

Plant Population and Integrated Nutrient Management Effects on Growth and Rhizome Yield of Turmeric (*Curcuma longa* L.) in the Humid Rainforest Zone of Nigeria

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Abstract

Turmeric (*Curcuma longa* L.) is an economically important rhizome crop whose productivity is strongly influenced by plant population and nutrient availability. A two-year field experiment was conducted in 2019 and 2020 at the Teaching and Research Farm of the Department of Agronomy, University of Cross River State, Obubra Campus, Nigeria, to evaluate the effects of plant population and fertilizer type on the growth, yield and yield components of turmeric. The experiment was arranged as a 4×4 factorial in a randomized complete block design with three replications. Four planting spacings (20×20 , 20×30 , 30×30 and 20×40 cm) were combined with four nutrient treatments: unfertilized control, 300 kg ha^{-1} NPK 15:15:15, 10 t ha^{-1} moringa leaf manure, and 150 kg ha^{-1} NPK + 5 t ha^{-1} moringa leaf manure. Growth and yield parameters were evaluated. Fertilizer application significantly improved plant height, tiller production, leaf development, shoot dry matter, rhizome number and fresh rhizome yield compared with the unfertilized control. The integrated treatment of 150 kg ha^{-1} NPK + 5 t ha^{-1} moringa leaf manure generally produced the highest vegetative growth and fresh rhizome yield, attaining fresh rhizome yield of 6.34 and 6.52 t ha^{-1} in 2019 and 2020, respectively. Plant spacing also influenced several growth and yield attributes, with wider spacings, particularly 30×30 cm and 20×40 cm, generally producing greater rhizome yield per plant and per unit area. The results in this study showed that combining inorganic and organic nutrient sources increased turmeric yield over sole inorganic fertilization. Therefore, for optimum yield of turmeric, it is recommended that moringa leaf biomass (5 t/ha) should be combined with 150 kg/ha NPK fertilizer at a spacing of $30 \text{ cm} \times 30 \text{ cm}$.

Key words: Turmeric, moringa, integrated nutrients, rhizome, tiller

Introduction: Turmeric (*Curcuma longa* L.) is a herbaceous, rhizomatous perennial belonging to the family Zingiberaceae. Its underground rhizome is the principal economic product and is used as a spice, natural colourant, and raw material for food, pharmaceutical, cosmetic and nutraceutical products. Interest in turmeric is also associated with its curcuminoids and volatile oils, which contribute to its characteristic colour, aroma and biological properties (Dosoky and Setzer, 2018; Ibáñez and Blázquez, 2020). These uses create opportunities for improved production, but realizing this potential depends on agronomic practices that support reliable rhizome yield and quality. In Nigeria, turmeric production offers opportunities for smallholder farmers and for domestic value chains, yet agronomic recommendations need to be adapted to local soils, rainfall patterns and production systems. Evidence from Nigerian studies confirms that turmeric responds to fertilizer management. Ojikpong (2018), working under Obubra conditions, reported significant effects of planting date and NPK 15:15:15 fertilizer on growth and yield, while Ojikpong and Undie (2019) documented responses to nitrogen rate and split application. Akpan, Orji and Uhala (2021) also reported growth and yield responses of turmeric varieties to inorganic fertilizer levels in south-eastern Nigeria. Although these studies support the importance of nutrient management, locally tested combinations of plant population and organic-inorganic nutrient sources remain relevant for refining recommendations for the humid

rainforest zone. Plant population is a major component of crop management because spacing determines the number of plants established per unit area and affects competition for light, water, nutrients and physical growing space. Close spacing can increase the number of plants per unit area and accelerate canopy closure, but excessive competition may limit tillering and rhizome expansion per plant. Wider spacing can improve the growth of individual clumps, although the resulting lower plant population may not always maximize yield per hectare. Recent work by Khedkar, Mali, Khedkar, Salvi, Salvi and Malshe (2023) examined the combined influence of plant spacing and nitrogen doses on turmeric growth and yield, reinforcing the need to consider spacing alongside nutrient supply rather than treating either factor in isolation. Verma, Patel, Deshmukh, Jha, Ngachan, Singha and Deka (2019) likewise compared organic and traditional production practices for ginger and turmeric under humid subtropical conditions and showed that production response should be interpreted in relation to the growing environment and management system. Nutrient availability is particularly important in turmeric because the crop develops substantial foliage and underground storage rhizomes over a relatively long growing period. Nitrogen supports leaf and shoots development, while phosphorus and potassium contribute to root development, energy transfer, enzyme activity and the movement of assimilates into developing rhizomes. However, the performance of a fertilizer treatment depends

on the rate, timing, soil condition and crop environment. Mekonnen and Garedew (2019), for example, investigated turmeric responses to nitrogen rate and application timing, illustrating the importance of nutrient management beyond fertilizer choice alone.

Integrated nutrient management combines mineral fertilizers with organic manures and, where appropriate, beneficial microorganisms to supply nutrients while making use of locally available organic resources. Organic amendments can add nutrients and organic matter, while mineral fertilizers provide nutrients in forms that are generally more readily available to the crop. Datta, Jana, Bhaisare and Nimbalkar (2017) evaluated organic nutrient sources and biofertilizers for turmeric growth, yield and quality. Kanaugia, Tzudir, Maiti and Sentimenla (2018) found that a combination of mineral fertilizer, poultry manure and *Azospirillum* improved several growth, yield and quality indicators compared with the control. Amala, Prabhakar, Padma and Triveni (2019) also reported improved fresh rhizome yield and curcumin content under an integrated treatment involving reduced NPK, farmyard manure, vermicompost, neem cake and biofertilizers. These results indicate that combining nutrient sources can be a useful strategy, although the best treatment is dependent on the materials used and local growing conditions. More recent studies provide further evidence that organic and mineral nutrient sources can have complementary effects, but they also show that the response is not identical across all nutrient sources or environments. Sunuwar Koirala, Acharya, Chaudhary, Bhandari, Rai, Nirawla and Mehta (2024), comparing synthetic fertilizer with several organic manures in eastern Nepal, reported the highest fresh rhizome yield under the recommended NPK treatment, while goat and poultry manure also performed favourably relative to the unfertilized control. Sagwal, Bora, Thakur, Ketan, Sharma and Bhagta (2025) found that treatments combining a proportion of the recommended fertilizer dose with farmyard manure or vermicompost improved selected turmeric growth and soil nutrient indicators. Taken together, these studies support evaluating locally available organic materials in combination with mineral fertilizer rather than assuming that one nutrient source will be optimal under all conditions. Moringa (*Moringa oleifera*) leaves are a potentially useful locally available biomass for nutrient recycling. Their suitability as a soil amendment should, however, be assessed in the production environment where they are to be used, particularly in relation to the crop's nutrient demand and the properties of the soil. Integrating moringa leaf biomass with a reduced mineral fertilizer rate may provide a practical way to combine organic nutrient inputs with the more immediately available nutrients supplied by NPK fertilizer. The effectiveness of this approach also needs to be evaluated alongside planting spacing, because plant density can influence how effectively available nutrients and other growth resources are converted into rhizome yield. Despite the growing body of research on turmeric nutrition, evidence on the combined effects of plant spacing and moringa leaf biomass integrated with NPK fertilizer under the humid rainforest conditions of south-eastern Nigeria remains limited. This is an important knowledge gap because recommendations developed in other agroecological regions

may not transfer directly to the acidic, relatively low-fertility soils and humid conditions of Obubra, Cross River State. The present study therefore evaluated the effects of plant spacing and fertilizer type on turmeric growth, yield and yield components during the 2019 and 2020 cropping seasons. Specifically, it aimed to identify a suitable plant population and nutrient treatment for improving turmeric productivity under the study conditions.

Study Area: The experiment was conducted at the Teaching and Research Farm of the Department of Agronomy, Faculty of Agriculture and Forestry, of the then Cross River University of Technology (CRUTECH), Obubra Campus, now University of Cross River State (UNICROSS), Okuku Campus, Cross River State, Nigeria. The experimental site is located within the south-eastern rainforest agroecological zone of Nigeria, approximately between latitudes 5°45' and 6°15' N and longitudes 8°15' and 8°45' E. The area has a humid tropical climate characterized by distinct wet and dry seasons. Mean annual rainfall is approximately 2,000mm–2,500mm, with peak rainfall generally occurring between July and September. Mean annual temperature ranges from approximately 26 to 28°C, while relative humidity is generally between 70 and 85%. The soils are predominantly acidic Ultisols and are generally characterized by low inherent fertility.

Experimental Design and Treatments: The experiment was conducted during the 2019 and 2020 cropping seasons. A 4 × 4 factorial arrangement was fitted into a randomized complete block design (RCBD) with three replications. The treatments consisted of four planting spacings (20cm x 20cm, 30cm x 20cm, 30cm x 30cm and 40cm x 20cm) and four fertilizer types (0 fertilizer, NPK 300kg/ha, moringa 10 t/ha, and 150 kg/ha NPK + 5 t/ha moringa leaf). The sixteen treatment combinations were replicated three times, giving 48 experimental plots. Each plot measured 3 × 3 m, while the overall experimental field measured approximately 24 × 30 m.

Soil Sampling and Analysis: Before planting, soil samples were collected from the experimental field and analyzed for selected physical and chemical properties. The soil was sandy loam, with a mean pH of approximately 5.53. Initial soil total nitrogen was low, while available phosphorus and exchangeable bases were also relatively low, reflecting the generally low inherent fertility of the experimental site.

The initial mean organic matter content was approximately 2.77%. The experimental soil therefore provided a suitable basis for evaluating responses to external nutrient inputs.

Planting Material and Field Establishment: Healthy and disease-free turmeric rhizomes obtained from a local source within Cross River State were used as planting materials. Rhizomes were selected for uniformity to promote relatively even establishment. The field was cleared and prepared to obtain a suitable tilth. Rhizome sets were planted at approximately 5–7 cm depth at the specified treatment spacings, with the buds positioned appropriately for emergence.

Fertilizer and Moringa Manure Application: Moringa leaf biomass was applied fresh. This material was incorporated into the soil approximately two weeks before planting to allow decomposition and nutrient release. The NPK fertilizer treatments were applied according to the specified rates.

Crop Management: All plots received similar cultural management practices throughout the experiment. Weeding and other necessary field operations were performed uniformly to minimize confounding effects among treatments.

Soil sampling and processing. At the commencement of the experiment, composite soil samples were collected at random points within the experimental plot which were bulked using a soil auger at the 0 – 20 cm. Postharvest soil samples were also collected from each treatment. The samples were air dried and sieved through a 2mm mesh ready for laboratory analysis.

Plant Sampling and analysis: A net plot of inner rows for each treatment was used with five tagged plants for growth parameters. At 6 and 10 weeks after planting (WAP), the plants height was measured using meter rule and thereafter the shoots were carefully harvested by destructive sampling. This was done for the two seasons of 2019 and 2020. The shoots were later oven dried in paper bags at a temperature of 65°C to constant weight and the dry matter weight determined.

Soil Analysis: Routine analysis was conducted for the composite and the postharvest samples to determine the particle size distribution using the Bouyouchos Hydrometer method as outlined by Udo, Ibia, Ogunwale, Ano and Esu(2009). Soil pH using glass electrode pH meter and soil N by the Macro Kjeldahl apparatus as described by Udo *et al.*, (2009). Soil organic matter was analysed using the Walkley – Black wet Oxidation method as outlined by Page, Miller and Keeney (1982). The excess was titrated against ferrous sulphate. The organic carbon was then calculated using the relationship. % org. C. = $N(V1 - V2) 0.3 f$. The % org. mater in soil = % org. C x 1.729. Soil phosphorus was determined using the Bray 1 method as described by Page *et al.*, (1982)

Statistical Analysis:: Analysis of variance (ANOVA) for RCBD was performed on the turmeric plant height, number of leaves, leaf area, plant dry matter, number of finger and mother rhizomes and rhizome yield per unit area using the computer software Genstat (Genstat 2005). FLSD was calculated on the means at $P > 0.05$ to separate the mean

Results and Discussion: Initial Soil Characteristics: The initial experimental soil properties (Table 1) were sandy loam and moderately acidic. Mean soil pH was approximately 5.53 across the two experimental seasons. Organic matter averaged 2.77%, while total nitrogen was approximately 0.08%. Available phosphorus was about 6.13 mg kg⁻¹. Exchangeable Ca, Mg and K were relatively low, indicating that nutrient availability was an important consideration for crop production at the site. The moringa

leaf biomass (Table 2) used as organic amendment contained approximately 4.10% N, 1.21% P and 1.71% K, with an organic carbon content of about 10.8%. The low C:N ratio of approximately 2.6 indicated that the material was readily decomposable and potentially capable of releasing nutrients during crop growth.

Plant Height: Application of NPK and Moringa leaf biomass singly and in combination significantly ($P < 0.05$) increased plant height of turmeric. The result indicated that application of NPK at 300 kg-1 and 150 kg-1 + Moringa leaf biomass at 5 t ha⁻¹ produced tallest plants (84.51 cm and 85.37 cm) respectively in 2019 and (89.32 cm and 88.34 cm) respectively for same treatments in 2020. The control that received no fertilizer produced plants with the least plant height (57.3 cm and 58.90 cm) respectively for 2019 and 2020. The plant spacing significantly $P < 0.05$ affected the height of the turmeric plants at 10 WAP. Plants spaced at 20 cm x 20 cm produced taller plants (67.68 cm and 66.66 cm) respectively for 2019 and 2020 than the other plant spacing. There was no interaction effect between fertilizer type and plant spacing in both years. The tallest plants of the turmeric were obtained with the NPK level up to 300 kg/ha and with the combination of moringa leaf biomass at 150 t/ha and the NPK fertilizer at 150 kg/ha. However, the plant height decreased as the spacing increased. This decrease in plant height of the turmeric could be due to the intense competition for light, nutrients and space among the plants, some of them may have shedded their canopies to fit the vertical space. This study findings are in agreement with Nautiyal, Tiwari, Upadhyay and Chauhan (2016) who reported taller plants of turmeric spaced at 20 cm x 20 cm compared with wider spacing of 30 cm x 40 cm; 40 cm x 40 cm that produced shorter plants. The increased in plant height recorded with inorganic NPK fertilizer at 300 kg/ha was similar to the results obtained by Ojikpong (2018) who reported tallest plants of turmeric with the application of NPK 15:15:15 at the rate of 300 kg/ha and Akpan *et al.*, (2021) at a study at Umudike where application rate of NPK 15:15:15 produced highest growth. The combined application of organic and inorganic at 50:50 that resulted in the tallest plants as recorded in this study has been reported by Singh, Mukhi and Mishra (2016) and Anuradha, Patil, Kurubar, Ramesh and Hirgonda (2022) who reported that integrated approach of inorganic and organic manures resulted in the higher plants performance as turmeric is a heavy feeder. The non-significant result on interaction effect on this study is also reported by Akpan *et al.*, (2021).

Tiller Production: The number of tillers per plant was significantly ($P < 0.05$) affected by the main effects of fertilizer type and plant spacing as well as the interaction of the two factors (Table 4). Application of NPK at 300 kg ha⁻¹ and 150 kg ha⁻¹ NPK + Moringa leaf biomass at 5 t ha⁻¹ produced highest number of tillers (8.12 and 8.14) respectively in 2019 and 7.24 and 7.88 respectively in 2020. The least number of tillers was produced in the control plots (4.62 and 4.45), respectively for 2019 and 2020. Plant spacing of 20 cm x 30 cm, 20 cm x 40 cm and 30 cm x 30 cm produced significantly higher number of tillers (6.02, 6.91 and 6.84) respectively in 2019 and (5.92, 6.20 and 6.44) respectively in 2020 than plants spaced at 20 cm x 20 cm with tillers of 5.4 and 4.95 in 2019 and 2020, respectively.

At interaction, application of 300 kg ha⁻¹NPK and 150 kg ha⁻¹ + 5 t ha⁻¹ moringa leaf biomass at a plant spacing of 30cm x 30 cm significantly produced higher number of tillers than the other fertilizer treatments and spacing. The production of higher number of tillers per clump of the turmeric plants that was influenced by higher rates of the fertilizer and the combination of the organic and inorganic forms and the wider spacing of the plants is an indication of sufficient nutrients provided by the fertilizer levels and the larger feeding area for the plants. Higher amount of nutrients and less plant population in the wider spaced plants is attributable to the higher number of tillers produced by the plants. This result is in agrees with Verma et al (2019) who noted that tillers in turmeric plants increased with increasing plant spacing and decreased with decreasing spacing. The more tiller production with application of integrated organic and inorganic nutrients sources could be due to its marked influence on the capacity of plant to absorb and utilize optimum amount of released nutrients in build-up of plant tissue and vegetative growth (Leva, Thanki, Patel and Patel, 2013). This result could also be attributed to the rapid conversion of synthesized carbohydrates into protein and consequently the increase in number and size of growing cells, resulting ultimately in increased number of tillers (Singh and Agarwal, 2001).

Number of leaves per plant and Leaf Area: Analysis of variance of the data revealed that the leaf number and the leaf area (Table 5) was significantly ($P<0.05$) affected by the main effects of fertilizer type, while plant spacing affected only the leaf area. Application of NPK fertilizer at 300 kg/ha and combination of 150 kg/ha of the NPK + 5 t/ha moringa leaf biomass produced highest number of leaves per plant of turmeric (20.32 and 20.64) respectively in 2019 and (20.84 and 21.02) respectively in 2020. The least number of leaves produced by the plants was obtained from the control that received no fertilizer. The largest leaves of turmeric plants (Table 5) was produced in the treatments of 150 kg/ha NPK 15:15:15 + 5 t/ha with a leaf area of 8112.67 cm² and 7988.40 cm² in 2019 and 2020 respectively. For the plant spacing, plants spaced at 20 cm x 30 cm, 20 cm x 40 cm and 30 cm x 30 cm produced larger leaves (5822.31 cm², 5874.21 cm² and 5988.41 cm²) respectively in 2019 and (5488.42 cm², 5344.30 and 5588.20 cm²) in 2020 than plants that were spaced 20 cm x 20 cm which leaf areas were 4284 cm² and 4311.22 cm² respectively for the 2019 and 2020 planting seasons. The significant response of leaf number and leaf area to higher rates of fertilizer, especially the combined organic and inorganic is an indication that the fertilizer was taken up by the plant and subsequently utilized in cell multiplication, amino acid synthesis and energy formation that acts as structural compound of the chloroplast which carries out photosynthesis (Ng'etich, Niyokuri, Rono and Ogwen, 2013). Moreover, adequate application of fertilizer helps the crop to increase their cell division and cell enlargement, resulting in greater leaf-area development. This leaf area expansion favoured subsequent interception and efficient utilization of solar radiation enhancing overall photosynthetic activities (Kanaujia, Tzudir, Maiti and Sentimenla, 2018). Similar results were reported by Yu, Ren, Zhao, Lia and Zhang (2022). The least number of leaves and smallest leaf area found in the control plots of this experiment corroborates the assertion of Cechin and

Fumis(2004) who reported that adequate nutrients are critical to promote growth and development of the aerial organs of the plant.

Shoot Dry Matter and Rhizome Yield: The results of shoot dry matter per plant and per unit area as influenced by fertilizer type and plant spacing are presented in Tables 6 and 7. Shoot dry matter and rhizome yield of Turmeric were significantly ($P<0.05$) affected by the main effects of fertilizer type and plant spacing. Application of NPK fertilizer 150 kg/ha + 5 t/ha moringa leaf biomass produced heaviest dry matter/ biomass (134.2 g/plant and 135.3 g/plant) per plant of turmeric respectively in 2019 and 2020. The shoot dry matter yield of the Turmeric in 2020 followed the same trend as the result obtained in 2019 with the plant spacing of 20 cm x 20 cm producing lower plant dry matter (Table 6). There was a significant interaction effect between fertilizer type and plant spacing. Application of NPK 15.15.15 at 300 kg/ha, 150 kg /ha NPK + 5 t/ha moringa leaf biomass and 5 t/ha moringa leaf biomass at the plant spacing of 20 cm x 40 cm and 30 cm x 30 cm produced heavier shoot dry matter than the lower fertilizer rates with 20 cm x 20 cm spacing, obtained from fertilized turmeric plants, particularly the combined organic and inorganic fertilizer and the higher level of inorganic NPK agrees with the findings of Akpan et al., (2021) who reported higher shoot dry matter yield with higher fertilizer levels. Thiyyagarajan, Vijayakumar, Selvaraj, Durnisamy, and Yassin (2011) also noted that turmeric dry matter production was directly influenced by nutrient application, particularly N. Shoot dry weight per plant which was significantly lighter at a 20 cm x 20 cm spacing and heavier at a 30-cm x 30 cm and 20 cm x 40 cm spacing in this study is similar to the result obtained by Hossain, Ishimine, Motomura and Akamine (2005); Isimine, Hossain, Ishimine and Murayama (2003) who reported lighter shoot dry matter in plants spaced 20 cm x 20 cm and heavier in plants spaced 30 cm x 30 cm.

Number of mother and finger rhizomes per plant: The result number of mother and finger rhizomes was significantly ($P<0.05$) influenced by fertilizer type and plant spacing as well as the interaction (Table 7). The result indicated that application of NPK fertilizer at 300 kg/ha and combination of 150 kg/ha NPK + 5 t/ha moringa leaf biomass produced highest number of finger and mother rhizomes per plant of turmeric. The number of mother rhizome per plant was 4.62 and 4.82 respectively in 2019 and 4.58 and 4.86 respectively in 2020. Plant spacing significantly ($P<0.05$) affected number of mother rhizomes and finger rhizomes produced by the turmeric plants. The number of mother rhizomes (Table 7) in 2019 was highest in plants spaced at 20 cm x 40cm and 30 cm x 30 cm (4.38 and 4.42) respectively. The result for 2020, followed the same trend as the result obtained in 2019. The interaction between fertilizer type and plant spacing indicated that 300 kg/ha NPK applied singly and 150 kg/ha NPK + 5 t/ha moringa leaf biomass with plant spacing of 20 cm x 40 cm and 30 cm x 30 cm produced higher number of mother rhizomes of turmeric than the other treatments combination. The interaction of fertilizer type with plant spacing at 20 cm x 40 cm and 30cm x 30 cm that produced higher number of rhizomes agrees with the findings of Singh, Singh, Singh

(2001) who reported that optimum spacing ensures efficient interception of radiation and synergistic interaction of space and fertilizer.

Fresh Rhizome yield of Turmeric.: Weight of fresh rhizome yield per plant and per unit area is presented (Table 8) revealed that weight of fresh mother and finger rhizomes per plant and per unit area were significantly ($P < 0.05$) influenced by the main effects of fertilizer type and spacing as well as by the interaction of the two factors. The highest weight of fresh rhizome per plant was obtained where 150 kg/ha NPK and 5 t/ha moringa leaf biomass was applied which weights were 220.2 g/plant and 211.3 g/plant respectively for 2019 and 2020

planting seasons. The least yield per plant was 92.2 g/plant and 89.5 g/plant from the control where no fertilizer was applied. Plant spacing of 20 cm x 40 cm and 30 cm x 30 cm produced higher yield per plant of 201.1 g/plant and 203.2 g/plant respectively for 2019 and 198.4 g/plant and 196.7 g/plant. Plant spacing of 20 cm x 20 cm and 20 cm x 30 cm produced lower yield per plant of 176.6 g/plant and 169.7 g/plant respectively for 2019 and 2020. At interaction, 150 kg/ha NPK + 5 t/ha moringa leaf biomass at the plant spacing of 30 cm x 30 cm and 20 cm x 40 cm produced highest yield per plant (Table 8). Application of 150 kg/ha NPK + 5 t/ha moringa leaf biomass produced highest rhizome yield of 6341.6 kg/ha and 6521.3 kg/ha in 2019 and 2020 respectively. At the interaction, the highest rhizome yield per unit area were obtained similarly from plot which received 150 Kg NPK /ha + 5 t/ha moringa leaf biomass in the 30 cm x 30 cm plant spacing and the 20 cm x 40 cm, followed by the plots which were treated with 300 Kg/ha NPK with same spacing. The lowest rhizome yield per unit area were recorded from plots treated with 0 Kg NPK /ha (Table 8). The highest yield per unit area obtained with a 30cm spacing followed by a 20cm spacing was reported by (Hossain et al., 2005). Integrated approach of inorganic and organic manures resulted in the higher yield compared to others. As turmeric is heavy feeder the combined inorganic and organic fertilizers could have provided the nutrients continuously throughout the growing period which ultimately helps in higher nutrients accumulation in the rhizome. Influence of integrated application of 50% (150 kg/ha NPK) through inorganic sources with 50 % (5 t/ha moringa leaf biomass) through organic source was found to be superior with respect to growth and yield of turmeric. The synergistic beneficial effect of soil applied NPK 150 Kg /ha + 5 t/ha moringa leaf biomass on yield attributes of turmeric like mother and finger rhizome number per plant agree with the findings of (Reddy, Devi, and Sridevi 2003; Nanda, Mohapatra and Mukhi 2012; Leva, Thanki, Patel and Patel 2013; Ojikpong, 2018). The higher average rhizome yield also could be due to more luxuriant growth, more foliage and leaf area and higher supply of photosynthates which helped in producing bigger rhizomes, hence resulting in higher yields (Khedkar et al; 2023).

Conclusion: The two-year field study demonstrated that both plant population and nutrient management influenced the growth and productivity of turmeric under the humid rainforest conditions of Obubra, Cross River State, Nigeria. Fertilizer application significantly increased plant height, tiller production, leaf development, shoot dry matter, rhizome number and fresh rhizome yield compared with the

unfertilized control. The integrated application of 150 kg ha⁻¹ NPK 15:15:15 + 5 t ha⁻¹ moringa leaf manure consistently produced better vegetative growth, superior yield and yield components. Wider plant spacing, particularly 30 × 30 cm and 20 × 40 cm, favoured individual plant development, tillering and rhizome formation compared with the closest spacing of 20 cm x 20 cm. Under conditions similar to those of the experimental site, integrated nutrient management involving NPK and moringa leaf manure, together with an appropriate plant population, provides a promising approach for improving turmeric productivity. The results have implications for turmeric production in the humid rainforest zone of Nigeria. The response to the integrated nutrient treatment indicates that partial substitution of mineral fertilizer with a nutrient-rich organic biomass can support high crop productivity.

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Table 1: Some Mechanical and Chemical Properties of the Soil of Experimental Sites

Parameter Description	2019	2020	MEAN
Physical properties			
Sand (%)	85.3	83.9	84.6
Clay (%)	68	89	78.5
Silt (%)	79	72	75.5
Textural Class	Sandy Loam		Sandy Loam
Chemical Properties			
Soil pH (1: 2.5; soil: water)	5.50	5.56	5.53

Total Nitrogen (%)		0.08		0.09		0.08
Available Phosphorus (mg Kg ⁻¹)	6.66			5.60		6.13
Organic Matter (%)		2.80		2.74		2.77
Organic Carbon (%)		1.62		1.58		1.60
Exchangeable Bases (Cmol/Kg)						
Ca			2.65		2.20	2.43
K			0.22		0.24	0.23
Na			0.18		0.17	0.175
Mg			1.05		1.08	1.06
Exch. Acidity (cmol/kg)	2.75	2.84	2.79			
ECEC (Cmole Kg ⁻¹)	6.75			6.21	6.48	

TABLE 2: NUTRIENT COMPOSITION OF THE ORGANIC MANURE SOURCE

Manure	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Org.C (%)	C:N
Moringa leaf	4.10	1.21	1.71	13.6	0.12	2.19	10.8	2.6

Table 3. Effects of Plant spacing and Fertilizer Type on plant height (cm)

Treatments	6 WAP		10 WAP	
Fert. Rates	2019	2020	2019	2020
Control	48.54	44.61	57.37	58.9
300kg NPK	63.65	65.67	84.51	89.32
10t/Ha Moringa	54.03	51.47	74.74	78.76
150kg NPK +5t moringa	63.12	64.13	85.37	88.34
LSD (0.05)	1.81	1.88	1.48	1.52
Plant Spacing				
20cm x 20cm	54.23	53.41	67.68	66.66
30cm x 30cm	54.45	54.50	65.04	65.09
20cm x 40cm	53.90	54.28	64.60	64.54
30cm x 30cm	52.73	52.31	64.15	64.17
LSD (0.05)	NS	NS	0.34	0.64
F Rate X P Space				
LSD (0.05)	NS	NS	NS	NS

Table 4. Effects of Plant spacing and Fertilizer Type on Tiller Number

Treatments			Tiller Number	
Fert Rates	2019		2020	
Control			4.62	4.45
300kg NPK	8.12		7.24	
10t/Ha Moringa		6.92		6.41
150kg NPK +5t moringa	8.84		7.88	
LSD (0.05)		0.48		0.52
Plant Space				
20cm x 20cm			5.41	4.96
20cm x 30cm			6.02	5.92
20cm x 40cm			6.91	6.20
30cm x 30cm			6.84	6.44
LSD (0.05)		0.34		0.64

Fert Rate X plant Space

LSD (0.05)

NS

NS

Table 5. Effects of Plant spacing and Fertilizer Type on Leaf Number and leaf area

Treatments		Leaf Number		Leaf Area (cm ²)	
Fert Rates	2019	2020	2019	2020	
Control		15.02	15.21	4284.21	4311.3
300kg NPK	20.32	20.84	7554.42	7654.10	
10t/Ha Moringa	19.81	19.94	6443.22	7224.30	
150kg NPK +5t moringa	20.64	21.02	8112.67	7988.40	
LSD (0.05)	0.81	0.88	556.4	337.50	
Plant Space					
20cm x 20cm		17.30	17.01	4664.41	4766.21
20cm x 30cm		17.41	17.51	5822.31	5488.42
20cm x 40cm		16.9	17.02	5874.21	5344.30
30cm x 30cm		17.20	17.60	5988.41	5899.40
LSD (0.05)	NS	NS	0.34	0.64	
Fert Rate X plant Space					
LSD (0.05)	NS	1.01	NS	NS	

Table 6. Effects of Plant spacing and Fertilizer Type on Tumeric Shoot Dry Matter

Treatments		g/plant		g/m ²	
Fert Rates	2019	2020	2019	2020	
Control		76.2	81.1	3.37	3.39
300kg NPK	129.4	130.2	4.51	4.32	
10t/Ha Moringa	121.8	124.5	4.74	4.76	
150kg NPK +5t moringa	134.2	135.3	5.37	5.34	
LSD (0.05)	6.81	5.8	0.48	0.52	
Plant Space					
20cm x 20cm		98.8	96.9	4.68	4.66
20cm x 30cm		109.6	108.8	5.04	5.09
20cm x 40cm		114.7	111.8	5.17	5.37
30cm x 30cm		117.4	115.1	4.60	4.54
LSD (0.05)	7.61	6.8	0.34	0.64	
Fert Rate X plant Space					
LSD (0.05)	NS	NS	NS	NS	

Table 7. Effects of Plant spacing and Fertilizer Type on Number of Rhizomes

Treatments		Mother		Finger	
Fert Rates	2019	2020	2019	2020	
Control		2.42	2.58	6.12	5.82
300kg NPK	4.62	4.58	9.82	9.89	
10t/Ha Moringa	4.41	4.24	8.94	8.10	
150kg NPK +5t moringa	4.82	4.86	9.92	10.10	
LSD (0.05)	0.81	0.88	0.48	0.52	
Plant Space					
20cm x 20cm		2.78	2.41	6.21	6.44
20cm x 30cm		3.42	3.88	7.81	8.10
20cm x 40cm		4.38	4.48	7.66	7.82
30cm x 30cm		4.42	4.54	7.88	8.20
LSD (0.05)	0.61	0.78	0.34	0.64	
Fert Rate X plant Space					
LSD (0.05)	NS	1.01	NS	NS	

Table 8. Effects of Plant spacing and Fertilizer Type on Fresh Rhizome Yield

Treatments		g/plant	t/ha		g/plant	t/ha
Fert Rates	2019	2019		2020	2020	
Control		922.1	3176.46		89.5	3097.27
300kg NPK	206.1	6214.8		198.4	6421.2	
10t/Ha Moringa	164.8	5966.5	161.4		6042.4	
150kg NPK + 5t moringa	220.3	6341.6		211.3		6521.3
LSD (0.05)	0.81	0.88		0.48	0.52	
Plant Space						
20cm x 20cm		99.5	3421.4		98.7	3241.5
20cm x 30cm		201.5	3493.5		198.8	3351.6
20cm x 40cm		161.4	3561.4		165.2	3541.2
30cm x 30cm		203.2	3572.2		200.3	3594.3
LSD (0.05)	0.61	0.78		0.34	0.64	
Fert Rate X Plant Space						
LSD (0.05)	NS	1.01		NS	NS	