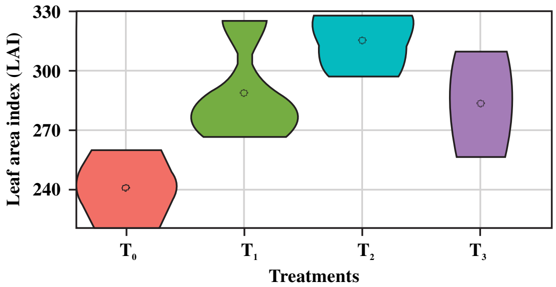

Fig. 5: Violin plots showing the effect of treatment on leaf area index (LAI)
T_0: Control (no amendment), T_1: Poultry manure (PM) at 10 t ha^{-1}, T_2 = PM at 5 t ha^{-1} + NPK 20:10:10 at 150 kg ha^{-1}, T_3: NPK 20:10:10 at 300 kg ha^{-1}

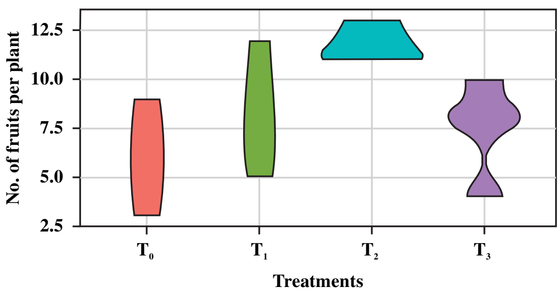

Fig. 6: Violin plot showing the effect of treatment on fruits per plant
T_0: Control (no amendment), T_1: Poultry manure (PM) at 10 t ha^{-1}, T_2 = PM at 5 t ha^{-1} + NPK 20:10:10 at 150 kg ha^{-1}, T_3: NPK 20:10:10 at 300 kg ha^{-1}

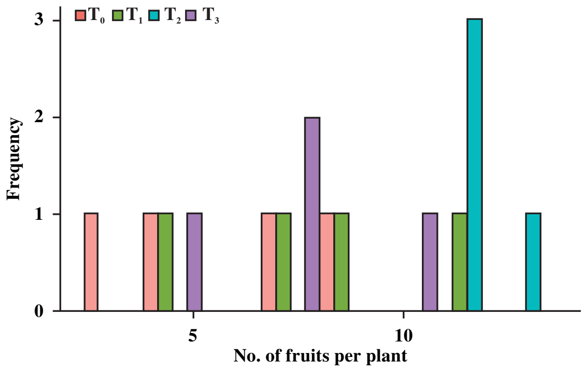

Fig. 7: Histogram showing the mean number of fruits per Treatment

T_0: Control (no amendment), T_1: Poultry manure (PM) at 10 t ha^{-1}, T_2 = PM at 5 t ha^{-1} + NPK 20:10:10 at 150 kg ha^{-1}, T_3: NPK 20:10:10 at 300 kg ha^{-1},

number per plant (Fig. 6 and 7). The increased LAI under T_2 indicated enhanced canopy development and efficient light interception, which are critical for photosynthetic activities and assimilated production during fruit formation. This response highlights the role of readily available mineral nutrients, particularly nitrogen and potassium, in supporting rapid canopy expansion and fruit set.

The integrated nutrient treatment (T_2) optimized vegetative growth through improvements in soil quality and nutrient buffering and enhanced reproductive output through immediate nutrient availability. These results underscore the importance of integrated nutrient management for achieving balanced growth and sustainable cucumber productivity.

CONCLUSION

This study assessed the effects of poultry manure, NPK 20:10:10 fertilizer, and their integrated application on soil fertility and cucumber (*Cucumis sativus* L.) yield. Application of these amendments significantly improved soil physicochemical properties following cucumber harvest, notably increasing soil pH, organic carbon content and nutrient retention capacity. The use of NPK fertilizer and integrated nutrient management particularly enhanced available phosphorus and exchangeable potassium, reflecting the rapid nutrient release characteristics of mineral fertilizers. In contrast, control plots exhibited the lowest soil fertility indices, indicating nutrient depletion resulting from continuous cultivation without soil amendments. Among the treatments, the integrated application (T_2) produced the greatest improvements in vegetative growth parameters, including vine length, leaf number, and leaf area index, which translated into higher fruit number per plant and improved overall yield. These findings underscore the value of integrated nutrient management in synchronizing nutrient supply, enhancing soil quality and optimizing cucumber productivity in sandy loam soils. While sole applications of either poultry manure or NPK fertilizer may be used as alternatives, they generally produced lower growth and yield outcomes. To maximize the benefits of poultry manure, it is recommended that it be incorporated into the soil at least two weeks before transplanting. Additionally, long-term studies are warranted to evaluate the sustained effects of integrated nutrient management on soil health and yield stability. In summary, a balanced nutrient supply through integrated management is essential for enhancing cucumber productivity while maintaining soil quality.

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