OPTIMIZING PLANT POPULATION AND NPK FERTILIZER REGIMES FOR ENHANCED FIELD PERFORMANCE OF YAM MINITUBERS (*Dioscorea rotundata*) IN ABUJA, NIGERIA

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ABSTRACT

Yam (Dioscorea rotundata) remains a critical food and economic crop in Nigeria, yet its productivity is constrained by declining soil fertility, high production costs, and limited availability of quality seed yam. Recent advances in seed yam technologies have enabled large-scale production of clean minitubers; however, the field agronomy required to optimize their performance is not well established. This study evaluated the effects of plant population, NPK fertilizer type, and fertilizer rate on the growth and yield of field-grown yam minitubers under low-fertility savanna conditions in Abuja, Nigeria. A split–split plot experiment comprising three plant populations (266,000; 133,000; 88,000 plants ha^{-1}), three NPK fertilizer types (15:15:15, 20:10:10, 27:13:13), and four fertilizer rates (0, 200, 400, 600 kg ha^{-1}) was conducted over two seasons in 2023 and 2024. Results showed significant main and interaction effects across most vegetative and yield traits. The 133,000 plants ha^{-1} population produced the highest fresh tuber yield (~17.5 t ha^{-1}), while the lowest density (88,000 plants ha^{-1}) produced the largest individual tubers, demonstrating a clear density-driven yield–size trade-off. Among fertilizer types, NPK 15:15:15 outperformed 20:10:10 and 27:13:13 for yield and tuber weight, reflecting the importance of balanced nutrient supply on nutrient-depleted soils. Yield responses peaked at 400 kg ha^{-1}, declining at 600 kg ha^{-1} due to excessive vegetative growth. A strong three-way interaction (population × fertilizer type × rate) identified 133,000 plants ha^{-1} × NPK 15:15:15 × 400 kg ha^{-1} as the optimal combination for maximizing yield. These findings provide evidence-based agronomic recommendations to support sustainable intensification and improved seed yam production systems in the West African savanna.

Keywords: Yam minitubers; plant population; NPK fertilizer; tuber yield; growth physiology;

INTRODUCTION

Yam (*Dioscorea* spp.) remains one of the most socio-economically significant staple crops in West Africa, ranking second only to cereals in regional food systems and serving as a major source of dietary energy, cultural identity, and rural income. Nigeria alone produces more than 45 million metric tonnes annually, making it the global leader in yam production, with yam providing over 200 kilocalories per capita daily for more than 60 million Nigerians (Musa, Shuaib, & Ogidan, 2023). Beyond its nutritional role, yam contributes substantially to household livelihoods, market supply chains, and cultural practices, including festivals and traditional ceremonies where it symbolizes wealth and food security in farming communities (Owusu *et al*., 2022). However, despite these contributions, yam productivity in Nigeria remains far below its biological potential. Recent regional analyses show that Nigeria achieves only 17.3% of potential yields, a performance gap largely driven by declining soil fertility, suboptimal agronomic practices, and production constraints typical of smallholder farming systems (Neina, 2021; Musa, Shuaib, & Ogidan, 2023).

Yam production depends heavily on fertile soils, adequate staking materials, and labor-intensive operations, yet contemporary production systems in Nigeria operate under severe resource limitations. Long-term cultivation without adequate soil nutrient replenishment has contributed to widespread soil degradation and nutrient depletion, with nitrogen and phosphorus deficiencies frequently identified as primary causes of reduced yam vigor and poor tuber bulking capacity (Matsumoto, *et al*., 2021; Owusu *et al*., 2022). The ecological challenges associated with continued land expansion including deforestation, biodiversity loss, and declining soil productivity have further highlighted the urgency of adopting sustainable intensification strategies that optimize nutrient management and use of available land resources. Fertilizer use in yam systems remains low and inefficient; when applied, it often follows generalized recommendations that do not account for specific production conditions or planting materials. This mismatch between fertilizer recommendations and field realities contributes to yield stagnation and increased production costs for smallholder farmers across the yam belt in Nigeria (Neina, 2021; Twumasi, *et al*., 2024).

A major bottleneck in yam intensification is the shortage of high-quality seed yam, which accounts for 40–50% of production costs and is frequently cited as a limiting factor in sustainable yam production (Adams, & Nkoro, 2021). Traditional propagation methods require large ware tubers and exhibit low multiplication rates, encouraging the accumulation of pests and diseases across production cycles. To address these limitations, innovations such as aeroponics, hydroponics, temporary immersion bioreactors (TIB), and single-node vine technologies have been developed under initiatives like the Yam Improvement for Income and Food Security in West Africa (YIIFSWA). These technologies enable the production of clean and disease-free minitubers for rapid multiplication of seed yam, significantly improving the quantity and quality of planting materials available to farmers and seed enterprises. Despite these advances, the agronomic management of field-grown yam minitubers including their nutrient requirements, population density thresholds, and growth behavior remains insufficiently studied. Minitubers, owing to their small size and limited storage reserves, respond differently to field conditions compared to larger setts; thus, findings from conventional yam agronomy cannot simply be extrapolated to minituber-based systems (Neina, 2021; Aighewi, *et al*., 2021).

Moreover, few studies have examined the interactive effects of plant population density, fertilizer type, and fertilizer application rate on yam growth and yield, particularly under the nutrient-depleted soil conditions common in Nigerian savanna ecologies. Existing research has highlighted the role of integrated soil fertility management (ISFM) and balanced NPK fertilization as essential drivers for crop intensification in yam production, especially as climate change threatens yam productivity through erratic rainfall patterns and rising temperatures. However, empirically validated agronomic packages tailored to the needs of minituber propagation systems are largely lacking. Without such evidence, farmers may apply either insufficient nutrients resulting in poor establishment and low yields or excessive fertilizer levels that promote vegetative growth at the expense of tuber development. Similarly, plant population density, an important determinant of canopy structure, competition for resources, and final tuber size, remains poorly optimized for minituber production systems. Smallholder farmers often plant at densities based on traditional knowledge rather than scientifically validated spacing recommendations, leading to inefficiencies and yield variability across production landscapes (Owusu *et al*., 2022; Mondo *et al*., 2024).

Given these realities, the scientific literature points to several critical knowledge gaps. First, there is limited understanding of how varying plant population densities affect the growth physiology, canopy development, and tuber yield of yam grown from minitubers. Second, the influence of different NPK fertilizer formulations and application rates on nutrient uptake, biomass partitioning, and tuber bulking in minituber-based systems has not been thoroughly quantified. Third, there is little empirical evidence on the interactive effects of population density × fertilizer type × fertilizer rate, despite the fact that yam productivity is highly sensitive to multi-factor agronomic interactions under tropical field conditions. Collectively, these gaps limit the development of integrated agronomic recommendations capable of supporting sustainable intensification, enhancing nutrient-use efficiency, and improving seed yam output for producers and seed entrepreneurs.

Aim of the Study:

This study aimed to evaluate how plant population density, NPK fertilizer type, and fertilizer application rate influence the growth and yield performance of yam minitubers under field conditions in Abuja, Nigeria. It sought to identify the most productive and nutrient-efficient combination of plant density and fertilizer management appropriate for smallholder-managed, nutrient-depleted soils. Ultimately, the findings were intended to generate evidence-based agronomic recommendations that support sustainable intensification and strengthen seed yam production systems in West Africa.

Materials and Methods

Description of the Study Area

Field experiments were conducted during the 2023 and 2024 cropping seasons at the International Institute of Tropical Agriculture (IITA) research station in Kubwa, Bwari Area Council, Abuja, Nigeria (Latitude 9.164694°N, Longitude 7.345136°E, elevation 424 m above sea level). The site lies within the Southern Guinea Savanna and experiences a unimodal rainfall pattern with mean annual rainfall of 1200–1600 mm and daily temperatures commonly ranging between 24–32°C. Soils in the study area are classified as sandy-loam and are moderately acidic, with pre-plant laboratory assessments indicating low total nitrogen (0.047–0.054%), low available phosphorus (3.5–5.0 µg g^{-1}), and declining exchangeable cations (Ca, Mg, K) conditions typical of savanna yam-growing environments dominated by low fertility and degraded soils (IITA, 1989).

Experimental Materials

The yam variety evaluated was Kpamyo (TDr 95/19177), an improved white yam (Dioscorea rotundata) cultivar widely used for seed production and known for its good bulking characteristics. Planting materials consisted of minitubers weighing <10 g, sourced from IITA's clean seed multiplication unit. Three NPK fertilizer types were tested: 15:15:15, 20:10:10, and 27:13:13 representing common compound blends available to Nigerian yam farmers.

Experimental Design and Treatments

The study was laid out in a split–split plot arrangement within a Randomized Complete Block Design (RCBD) with three replications, giving a total of 108 experimental plots (36 treatment combinations × 3 replicates). The factor structure was as follows:

Main plot factor:

Plant population density

266,000 plants/ha
133,000 plants/ha
88,000 plants/ha (corresponding to intra-row spacing of 5 cm, 10 cm, and 15 cm on 0.75-m ridges)
Sub-plot factor:
NPK fertilizer type
15:15:15
20:10:10
27:13:13
Sub-sub-plot factor:
Fertilizer application rate
0, 200, 400, and 600 kg/ha
Gross plot size measured 3 m × 2 m, consisting of four ridges, while net plots were defined as the two central ridges to minimize border effects. Across all treatments, the total plant stands established amounted to 2,628 plants over both years combined.

Field Establishment and Agronomic Management
Land preparation and planting

Fields were ploughed, harrowed, and ridged mechanically. Minitubers were pre-treated by dipping in a fungicide–insecticide mixture (mancozeb 80% WP + cypermethrin 40 EC) to provide early protection against soil-borne diseases and insect pests. Planting dates were 13 June 2023 and 6 June 2024, closely aligned with the onset of effective rainfall. All plots were trellis-staked at 6 weeks after planting (WAP) to ensure adequate vine support, which is essential for yam canopy development in high-density systems.

Nutrient application

Fertilizers were applied by band placement at 6 and 10 WAP for all non-zero treatments. Rates were calculated based on the assigned treatment combination. The split application ensured minimal nutrient losses and improved synchronization with yam nutrient demand periods.

Weed and pest control

Weed management involved the application of Premextra® (atrazine + s-metolachlor) as pre-emergence herbicide, followed by a post-emergence application of Gramoxone® (paraquat) at 2 WAP. Additional manual weeding was done as necessary to maintain weed-free plots. No major insect outbreaks were observed, partly attributed to clean planting materials and the pre-plant cypermethrin dip.

Data Collection Procedures

Data were collected using standardized protocols at key phenological stages:
Crop establishment and vegetative growth
Plant height (cm) at 8 and 12 WAP
Number of leaves at 8 and 12 WAP
Leaf Area Index (LAI) using a CI-110 Plant Canopy Imager
Yield and yield components
At physiological maturity (December 2023 and 2024), plants were carefully harvested and evaluated for:
Fresh tuber yield per plot (kg)
Sett Multiplication Ratio (SMR)
Harvest Index (HI)
Fresh tuber yield was converted to per-hectare basis using the plot area and total plant stand count.

Statistical Analysis

Data were subjected to Analysis of Variance (ANOVA) appropriate for a split–split plot design using R software (Agricolae package). The linear model accounted for:
Main effects: plant population (P), fertilizer type (T), fertilizer rate (L)

Means were separated using Least Significant Difference (LSD) at $p \leq 0.05$, and Duncan's Multiple Range Test (DMRT) was used where interaction effects were significant. Standard errors were reported for all means to indicate precision. Although a combined analysis was presented, each year's data were first checked for homogeneity before pooling.

Results

Soil Properties of the Experimental Site

Baseline soil analysis showed that the experimental site was characterized by sandy-loam texture, slightly acidic pH, and low nutrient status notably low total nitrogen (0.047–0.054%), low available phosphorus (3.5–5.0 mg/Kg), and declining exchangeable Ca, Mg, and K values (Table 1). Similarly, effective cation exchange capacity (ECEC) decreased across the two seasons, confirming the site's low fertility and high likelihood of fertilizer responsiveness (Table 1).

Table 1: Physical and chemical properties of the soil of the two experimental sites before cropping in 2023 and 2024 at the research farm, IITA, Kubwa, FCT.

Properties	2023	2024
Percent Sand	74.0	76.0
Percent Silt	11.0	10.0
Percent Clay	15.0	14.0
Textural class	Sandy loam	Sandy loam
pH (H_2O)	6.40	6.30
pH (KCl)	5.50	5.40
Percent organic carbon	0.57	0.63
Total Nitrogen (%)	0.047	0.054
Available Phosphorous (mg/Kg soil)	4.97	3.49
Calcium (c/molkg^{-1})	2.50	1.38
Magnesium (c/molkg^{-1})	0.60	0.58
Potassium (cmolkg^{-1})	0.20	0.14
Sodium (cmolkg^{-1})	0.09	0.26
ECEC (cmolkg^{-1})	3.39	2.38

Crop Establishment

Plant population density significantly influenced stand establishment, with the highest establishment observed at 266,000 plants/ha, followed by 133,000 and 88,000 plants/ha. Fertilizer type and fertilizer level had no significant effect on establishment, indicating that minituber emergence was more sensitive to population-driven micro-environmental conditions than nutrient inputs at early stages.

Table 2: Percent crop establishment as influenced by different regimes of inorganic fertilizer application

Plant population	2023	2024	Combined
266,000 plants/ha	95.6	95.6	95.6
133,000 plants/ha	95.1	94.8	95.0
88,000 plants/ha	92.7	92.2	92.5
LSD	0.79	1.71	1.12
Significance	*	*	*
Fertilizer types			
NPK 15:15:15	94.9	94.3	94.6
NPK 20:10:10	93.7	93.1	93.4
NPK 27:13:13	94.9	95.1	95.1
LSD	2.52	2.33	2.15
Significance	NS	NS	NS
Fertilizer levels			
0 kg/ha	94.2	94.1	94.1
200 kg/ha	94.6	94.2	94.4
400 kg/ha	95.4	94.9	95.1
600 kg/ha	93.8	93.6	93.7
LSD	2.08	2.76	2.5
Significance	NS	NS	NS
Interactions			
Population X Fertilizer types	NS	NS	NS
Population X Fertilizer Levels	NS	NS	NS
Fertilizer types X Fertilizer Levels	NS	NS	NS
Population X Fertilizer types X Fertilizer Levels	NS	NS	NS

Means followed by the same letter(s) in a column of any set of treatments are not significantly d ifferent at p ≤ 0.05 using LSD. WAP = weeks after planting. * = Significant at p ≤ 0.05, NS = Not significant at p ≤ 0.05.

Plant height

Plant height increased significantly with rising population density, with the tallest vines recorded at 266,000 plants/ha. Fertilizer type and rate also influenced height: NPK 27:13:13 frequently produced the tallest plants at 12 WAP, while height generally increased with fertilizer rate, peaking at 600 kg/ha in both seasons. Significant population × rate and type × rate interactions were observed, reflecting combined effects of competition and nutrient availability on canopy elongation.

Table 3: Plant height (cm) as influenced by different regimes of inorganic fertilizer application

Plant population	2023	2024	Combined	2023	2024	Combine
	8 WAP	8 WAP	8 WAP	12 WAP	12 WAP	12 WAP
266,000 Plants/Ha	86.9	93.3	90.1	197.5	208.0	202.8
133,000 Plants/Ha	88.1	93.6	90.8	188.6	199.2	193.9
88,000 Plants/Ha	83.6	87.9	85.8	183.9	195.4	189.6
LSD	5.75	4.19	4.91	8.25	4.78	5.83
Significance	NS	*	*	*	*	*
Fertilizer types						
NPK 15:15:15	86.9	91.9	89.4	188.2	197.9	193.0
NPK 20:10:10	84.1	90.2	87.2	184.4	196.4	190.4
NPK 27:13:13	87.6	92.6	90.1	197.4	208.3	202.9
LSD	8.1	9.77	9.34	9.8	10.67	9.64
Significance	NS	NS	NS	*	*	*
Fertilizer levels						
0 kg/ha	74.2	79.8	77.0	133.9	143.0	138.5
200 kg/ha	90.5	96.1	93.3	165.8	177.3	171.5
400 kg/ha	91.5	98.0	94.7	212.4	224.7	218.6
600 kg/ha	88.6	92.5	90.5	247.8	258.5	253.2
LSD	9.25	8.6	8.16	9.34	10.66	9.96
Significance	*	*	*	*	*	*
Interactions						
Population X Fertilizer types	NS	NS	NS	*	*	*
Population X Fertilizer Levels	*	*	*	*	*	*
Fertilizer types X Fertilizer Levels	*	*	*	*	*	*
Population X Fertilizer types X Fertilizer Levels	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) in a column of any set of treatments are not significantly d ifferent at $p \leq 0.05$ using LSD. WAP = weeks after planting. * = Significant at $p \leq 0.05$, NS = Not significant at $p \leq 0.05$.

Leaf number and LAI values

Leaf number and leaf area index (LAI) values followed similar trends:

Higher fertilizer levels, especially 400–600 kg/ha, consistently increased LAI.

Population effects were evident, with denser stands producing more total foliage but smaller individual canopy sizes.

Table 4: Number of leaves of 8 and 12 WAP as influenced by different regimes of inorganic fertilizer application

Plant population	2023 8 WAP	2024 8 WAP	Combined 8 WAP	2023 12 WAP	2024 12 WAP	Combined 12 WAP
266,000 plants/ha	21.7a	24.0a	22.9a	81.3a	85.9a	83.6a
133,000 plants/ha	22.9a	23.1ab	23.0a	77.3a	83.6a	80.4a
88,000 plants/ha	21.2a	22.1b	21.6a	74.0a	83.1a	78.6a
LSD	3.99	1.38	2.1	7.99	20.76	11.6
Significance	NS	*	NS	NS	NS	NS
Fertilizer types						
NPK 15:15:15	21.8a	23.8a	22.8a	75.9a	84.7a	80.3a
NPK 20:10:10	21.3a	22.0a	21.7a	72.9a	81.4a	77.1a
NPK 27:13:13	22.6a	23.4a	23.0a	83.8a	86.6a	85.2a
LSD	3.11	2.22	2.39	11.01	8.79	9.83
Significance	NS	NS	NS	NS	NS	NS
Fertilizer levels						
0 kg/ha	19.2b	19.4b	19.3b	57.7b	63.9c	60.8d
200 kg/ha	23.5a	24.3a	23.9a	65.3b	77.6bc	71.4c
400 kg/ha	22.8a	25.4a	24.1a	89.3a	91.5ab	90.4b
600 kg/ha	22.2ab	23.2a	22.7a	97.8a	103.8a	100.8a
LSD	3.17	2.74	2.61	14.32	14.37	9.28
Significance	NS	*	*	*	*	*
Interactions						
Population X Fertilizer types	NS	NS	NS	NS	NS	NS
Population X Fertilizer Levels	NS	*	*	*	*	*
Fertilizer types X Fertilizer Levels	*	*	*	*	*	*
Population X Fertilizer types X Fertilizer Levels	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) in a column of any set of treatments are not significantly different at p ≤ 0.05 using LSD. WAP = weeks after planting. * = Significant at p ≤ 0.05, NS = Not significant at p ≤ 0.05.

LAI response showed significant interactions involving fertilizer type and rate, indicating strong nutrient × canopy effects on photosynthetic capacity.

Table 5: Leaf Area Index as influenced by different regimes of inorganic fertilizer application

Plant population	2023	2024	Combined
266,000 plants/ha	3.6	3.5	3.5
133,000 plants/ha	3.3	3.2	3.3
88,000 plants/ha	3.2	3.1	3.2
LSD	0.47	0.48	0.47
Significance	NS	NS	NS
Fertilizer types			
NPK 15:15:15	3.3	3.2	3.3
NPK 20:10:10	3.5	3.4	3.4
NPK 27:13:13	3.3	3.2	3.3
LSD	0.47	0.66	0.64
Significance	NS	NS	NS
Fertilizer levels			
0 kg/ha	2.1d	2.0d	2.1d
200 kg/ha	2.8c	2.7c	2.76c
400 kg/ha	3.8b	3.7b	3.8b
600 kg/ha	4.8a	4.7a	4.7a
LSD	0.62	0.48	0.48
Significance	*	*	*
Interactions			
Population X Fertilizer types	NS	NS	NS
Population X Fertilizer Levels	NS	NS	NS
Fertilizer types X Fertilizer Levels	NS	NS	NS
Population X Fertilizer types X Fertilizer Levels	NS	NS	NS

Means followed by the same letter(s) in a column of any set of treatments are not significantly different at $p \leq 0.05$ using LSD. WAP = weeks after planting. * = Significant at $p \leq 0.05$, NS = Not significant at $p \leq 0.05$.

Tuber Yield and Yield Components

Fresh tuber yield

Plant population, fertilizer type, and fertilizer rate all significantly affected tuber yield. The 133,000 plants/ha density produced the highest overall tuber yield (~17.5 t/ha combined), outperforming both higher and lower densities. Among NPK types, 15:15:15 consistently produced the highest yield (~17.3 t/ha combined), while 27:13:13 produced the lowest. Fertilizer rate showed a clear quadratic pattern:

Yield increased from 0 → 200 → 400 kg/ha,
Peaked at 400 kg/ha (~23.3 t/ha),
Declined at 600 kg/ha, likely due to excessive vegetative growth.

Multiple interactions were significant, including population × type, population × rate, type × rate, and the three-way interaction, with the optimal combination identified as: 133,000 plants/ha × NPK 15:15:15 × 400 kg/ha.

Table 6: Fresh tuber yield (t/ha) as influenced by different regimes of inorganic fertilizer application

Plant population	2023	2024	Combined
266,000 plants/ha	16.9a	17.0a	17.0a
133,000 plants/ha	17.4a	17.6a	17.5a
88,000 plants/ha	13.4b	13.7b	13.5b
LSD	2.09	1.81	1.87
Significance	*	*	*
Fertilizer types			
NPK 15:15:15	17.3a	17.4a	17.3a
NPK 20:10:10	15.7ab	15.8ab	15.7ab
NPK 27:13:13	14.8b	15.1b	14.9b
LSD	1.63	1.63	1.65
Significance	*	*	*
Fertilizer levels			
0 kg/ha	8.1d	8.0d	8.1d
200 kg/ha	13.9c	14.4c	14.2c
400 kg/ha	23.2a	23.3a	23.3a
600 kg/ha	18.4b	18.6b	18.5b
LSD	1.73	1.69	1.62
Significance	*	*	*
Interactions			
Population X Fertilizer types	*	*	*
Population X Fertilizer Levels	*	*	*
Fertilizer types X Fertilizer Levels	*	*	*
Population X Fertilizer types X Fertilizer Levels	*	*	*

Means followed by the same letter(s) in a column of any set of treatments are not significantly different at p ≤ 0.05 using LSD. WAP = weeks after planting. * = Significant at p ≤ 0.05, NS = Not significant at p ≤ 0.05.

Sett Multiplication Ratio (SMR)

SMR was strongly influenced by population and fertilizer rate but only marginally by fertilizer type. The highest SMR values occurred under lower population densities and fertilizer rates around 400 kg/ha, reflecting optimal resource distribution for seed tuber production. The three-way interaction was significant for SMR in both years, indicating a combined influence of canopy competition and nutrient partitioning on multiplication efficiency.

Table 7: **Sett multiplication ratio as influenced by different regimes of inorganic fertilizer application**

Plant population	2023	2024	Combined
266,000 plants/ha	38.2c	38.5c	38.4c
133,000 plants/ha	78.1b	78.7b	78.4b
88,000 plants/ha	89.7a	92.8a	91.2a
LSD	10.93	7.38	8.72
Significance	*	*	*
Fertilizer types			
NPK 15:15:15	74.3a	74.4a	74.4a
NPK 20:10:10	67.7a	69.1a	68.4a
NPK 27:13:13	64.0a	66.5a	65.2a
LSD	9.38	10.91	10.71
Significance	NS	NS	NS
Fertilizer levels			
0 kg/ha	35.3d	35.3d	35.3d
200 kg/ha	59.1c	62.2c	60.6c
400 kg/ha	103.3a	103.2a	103.2a
600 kg/ha	77.0b	79.3b	78.1b
LSD	10.89	9.39	9.02
Significance	*	*	*
Interactions			
Population X Fertilizer types	NS	NS	NS
Population X Fertilizer Levels	*	*	*
Fertilizer types X Fertilizer Levels	NS	NS	NS
Population X Fertilizer types X Fertilizer Levels	NS	NS	NS

Means followed by the same letter(s) in a column of any set of treatments are not significantly different at $p \leq 0.05$ using LSD. WAP = weeks after planting. * = Significant at $p \leq 0.05$, NS = Not significant at $p \leq 0.05$.

Harvest Index (HI)

Harvest Index was generally not significantly affected by population or fertilizer type, showing substantial stability across treatments. However, fertilizer rate exhibited modest effects, with 400 kg/ha producing the highest HI, reflecting better proportional allocation of biomass to tubers under balanced fertilization. Variations in HI across treatments were narrower compared to other yield parameters.

Table 8: **Harvest index as influenced by different regimes of inorganic fertilizer application**

Plant population	2023	2024	Combined
266,000 plants/ha	69.6a	72.8a	71.2a
133,000 plants/ha	69.5a	72.1a	70.8a
88,000 plants/ha	69.7a	73.2a	71.5a
LSD	0.95	1.32	1.07
Significance	NS	NS	NS
Fertilizer types			
NPK 15:15:15	69.6a	72.8a	71.2a
NPK 20:10:10	69.7a	72.3a	71a
NPK 27:13:13	69.4a	73.0a	71.2a
LSD	0.95	1.68	0.77
Significance	NS	NS	NS
Fertilizer levels			
0 kg/ha	69.5a	71.4b	70.5b
200 kg/ha	69.9a	72.7b	71.3ab
400 kg/ha	69.6a	75.0a	72.3a
600 kg/ha	69.4a	71.7b	70.5b
LSD	0.64	1.71	0.98
Significance	NS	*	*
Interactions			
Population X Fertilizer types	NS	NS	NS
Population X Fertilizer Levels	NS	NS	NS
Fertilizer types X Fertilizer Levels	NS	NS	NS
Population X Fertilizer types X Fertilizer Levels	NS	NS	NS

Means followed by the same letter(s) in a column of any set of treatments are not significantly different at $p \leq 0.05$ using LSD. WAP = weeks after planting. * = Significant at $p \leq 0.05$, NS = Not significant at $p \leq 0.05$.

Discussion

Population density shaped canopy architecture, source–sink balance, and yield formation.

Across seasons, 133,000 plants ha^{-1} delivered the highest fresh tuber yield, while 88,000 plants ha^{-1} produced the largest mean tuber weight, confirming a classic density trade-off between total yield and individual tuber size. The dense stand (266,000 plants ha^{-1}) increased vine height but did not translate into superior yield, indicating competition-induced shifts in assimilate partitioning that favored vegetative growth over tuber bulking. These results are internally consistent with the observed patterns in LAI and support the premise that an intermediate density optimizes photosynthate capture per unit area without excessively diluting assimilates among too many sinks. Under the study's low-fertility, sandy-loam conditions, this balance was most favorable at 133,000 plants ha^{-1}.

These density effects align with the findings of Owusu *et al.* (2022) that sustainable intensification principles for yam in the West African savannas, where improvements in productivity must increasingly come from better agronomic efficiency rather than land expansion. Optimizing canopy architecture through appropriate spacing is a central lever to raise land productivity while curbing the ecological costs of expanding yam fields.

NPK 15:15:15 consistently out-yielded 20:10:10 and 27:13:13, while 27:13:13 often produced the tallest vines. This divergence suggests that N-heavier blends (relative to P and K) promoted vegetative vigor without proportionate gains in tuber yield consistent with yam's requirement for balanced P and K to support tuber initiation, bulking, and efficient carbohydrate translocation. The increase in vegetative vigor with high N- fertilizer rates observed in this study is consistent with the findings of Hgaza *et al*. (2020), who reported increased vegetative vigor following application of higher N-fertilizer rates. The observed superiority of 15:15:15 thus reflects more balanced nutrient supply for source development (canopy) and sink growth (tubers) under the site's inherently low P and K status.

From a systems perspective, results reinforce the ISFM view that nutrient balance rather than nitrogen alone is decisive for yam productivity on depleted savanna soils, a context highlighted by regional assessments that call for fertilizer strategies tuned to local soil constraints.

Yield responses followed a convex pattern: increases from 0 → 200 → 400 kg ha^{-1}, a peak at 400 kg ha^{-1}, and a decline at 600 kg ha^{-1}. LAI rose with rate but began to plateau (or even signal luxury consumption) at higher doses, especially where vegetative growth outpaced tuber filling echoing the height response. The decline at 600 kg ha^{-1} indicates that over-application shifted the source–sink relationship toward foliage, reducing harvestable yield. Agronomically, 400 kg ha^{-1} appears to align canopy development with tuber bulking under the site's fertility constraints.

Significant Population × Type, Population × Rate, Type × Rate, and three-way (P × T × L) interactions show that the best agronomic outcome cannot be selected by optimizing one factor in isolation. The superior package 133,000 plants ha^{-1} × NPK 15:15:15 × 400 kg ha^{-1} delivered the highest fresh tuber yield, whereas lower density favored larger tubers and higher multiplication ratios (SMR) for seed purposes. This differentiation underscores that target product (seed vs ware tuber) should drive factor combinations.

Pre-plant analyses showed low total N, low Mehlich-P, and falling ECEC conditions that predict large marginal gains from added nutrients and from optimizing stand density to reduce below-ground competition. The yield peak at 400 kg ha^{-1} likely reflects the dose at which applied NPK best compensates for soil deficits without triggering an imbalance toward foliage. The fact that 15:15:15 outperformed 27:13:13 is consistent with the site's P and K limitations; additional N, in the absence of proportionate P and K, mostly fueled vine growth.

These findings resonate with the broader sustainable intensification literature: in yam-dominated landscapes facing soil degradation and climate variability, improvements in nutrient-use efficiency and density management are indispensable to raise yields without further land expansion.

Seed-focused goal (maximize tuber

number/SMR): favor lower density with balanced fertilization around 400 kg ha^{-1} to produce more/larger planting pieces.

Bulk yield goal (maximize t ha^{-1}): choose 133,000 plants ha^{-1} with NPK 15:15:15 at 400 kg ha^{-1}.

These agronomic packages complement upstream seed-system innovations (bioreactors, aeroponics, vine cuttings) that have expanded supplies of clean minitubers; field-level optimization ensures those planting materials translate into higher, more reliable output.

The density-mediated trade-off (total yield vs tuber size) and the dominance of balanced NPK over N-heavy regimes align with general principles for tuber crops on low-fertility tropical soils, as emphasized in regional reviews advocating ISFM for yam. The study extends this knowledge specifically to minituber-based systems, for which rigorous field agronomy has been sparse, and demonstrates that the optimum lies at an intermediate density and moderate, balanced fertilization.

Conclusions

This study demonstrated that yam minituber productivity in the Southern Guinea Savanna is strongly influenced by plant population, fertilizer type, and fertilizer rate. An intermediate population of 133,000 plants ha^{-1} consistently produced the highest fresh tuber yield, while lower density favored larger tubers and higher multiplication ratios (SMR), reflecting a clear density-driven yield–size trade-off. Among fertilizer types, NPK 15:15:15 delivered superior yield performance compared with 20:10:10 and 27:13:13, indicating the importance of balanced nutrient supply on low-fertility soils. Fertilizer rate responses followed a quadratic pattern, with yield peaking at 400 kg ha^{-1} and declining at 600 kg ha^{-1} due to excessive vegetative growth. Significant interactions among population, fertilizer type, and fertilizer rate confirm that optimal performance requires integrated recommendations rather than single-factor adjustments. Overall, the combination 133,000 plants ha^{-1} × NPK 15:15:15 × 400 kg ha^{-1} emerged as the most productive package for maximizing yield of field-grown minitubers in Abuja, Nigeria.

Recommendations

For practical field application, farmers targeting high fresh tuber yield should adopt 133,000 plants ha^{-1} and apply NPK 15:15:15 at 400 kg ha^{-1}, split at 6 and 10 WAP for efficient nutrient uptake. Where the goal is seed yam production (large, high-quality planting pieces), farmers may use lower densities (88,000 plants ha^{-1}) combined with moderate fertilization (≈400 kg ha^{-1}) to maximize tuber size and multiplication ratio. Extension systems should emphasize balanced fertilizers rather than N-heavy blends, especially in nutrient-depleted savanna soils. Future research should validate these findings across multiple locations and incorporate economic analysis to refine cost-effective fertilization strategies.

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