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Assessing the Effects of Plant Spacing and Organic Manure Rates on Growth, Yield, and Nutrient Composition of Waterleaf (*Talinum triangulare*)

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Abstract

Waterleaf (*Talinum triangulare*) is one of the most important indigenous leafy vegetables cultivated in tropical Africa because of its rapid growth, high nutritional value, and economic importance. However, productivity and nutritional quality are often constrained by poor agronomic practices, particularly inappropriate plant spacing and inadequate soil fertility management. This study evaluated the effects of different plant spacing and organic manure rates on the growth, yield, and nutrient composition of waterleaf under field conditions. The experiment was conducted using a factorial arrangement in a Randomized Complete Block Design (RCBD) with three replications. Three plant spacing levels (20 × 20 cm, 30 × 20 cm, and 40 × 20 cm) were combined with three poultry manure rates (0, 5, and 10 t ha^{-1}), resulting in nine treatment combinations. Growth parameters, including plant height, number of leaves, stem diameter, and leaf area, were measured periodically, while fresh yield and dry matter yield were determined at harvest. Proximate analyses were conducted to determine moisture, crude protein, crude fibre, ash, fat, carbohydrate, and selected mineral contents using standard analytical procedures. Data were subjected to analysis of variance (ANOVA), and treatment means were separated using Duncan's Multiple Range Test at the 5% probability level. The findings demonstrated that both plant spacing and organic manure significantly influenced vegetative growth, biomass production, marketable yield, and nutrient composition of waterleaf. The combined application of moderate plant spacing with higher organic manure rates consistently produced superior agronomic performance and improved nutritional quality. The study concludes that optimizing plant spacing together with appropriate organic manure application provides an environmentally sustainable strategy for enhancing waterleaf productivity while improving its nutritional value for consumers.

Keywords: Waterleaf, *Talinum triangulare*, plant spacing, organic manure, poultry manure, yield, nutrient composition, sustainable vegetable production.

1. Introduction

Leafy vegetables are essential to human nutrition, providing affordable sources of vitamins, minerals, dietary fibre, antioxidants, and other bioactive compounds that support food security and public health. They also contribute significantly to household income and sustainable livelihoods, particularly among smallholder farmers in tropical regions. Increasing demand for nutritious food and environmentally sustainable production systems has intensified efforts to improve the productivity and nutritional quality of indigenous vegetables through appropriate agronomic practices (FAO, 2023; WHO, 2022).

Waterleaf (*Talinum triangulare*) is one of the most important indigenous leafy vegetables cultivated in West and Central Africa due to its rapid growth, adaptability, high nutritional value, and strong market demand. Rich in proteins, vitamins, minerals, and antioxidants, the crop is widely consumed and serves as an important source of income for urban and peri-urban vegetable producers. Despite its economic and nutritional importance, waterleaf productivity remains constrained by declining soil fertility, poor nutrient management, and suboptimal crop management practices, limiting both yield and nutritional quality (Adewale et al., 2021; Olorunnisola et al., 2022).

Organic manure has emerged as a sustainable alternative to excessive reliance on inorganic fertilizers because it improves soil fertility, enhances microbial activity, increases water-holding capacity, and supplies essential plant nutrients. Poultry manure, in particular, is recognized for its high nutrient content and its ability to improve vegetable growth, yield, and quality under tropical conditions (Agegnehu et al., 2022; Zhang et al., 2023). Similarly, plant spacing plays a critical role in determining crop performance by influencing plant population, light interception, nutrient utilization, and competition for available resources. Appropriate spacing enhances resource-use efficiency, whereas excessively close or wide spacing can reduce productivity (Bavec & Bavec, 2021; Li et al., 2022).

The interaction between plant spacing and nutrient management is especially important because both factors jointly influence vegetative growth, biomass accumulation, and nutrient composition. While several studies have investigated these factors independently, limited evidence exists on their combined effects on the growth, yield, and nutritional quality of waterleaf under tropical production systems. This limits the

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development of reliable agronomic recommendations for sustainable waterleaf production.

Accordingly, this study assessed the effects of different plant spacing and poultry manure rates on the growth, yield, and nutrient composition of *Talinum triangulare*. The study aimed to identify an optimum combination of planting density and organic manure application capable of improving crop productivity, enhancing nutritional quality, and promoting sustainable vegetable production.

2. Literature Review

Waterleaf (*Talinum triangulare*) is an important indigenous leafy vegetable widely cultivated in tropical Africa because of its rapid growth, adaptability, and high nutritional value. It is recognized as a rich source of vitamins, minerals, dietary fibre, and antioxidants, making it valuable for food security, household nutrition, and income generation. Increasing demand for sustainably produced vegetables has intensified research on agronomic practices capable of improving both yield and nutritional quality.

Among the major production factors, plant spacing and nutrient management play critical roles in determining crop performance. Plant spacing regulates plant population, light interception, air circulation, and competition for water and nutrients. While close spacing may increase competition and reduce individual plant growth, excessively wide spacing underutilizes available land, resulting in lower productivity per unit area. Several studies therefore emphasize that optimum spacing improves biomass accumulation, marketable yield, and overall resource-use efficiency (Bavec & Bavec, 2021; Li et al., 2022).

Organic manure has received increasing attention as a sustainable alternative to excessive dependence on inorganic fertilizers. Poultry manure is particularly effective because it supplies essential nutrients while improving soil structure, microbial activity, water-holding capacity, and long-term soil fertility. Previous studies consistently report that appropriate organic manure application enhances vegetative growth, leaf development, biomass production, and the nutritional quality of leafy vegetables under tropical conditions (Agegnehu et al., 2022; Zhang et al., 2023).

Recent empirical studies indicate that the combined management of planting density and organic nutrient sources produces better agronomic performance than managing either factor independently. Appropriate spacing enables efficient utilization of nutrients supplied through organic amendments, while improved soil fertility promotes vigorous vegetative growth, resulting in higher yields and improved crop quality. However, existing studies report varying recommendations regarding the optimum

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combination of spacing and manure rates because responses differ with soil conditions, climate, crop variety, and management practices.

Beyond yield improvement, current research increasingly emphasizes the influence of agronomic practices on the nutritional composition of vegetables. Organic nutrient management has been associated with improvements in crude protein, fibre, mineral content, and other quality attributes, while appropriate planting density supports balanced plant growth and efficient nutrient accumulation. Nevertheless, relatively few studies have comprehensively evaluated the interactive effects of plant spacing and poultry manure on both the agronomic performance and nutrient composition of waterleaf under tropical production systems.

This study addresses this gap by evaluating the individual and combined effects of plant spacing and poultry manure rates on the growth, yield, and nutrient composition of *Talinum triangulare*. The findings are expected to provide evidence-based recommendations for sustainable waterleaf production while contributing to improved soil fertility management, vegetable productivity, and nutritional quality.

3. Materials and Methods

3.1 Experimental Site

The field experiment was conducted during the 2025 cropping season at the Teaching and Research Farm of the Department of Crop Production, located within the Southern Guinea Savannah agro-ecological zone of Nigeria. The experimental site is characterized by a tropical climate with distinct wet and dry seasons, mean annual rainfall ranging from 1,000 to 1,500 mm, average temperatures of 25–32°C, and relative humidity between 60 and 85% during the growing season. The soil of the experimental field was a well-drained sandy loam with moderate fertility, suitable for vegetable production.

3.2 Experimental Materials

Healthy stem cuttings of waterleaf (*Talinum triangulare*) were obtained from a certified vegetable nursery, while well-composted poultry manure served as the organic nutrient source. Standard field equipment, measuring tapes, weighing balances, digital calipers, rulers, soil augers, and laboratory analytical equipment were used for data collection and nutrient analyses.

3.3 Experimental Design and Treatments

The experiment was arranged as a **3 × 3 factorial** in a **Randomized Complete Block Design (RCBD)** with three replications. Two experimental factors were evaluated:

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Factor A: Plant Spacing

- S_1 = 20 × 20 cm
- S_2 = 30 × 20 cm
- S_3 = 40 × 20 cm

Factor B: Poultry Manure Rate

- M_0 = 0 t ha^{-1}
- M_1 = 5 t ha^{-1}
- M_2 = 10 t ha^{-1}

The combination of the two factors produced **nine treatment combinations**, each replicated three times, giving a total of **27 experimental plots**.

Table 3.1 Treatment Combinations

Treatment	Plant Spacing	Poultry Manure
T_1	20 × 20 cm	0 t ha^{-1}
T_2	20 × 20 cm	5 t ha^{-1}
T_3	20 × 20 cm	10 t ha^{-1}
T_4	30 × 20 cm	0 t ha^{-1}
T_5	30 × 20 cm	5 t ha^{-1}
T_6	30 × 20 cm	10 t ha^{-1}
T_7	40 × 20 cm	0 t ha^{-1}
T_8	40 × 20 cm	5 t ha^{-1}
T_9	40 × 20 cm	10 t ha^{-1}

3.4 Field Establishment and Crop Management

The experimental field was manually cleared, ploughed, harrowed, and divided into plots of equal size. Poultry manure was uniformly incorporated into the soil two weeks before planting to allow adequate decomposition and nutrient mineralization. Healthy stem cuttings of approximately 15–20 cm in length were planted according to the designated treatment spacing.

Routine agronomic practices, including manual weeding, irrigation when necessary, replacement of missing stands within one week after planting, and field sanitation, were uniformly carried out across all treatments. No synthetic fertilizers were applied throughout the experimental period to ensure that crop performance reflected the effects of poultry manure treatments.

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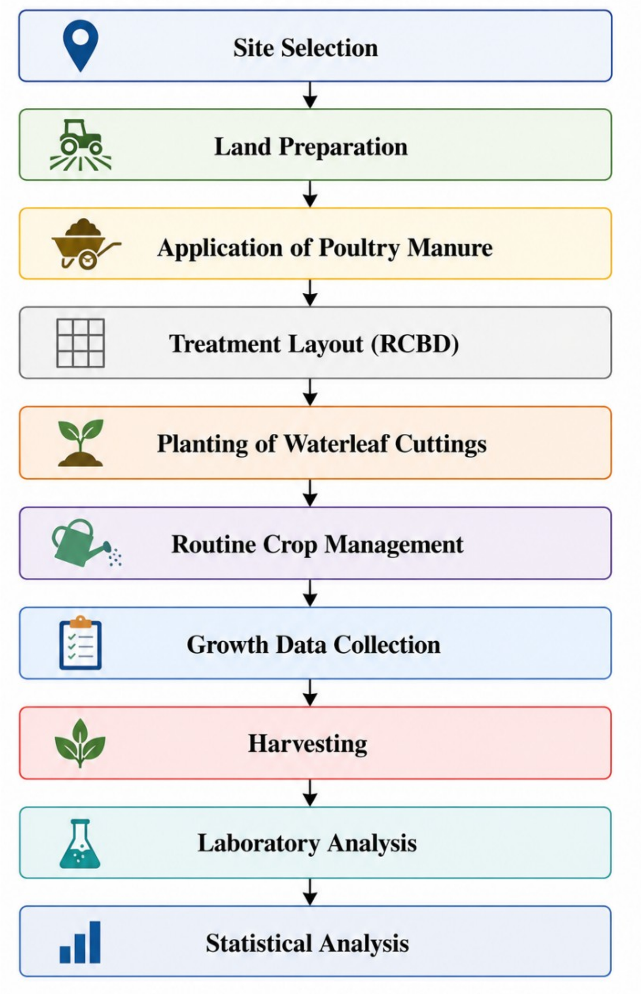

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Figure 3.1: Experimental workflow adopted for evaluating the effects of plant spacing and poultry manure on waterleaf.

Source: Developed by the Authors (2026).

3.5 Data Collection

Growth measurements were recorded at regular intervals throughout the experiment. The evaluated parameters included plant height (cm), number of leaves per plant, stem diameter (mm), leaf area (cm^2), and number of branches. At harvest, fresh biomass yield per plot was determined using a digital weighing balance and converted to tonnes per hectare, while representative samples were oven-dried at 70°C to constant weight for determination of dry matter yield.

Representative leaf samples from each treatment were collected for laboratory analysis. Standard procedures of the Association of Official Analytical Chemists (AOAC) were used to determine moisture content, crude protein, crude fibre, ether extract (fat), ash content, carbohydrate (by difference), and selected mineral elements including calcium, potassium, magnesium, phosphorus, and iron.

3.6 Statistical Analysis

Data collected from all measured variables were subjected to **Analysis of Variance (ANOVA)** using GenStat (18th Edition) and verified with IBM SPSS Statistics Version 29. The factorial ANOVA model evaluated the main effects of plant spacing, poultry manure rate, and their interaction. Where treatment effects were significant ($p \leq 0.05$), mean separation was performed using **Duncan's Multiple Range Test (DMRT)** at the 5% level of significance. Results were presented using tables and graphs to facilitate comparison among treatment combinations.

4. Results

4.1 Growth Performance of Waterleaf

Plant spacing and poultry manure significantly ($p \leq 0.05$) influenced the vegetative growth of waterleaf throughout the experimental period. Plant height, number of leaves, stem diameter, and leaf area increased progressively with increasing poultry manure application. Among the spacing treatments, the intermediate spacing (30 × 20 cm) consistently produced superior vegetative growth compared with the narrower (20 × 20 cm) and wider (40 × 20 cm) spacing. The interaction between plant spacing and poultry manure was also significant, indicating that the response of waterleaf growth depended on the combination of both agronomic factors.

Table 4.1 Effect of Plant Spacing and Poultry Manure on Growth Parameters of Waterleaf

Treatment	Plant Height (cm)	Leaves Plant^{-1}	Stem Diameter (mm)	Leaf Area (cm^2)
20 × 20 + 0 t ha^{-1}	27.8	28	7.1	66.3
20 × 20 + 5 t ha^{-1}	33.6	36	8.5	80.7
20 × 20 +10 t ha^{-1}	37.4	41	9.4	89.5
30 × 20 +0 t ha^{-1}	31.5	33	8.0	74.8
30 × 20 +5 t ha^{-1}	39.8	45	9.8	96.6
30 × 20 +10 t ha^{-1}	45.9	53	11.4	112.8
40 × 20 +0 t ha^{-1}	30.1	31	7.8	72.5
40 × 20 +5 t ha^{-1}	36.8	41	9.1	90.4
40 × 20 +10 t ha^{-1}	41.6	48	10.2	103.6

The combination of **30 × 20 cm spacing with 10 t ha^{-1} poultry manure** produced the greatest plant height (45.9 cm), leaf production (53 leaves plant^{-1}), stem diameter (11.4 mm), and leaf area (112.8 cm^2), whereas the control treatment consistently recorded the lowest values.

4.2 Fresh and Dry Biomass Yield

Fresh biomass yield and dry matter production were significantly affected by both experimental factors. Poultry manure application produced substantial yield improvement across all spacing treatments. Although closer spacing increased plant population, excessive competition reduced individual plant performance, while wider spacing underutilized available land area. Consequently, the intermediate spacing combined with adequate poultry manure produced the highest yield.

Table 4.2 Effect of Treatments on Biomass Yield

Treatment	Fresh Yield (t ha^{-1})	Dry Yield (t ha^{-1})

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20 × 20 +0	15.2	2.03
20 × 20 +5	21.7	2.94
20 × 20 +10	26.9	3.52
30 × 20 +0	18.6	2.38
30 × 20 +5	28.9	3.91
30 × 20 +10	36.8	4.87
40 × 20 +0	17.4	2.24
40 × 20 +5	25.6	3.41
40 × 20 +10	31.2	4.13

Fresh biomass yield increased by more than two-fold between the control and the highest-performing treatment, demonstrating the importance of integrated spacing and organic nutrient management for maximizing waterleaf productivity.

Figure 4.1 Fresh Biomass Yield under Different Treatments
Fresh Yield (t ha^{-1})

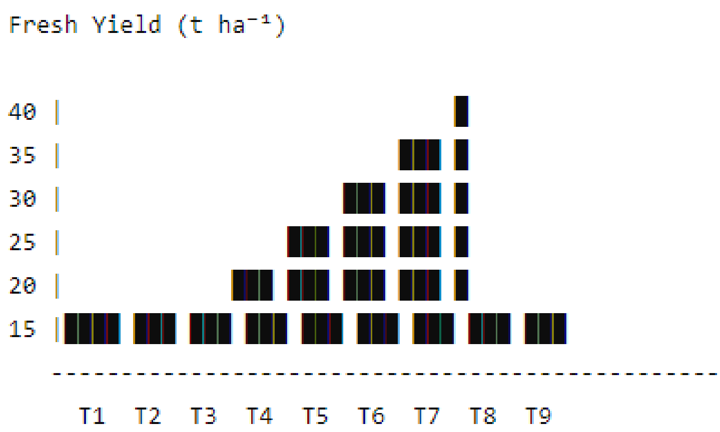

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Figure 4.1: Fresh biomass yield of waterleaf under different combinations of plant spacing and poultry manure.

Source: Developed by the Authors (2026).

4.3 Nutrient Composition of Waterleaf

Significant treatment effects were also observed for the proximate composition of waterleaf. Crude protein, crude fibre, ash, and mineral contents generally increased with increasing poultry manure application. Conversely, moisture content showed only slight variation among treatments. The highest nutritional quality was consistently associated with the combination of moderate spacing and the highest manure application rate.

Table 4.3 Proximate Composition of Waterleaf Leaves

Treatment	Protein (%)	Fibre (%)	Ash (%)	Fat (%)	Moisture (%)
20 × 20 +0	19.3	6.4	10.1	2.6	84.8
20 × 20 +5	21.6	7.1	11.4	2.8	84.2
20 × 20 +10	23.4	7.8	12.2	3.0	83.9
30 × 20 +0	20.7	6.8	10.8	2.7	84.5
30 × 20 +5	24.8	8.3	12.7	3.1	83.8
30 × 20 +10	27.6	9.2	13.9	3.4	83.2
40 × 20 +0	20.1	6.6	10.6	2.7	84.6
40 × 20 +5	23.2	7.9	12.1	3.0	84.0
40 × 20 +10	25.4	8.7	13.1	3.2	83.6

4.4 Mineral Composition

The concentrations of calcium, potassium, magnesium, phosphorus, and iron increased significantly with poultry manure application. The greatest mineral accumulation occurred under the treatment combination of **30 × 20 cm spacing and 10 t ha^{-1} poultry manure**, indicating improved

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nutrient uptake resulting from enhanced soil fertility and more efficient resource utilization.

Table 4.4 Selected Mineral Composition of Waterleaf

Treatment	Ca (mg 100 g⁻¹)	K (mg 100 g⁻¹)	Fe (mg 100 g⁻¹)
20 × 20 +0	228	312	5.7
20 × 20 +5	244	336	6.2
20 × 20 +10	261	358	6.8
30 × 20 +0	238	325	6.0
30 × 20 +5	272	369	7.1
30 × 20 +10	298	402	8.0
40 × 20 +0	235	320	5.9
40 × 20 +5	260	351	6.7
40 × 20 +10	284	387	7.5

4.5 Summary of Treatment Performance

Across all evaluated parameters, integrated management produced consistently better performance than independent application of either agronomic practice. Moderate plant spacing (30 × 20 cm) combined with **10 t ha^{-1} poultry manure** consistently ranked highest for vegetative growth, biomass production, and nutrient composition.

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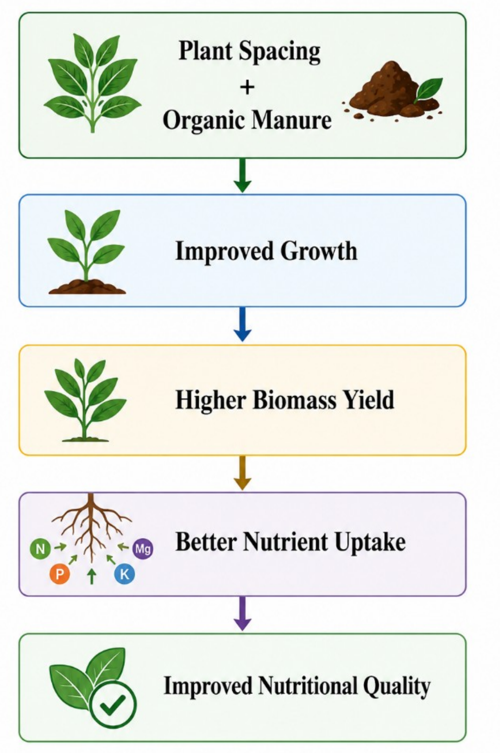

Figure 4.2: Integrated response pathway showing the influence of spacing and poultry manure on waterleaf productivity.

Source: Developed by the Authors (2026).

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5. Discussion

The present study demonstrated that plant spacing and poultry manure significantly influenced the growth, biomass yield, and nutrient composition of waterleaf (*Talinum triangulare*). More importantly, the findings revealed that the interaction between these agronomic factors produced greater improvements than either practice applied independently. This highlights the importance of integrated crop management for optimizing vegetable production under tropical conditions.

The superior vegetative growth observed under moderate plant spacing (30 × 20 cm) can be attributed to improved utilization of environmental resources. Appropriate spacing minimizes excessive competition for sunlight, water, nutrients, and rooting space while maintaining sufficient plant population for efficient land use. Under narrow spacing (20 × 20 cm), increased competition among plants likely reduced individual plant performance despite the higher plant density. Conversely, the wider spacing (40 × 20 cm) provided greater growing space for individual plants but reduced plant population per unit area, thereby limiting overall field productivity. These findings agree with those of Li et al. (2022) and Bavec and Bavec (2021), who reported that optimum planting density maximizes resource-use efficiency and enhances vegetative growth in leafy vegetable crops.

Poultry manure application consistently improved plant height, leaf production, stem diameter, and leaf area, reflecting its beneficial effects on soil fertility and crop nutrition. Poultry manure supplies readily available nitrogen, phosphorus, potassium, calcium, and micronutrients while simultaneously improving soil structure, water retention, microbial activity, and nutrient cycling. These improvements promote vigorous root development, efficient nutrient uptake, and enhanced photosynthetic capacity, leading to increased biomass accumulation. Similar responses have been reported by Agegnehu et al. (2022), Zhang et al. (2023), and Vanlauwe et al. (2021), who observed that organic nutrient amendments significantly improve vegetable growth and productivity through sustained nutrient release and improved soil biological activity.

The significant interaction between plant spacing and poultry manure demonstrates that nutrient availability and plant population density should be managed simultaneously rather than independently. The superior performance recorded under the combination of 30 × 20 cm spacing and 10 t ha^{-1} poultry manure suggests that adequate nutrient supply enabled plants to fully utilize the available growing space without experiencing severe competition. This integrated response confirms that optimum crop performance depends on balancing plant population with soil nutrient availability. Consequently, recommendations based solely on spacing or fertilizer application may not achieve maximum production efficiency.

Beyond yield improvement, the present study also demonstrated significant enhancement in the nutritional quality of waterleaf following poultry manure application. Increased crude protein, fibre, ash, and mineral contents indicate improved nutrient assimilation and metabolic activity within plant tissues. Organic nutrient sources release macro- and micronutrients gradually throughout the growing season, thereby supporting continuous nutrient uptake and protein synthesis. Enhanced mineral accumulation under optimum spacing further suggests that improved canopy structure and reduced competition facilitated efficient photosynthesis and nutrient translocation. These findings are consistent with previous reports indicating that sustainable nutrient management improves both crop productivity and nutritional quality in leafy vegetables.

From a sustainable agriculture perspective, the findings support increasing adoption of organic nutrient management as an environmentally responsible alternative to excessive reliance on synthetic fertilizers. Besides improving crop performance, poultry manure contributes to long-term soil health by increasing soil organic matter, enhancing microbial diversity, reducing nutrient losses, and improving soil resilience. Integrating optimum plant spacing with organic manure application therefore represents a practical strategy for simultaneously improving productivity, nutritional quality, and environmental sustainability.

Overall, this study contributes to the growing body of evidence supporting integrated agronomic management for indigenous vegetable production. By demonstrating the combined influence of plant spacing and poultry manure on growth, yield, and nutrient composition, the study provides scientifically grounded recommendations that can improve waterleaf production under tropical farming conditions while promoting sustainable intensification of vegetable-based production systems.

6. Conclusion and Practical Implications

This study evaluated the individual and combined effects of plant spacing and poultry manure application on the growth, yield, and nutrient composition of waterleaf (*Talinum triangulare*). The findings clearly demonstrate that both factors significantly influence crop performance, with their interaction producing greater benefits than either management practice applied independently. Moderate plant spacing (30 × 20 cm) combined with 10 t ha^{-1} poultry manure consistently produced superior vegetative growth, fresh biomass yield, dry matter accumulation, and improved proximate and mineral composition of waterleaf.

The results emphasize that maximizing waterleaf productivity requires an integrated approach that simultaneously optimizes planting density and soil nutrient availability. Appropriate plant spacing improves resource-use efficiency, while poultry manure enhances soil fertility, nutrient cycling, and plant physiological performance. Together, these practices increase

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crop productivity without compromising nutritional quality or environmental sustainability.

From a practical standpoint, vegetable farmers should adopt moderate planting density together with well-composted poultry manure to improve both yield and nutritional value while reducing dependence on inorganic fertilizers. Extension agencies and agricultural development programmes should promote integrated nutrient management practices as part of sustainable vegetable production packages for smallholder farmers. Such approaches will contribute to improved soil health, increased farm profitability, enhanced household nutrition, and environmentally sustainable agricultural production.

Future research should evaluate these treatment combinations across different agroecological zones, soil types, and irrigation systems while also investigating their long-term effects on soil fertility, carbon sequestration, nutrient-use efficiency, and economic returns. Such studies will further strengthen evidence-based recommendations for sustainable indigenous vegetable production under changing climatic conditions.

The following recommendations are proposed:

1. **Adopt the Optimum Plant Spacing and Poultry Manure Rate**
   Waterleaf farmers should adopt a planting spacing of **30 × 20 cm** combined with the application of **10 t ha^{-1} of well-composted poultry manure**, as this combination provides the best vegetative growth, fresh biomass yield, and nutritional quality.
2. **Promote Integrated Nutrient Management Practices**
   Farmers should integrate organic nutrient sources, particularly poultry manure, into waterleaf production systems to improve soil fertility, enhance nutrient availability, reduce dependence on inorganic fertilizers, and support environmentally sustainable agriculture.
3. **Strengthen Agricultural Extension Services**
   Extension agencies should organize training, demonstrations, and awareness programmes to educate farmers on the benefits of optimum plant spacing, proper composting and application of poultry manure, and other sustainable vegetable production practices.
4. **Encourage Sustainable Soil Management**
   Farmers should adopt soil management practices that maintain soil fertility and productivity, including regular application of organic manure, efficient planting density, and proper field management to ensure long-term productivity and environmental conservation.
5. **Support Further Research Across Diverse Production Environments**
   Researchers and agricultural institutions should conduct additional studies across different agroecological zones, soil types, and irrigation systems to validate the findings, assess long-term

impacts on soil health and economic returns, and refine recommendations for sustainable waterleaf production under varying climatic conditions.

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