

Effects of Organic Liquid Fertilizers and Plant Spacing on Growth and Yield of Tiger Nut (*Cyperus esculentus*) Varieties in Southern Guinea Savannah of Nigeria

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Abstract

Tiger nut is a nutritionally dense crop with various recognised health benefits. Two field trials were conducted in 2023 and 2024 at the University of Abuja Teaching and Research Farm, Nigeria, to assess the influence of organic liquid fertilisers and plant spacing on the growth and yield of two tiger-nut varieties (Kano-Yellow and Borno-Brown). The experiment used a $2 \times 3 \times 3$ factorial in a randomised complete block design with three replications, giving 54 plots. Factors were two varieties, three spacings (15×15 cm, 15×30 cm, 30×30 cm) and two fertiliser treatments (Supergro, Agri-Life, and a no-fertiliser control). While variety had no significant effect on most parameters, both fertilisers markedly improved growth: plant height (12.8 cm Supergro, 12.5 cm Agri-Life at 4 WAP), leaf number (27.3 Agri-Life at 4 WAP), leaf area (11.9 cm^2 Supergro, 11.5 cm^2 Agri-Life at 6 WAP), net accumulation rate ($10.9 \text{ g m}^2/\text{day}$ Supergro at 8 WAP), and biomass (10.9 kg/plot Supergro in 2023). Supergro produced the highest fresh nut count (21.6 nuts/plant) and the greatest yield at 15×15 cm spacing (29.8 t/ha, 2023). Plants at 30×30 cm were significantly taller ($p < 0.05$) and produced more biomass, yet spacing did not significantly affect overall nut yield per hectare. The brown variety yielded higher fresh biomass (7.8 kg/plot), while the yellow variety combined with Supergro gave the best nut count. Significant interactions were observed for variety \times fertiliser, fertiliser \times spacing, and the three-way interaction ($p < 0.05$). For optimal results, farmers should pair a high-density 15×15 cm spacing with Supergro organic fertiliser.

Keywords: Growth, Liquid organic fertilisers, Plant spacing, Tiger nut, varieties and yield.

1.0 Introduction

Tiger nut (*Cyperus esculentus*) is a round tuber crop consumed raw, dried, or processed (Bazine and Arslanoğlu, 2020). Tiger nut is known by various names, including nutgrass, Chufa, and earth almond (Samuel, 2016). Tiger nut thrives in warm and mild climates globally, primarily in Africa, the Middle East, Southern Europe, and the Indian subcontinent (Bazine and Arslanoğlu, 2020; Robert *et al.*, 2017). Leading producers include the US, Iran, Iraq, Nigeria, and Spain. The crop is recognisable by its bright green-yellow leaves and unique stems (Bryson and DeFelice, 2009). Tiger nuts may yield up to 2,420 seeds per plant, have tubers that range in diameter from 0.3 to 1.9 cm, and can regrow several times. According to Ayo *et al.* (2016), Nina *et al.* (2019) and Ayaşan *et al.* (2021), there are three primary types: yellow, brown, and black. Each has unique physical, chemical, and functional characteristics. The genetic makeup, growth conditions, farming methods, and geographic location all affect the chemical content of tiger nuts (Ihenetu 2021). Tiger nut's adaptability is partly due to its tuber's membrane properties responding to heat stress (Rubert *et al.*, 2018).



Kano Yellow Tiger Nut Variety (A). Borno Brown Tiger Nut Variety (B). Kano Black Tiger Nut Variety (C).

Figure 1.1: Fresh Kano-Yellow Tiger Nuts (A), Fresh Borno-Brown Tiger Nuts (B) and Fresh Kano-Black Tiger Nuts (C) varieties.

Tiger nut tubers exhibit various shapes, including oval, ovoid, and oblong (Asare *et al.*, 2020). Moisture content has a major effect on their thermophysical, rheological, and functional properties (Gasparre and Rosell, 2019; Usman *et al.*, 2019). Freshness and moisture content influence the tuber's geometry, porosity, density, and mechanical strength (Emurigho *et al.*, 2020). Elevated moisture levels affect thermal conductivity, diffusivity, specific heat, bulk density, and surface area (Usman *et al.*, 2019). Vital nutrients such as proteins, carbs, vitamins, minerals, phytochemicals, oil, and fibre are abundant in tiger nuts (Mohdaly, 2019) (Ihenetu *et al.*, 2021). They offer numerous health and nutritional benefits (Bazine and Arslanoğlu, 2020).

Tiger nut (*Cyperus esculentus* L.), is a nutritionally dense crop that is underestimated but has gained attention recently because of the range of health benefits found in its tubers (Rebezov *et al.*, 2023; Tan *et al.*, 2023). The lipid and dietary fibre profiles resemble those of nuts, while starch content is comparable to other tubers (Roselló-Soto *et al.*, 2019). Tiger nut oil is notable for its high concentrations of phytosterols, tocopherols, and essential unsaturated fatty acids (Roselló-Soto *et al.*, 2018; Duman, 2019; Mohdaly, 2019). The tubers are also rich in minerals like phosphorus, potassium, calcium, magnesium, and iron, as well as vitamins C, E, and B (Maduka and Ire, 2018). Tiger nut tubers offer significant economic and nutritional benefits, presenting a valuable opportunity to address dietary challenges. Their unique nutritional composition distinguishes them from other tubers and nuts (Sanchez-Zapata *et al.*, 2012). Numerous factors, such as variety, soil fertility, environmental conditions, farming

practices, and storage methods, also influence the nutritional quality of tiger nuts (Nina *et al.*, 2019). For agricultural products like tiger nuts, soil fertility is a critical determinant of quality.

Despite their potential, tiger nut yields remain low, primarily due to limited scientific and technological attention, especially in the southern Guinea savannah zone of Nigeria. Optimal plant spacing and nutrient availability are crucial for maximising cultivation. Research at the Institute of Botany, Inner Mongolia, China, reported that tiger nut performs best at row spacings of 30–50 cm, while spacings wider than 50 cm may reduce productivity (Xu *et al.*, 2018). Agricultural production in West Africa is severely constrained, resulting in consistently low crop yields. According to Zaman (2023), these yields are threatened by multiple factors, including poor soil fertility, inadequate weed and pest management, ecological degradation, disease outbreaks, conflicts, and the effects of climate change, such as rising temperatures and increasingly frequent extreme rainfall events like floods and droughts. These challenges are particularly pronounced in tropical rainfed farming systems (Furtak & Wolińska, 2023; MacCarthy *et al.*, 2023).

The heavy reliance on synthetic fertilisers in Sub-Saharan Africa degrades soil health and increases pest susceptibility, creating a cycle of dependency that directly undermines sustainable tiger nut production in Nigeria, a concern supported by Chianu *et al.* (2011) regarding soil degradation. This is compounded by critically low awareness of organic alternatives, which could otherwise enhance soil structure and crop resilience for improved yields. Philip *et al.* (2009) described sustainable agriculture as a system that integrates local crop production with reliance on externally sourced staples when domestic production is constrained by unfavourable conditions. In such systems, synthetic fertilisers have played a major role in boosting productivity and ensuring food security, particularly for populations with the economic capacity to afford them. However, concerns over environmental degradation, high input costs and long-term soil health have driven increasing interest in alternatives to conventional inputs. Consequently, organic fertilisers have been widely explored and adopted as sustainable substitutes for synthetic fertilisers, offering improved soil quality, reduced ecological impacts and enhanced long-term productivity (Kumar *et al.*, 2022; Bambang *et al.*, 2023).

According to earlier research, tiger nut tuber yield in marginal soils may be increased by applying nitrogen fertiliser (Tan *et al.*, 2023). However, little research has been done on how nitrogen fertiliser affects the functional structure of tiger nut leaves, as well as how nitrogen use efficiency (NUE) and tuber swelling characteristics are connected to canopy apparent photosynthesis (CAP) rate. Organic manure, in particular, is gaining popularity as an environmentally friendly alternative to inorganic fertilisers, which can be unsustainable and unaffordable for resource-constrained farmers (Bello *et al.*, 2021). By increasing crop output and resistance to abiotic stressors, including heat, drought, and heavy metals, organic materials can improve food security (Alam *et al.*, 2020; Ullah *et al.*, 2021; Bziouech *et al.*, 2022). According to Ojeniyi *et al.* (2017), applying poultry manure and NPK fertiliser together can have a synergistic effect that improves the physical characteristics of the soil and stabilises yields. Studies have demonstrated that combining organic and inorganic fertilisers can yield superior results compared to their application (Falodun *et al.*, 2013; Ekwere *et al.*, 2023). By adopting sustainable agricultural practices, such as optimal plant spacing and balanced fertiliser application, farmers can enhance tiger nut yields and quality, ultimately contributing to improved food security and economic benefits.

This study aimed to compare the production efficiency of selected tiger nut varieties to applied organic fertilizers. The objectives were (1). to evaluate the impact of two organic liquid fertilizers (Supergro and Agri-Life) on the growth and yield of two tiger nut varieties, (2). to investigate the effects of varying intra-row spacing on the growth and yield of these two varieties, and (3). to assess the combined influence of organic fertilizers and plant spacing on their performance.

2.0 Materials and Methods

2.1 Study Area

Two field experiments were conducted in the 2023 and 2024 growing seasons at the Teaching and Research farm of the Faculty of Agriculture, University of Abuja, Gwagwalada, Abuja, Nigeria, Federal Capital Territory (FCT). The precise location of the experimental farm is found at N 8°59'24.46944" North and 7°11'8.46708" East. The farm experiences a rainy season from April to October, featuring average temperatures of approximately 30 °C, 14% relative humidity, and yearly rainfall ranging from 1,100 mm to 1,800 mm (Idoko & Bisong, 2010; Barnabas & Nwaka, 2014). As stated by Ishaya and Grace (2007), the soil consists of a deep, well-drained sandy loam with average fertility, a pH of 5.6–5.8, and a moderate potential for runoff. During the dry season, temperatures range from 28 °C to 30 °C and can exceed 40 °C, particularly in Gwagwalada, accompanied by winds of 10 km/h from the northeast. The soil consists of a deep, well-drained sandy loam derived from granite and migmatite, exhibiting moderate runoff potential and a texture that includes loamy sand, clay loam, and sandy clay. Its fertility is average, with a pH of 5.6–5.8 (Ishaya & Grace, 2007).

2.2 Land Preparation and Soil Sample Collection

The experimental field was first cleared, packed, and stumped using machetes, rakes, and dibbers. After clearing, the land was ploughed, harrowed, and pulverised to achieve a fine tilth suitable for tiger nut cultivation. Each plot contained 4 ridges. Pegs (60 cm long) were used to establish the plots. Soil samples were collected from 10 locations within each experimental site at a depth of 0-30 cm using a handheld soil auger. The samples were bulked into a composite, air-dried, sieved through a 2-mm mesh, and analysed using FAO standard procedures (FAO, 2019) as described by Walkley and Black (1934).

2.3 Experimental Material, Treatment and Design

Two varieties of tiger-nut, Kano Yellow and Borno Brown, sourced from Ahmadu Bello University, Zaria, were utilised as the experimental materials. The study investigated the impacts of two organic liquid fertilisers (Supergro and Agri-Life) along with a zero-fertiliser control, combined with three planting distances (15 cm × 15 cm, 15 cm × 30 cm, and 30 cm × 30 cm).

The study utilised a Randomised Complete Block Design (RCBD) with three replications. Each replicate consisted of 18 plots, resulting in a total of 54 plots for the experiment. A 0.5 m walkway divided each 2.5 m x 3 m plot from the others in the replication. To facilitate adequate monitoring and evaluation of the study, a one-meter access pathway was installed between each replication and its adjacent counterpart. Every plot had four ridges; consequently, the study encompassed a total of 216 ridges, with the experimental layout covering 650 m², equivalent to 50 m by 13 m.

2.4 Agronomic Practices

Before planting, the tiger nut tubers were treated as a seed dressing using Thiram at a rate of 2–4 kg per 100 kg of nuts to protect them against soil-borne pathogens such as *Fusarium*,

Rhizoctonia, and *Pythium*, as well as early damping-off. Cured poultry manure was incorporated into all plots immediately after land preparation. The nuts were then hydro-primed for 24 hours at ambient temperature to enhance uniform sprouting, after which the uniformly sized, healthy nuts were manually sown on well-prepared ridges at a depth of 5–8 cm. Planting was done at the onset of the rainy season using a spacing of 30 cm within rows and 50 cm between rows to achieve a plant population of approximately 66,666 plants per hectare. Three nuts were placed per hole and thinned to two vigorous plants shortly after emergence. A light mulch was applied over the ridges to conserve soil moisture and help suppress weed emergence.

Weed management was carried out manually, with the first weeding conducted within the first four weeks after planting due to the crop's slow early growth and weak competitive ability. Subsequent weeding was performed at 6 and 9 weeks after planting to maintain a clean field. Insect pests were controlled as necessary using Cypermethrin 10% EC applied at 0.75 L per hectare. Fertiliser application was based on soil test recommendations. The crop matured within 120–150 days, signaled by the yellowing and drying of foliage. Harvesting was done manually using hoes to lift the plants carefully and avoid damaging the nuts. The harvested nuts were washed, sorted, and sun-dried to improve quality and ensure proper storage.

2.5 Data Collection and Analysis

Percent sprouting, plant height, number of leaves per plant, leaf area index (LAI) per plant, relative growth rate (RGR) and net accumulation rate (NAR), number of fresh leaves per plot, stand survival at harvest, number of fresh nuts per stand, total number of nuts/plot, fresh biomass yield (kg)/plot, harvest index (HI) per plot, and nut yield (t/ha) were among the data collected. The Net assimilation rate (NAR) of tigernut plants was determined as outlined by Fasheun (2021) using leaf area measurements taken at the initial (t_1) and final (t_2) growth stages with a leaf area meter. The data collected were subjected to analysis of variance (ANOVA) using the 'agricolae' package in the R Statistical Programme (version 4.5.0). Where the treatment means were significantly different ($p \leq 0.05$), the Least Significant Difference (LSD) was used to separate them.

3.0 Result

3.1 Pre-planting and Post-harvest Soil Characteristics of the Experimental Site

Table 3.1 presents the physical and chemical properties of the soil at the experimental site, both before planting and after harvest. The soil at the experimental site was Sandy Loam (SL) with a pH of 4.4 in water and 4.6 in KCl, indicating acidity. After harvest, pH significantly improved to 6.2 in water and 5.9 in KCl. The Total N was 0.012 before planting and 0.093 after harvest, while the available Phosphorus levels were 4.50 mg/kg before planting and 7.05 mg/kg after harvest. Effective Cation Exchangeable Capacity showed increases in Na (0.13 to 0.34 $\text{Cmol}^{-1}/100\text{g}$), K (0.52 to 1.63 $\text{Cmol}^{-1}/100\text{g}$), Mg (1.20 to 1.80 $\text{Cmol}^{-1}/100\text{g}$), Ca (2.43 to 3.68 $\text{Cmol}^{-1}/100\text{g}$), and Total Exchangeable Bases (TEB) 5.80 to 7.45 $\text{Cmol}^{-1}/100\text{g}$, respectively, indicating that the basic cations were initially present in relatively low concentrations before the two-year study.

The soil analysis conducted before planting showed low levels of Organic Matter (0.99), Organic Carbon (0.32), electrical conductivity (EC) of 0.19mS/cm, and inadequate base saturation, suggesting low fertility, which is consistent with Anyaegbu's (2013) assertion that acidic soil (pH 4.5) limits the productivity of root and tuber crops. Nedunchezhiyan and Ray (2010) suggested a pH level between 5.5 and 6.5 for maximising yields of tiger nuts and

sweet potatoes, emphasising that extreme pH levels can lead to toxicity, pest issues, and disease occurrences. Increased nitrogen levels following harvest demonstrated that fertiliser application had improved soil fertility. The application of fertilisers improved soil fertility, as evidenced by increased nutrient levels after harvest. The site was found to have a history of being consistently planted with sorghum and maize.

Table 3.1: Results of Laboratory Soil Analysis for the Pre-planting and Post-harvest Soil Tests

Soil property	Unit	Before planting	After harvest
pH (H ₂ O)	–	4.4	6.2
pH (KCl)	–	4.6	5.9
Organic carbon (OC)	%	0.32	1.45
Organic matter (OM)	%	0.99	2.52
Total nitrogen (TN)	%	0.012	0.093
Electrical conductivity (EC)	mS cm ⁻¹	0.19	0.32
Available phosphorus (P)	mg kg ⁻¹	4.50	7.05
Exchangeable Na	cmol kg ⁻¹	0.13	0.34
Exchangeable K	cmol kg ⁻¹	0.52	1.63
Exchangeable Mg	cmol kg ⁻¹	1.20	1.80
Exchangeable Ca	cmol kg ⁻¹	2.34	2.68
Total exchangeable bases (TEB)	cmol kg ⁻¹	5.80	7.45
Exchangeable acidity	cmol kg ⁻¹	0.78	1.10
Effective cation exchange capacity (ECEC)	cmol kg ⁻¹	6.55	8.55
Silt	g kg ⁻¹	102.12	118.30
Clay	g kg ⁻¹	188.30	190.30
Sand	g kg ⁻¹	693.40	691.40
Textural class	–	Sandy loam	Sandy loam

OC = Organic carbon; OM = Organic matter; TN = Total nitrogen; EC = Electrical conductivity; mS cm⁻¹ = milliSiemens per centimetre; mg kg⁻¹ = milligrams per kilogram; TEB = Total exchangeable bases; ECEC = Effective cation exchange capacity.

3.2 Plant Height

The combined analysis of plant height during the 2023 and 2024 growing seasons indicated that planting density and organic nutrient sources had a notable impact on tiger nut development, whereas varietal differences did not show a consistent effect (Table 3.2). The primary impact of variety was not significant ($p > 0.05$) in either season alone or in the overall analysis, suggesting that 'Yellow' and 'Brown' varieties retained comparable height trends over the study duration. The application of organic fertiliser showed notable impacts on the growth of plant height. The impact was mainly noted at 8 WAP during separate seasons, but the overall analysis showed noteworthy differences at 6 and 8 WAP ($p \leq 0.05$). At 6 WAP, Agri-Life (21.2 cm) and Control (20.8 cm) yielded significantly taller plants compared to Supergro (19.5 cm). By 8 WAP, Supergro produced the tallest plants at 23.6 cm, greatly surpassing Agri-Life at 20.9 cm and Control at 19.9 cm.

Plant spacing exhibited a significantly strong impact ($p \leq 0.05$) in the combined assessment throughout both growth phases. The plant heights for both 15 × 15 cm and 30 × 30 cm spacings were consistently the highest, showing statistical similarity to each other while

being significantly taller than those cultivated at the 15×30 cm spacing. This pattern was especially noticeable at 6 WAP, where the 15×15 cm and 30×30 cm spacings produced average heights of 21.8 cm and 21.6 cm, respectively, in contrast to 18.4 cm for the 15×30 cm spacing. Notable interaction effects offered a greater understanding of the connections between factors. The interaction between Variety and Spacing ($V \times S$) was significant at 8 WAP in the overall analysis, validating the pattern noted in 2023, in which ideal spacing differed by variety.

The interaction between Fertiliser and Spacing ($N \times S$) was significant at both 6 and 8 WAP in the combined analysis, showing that the effectiveness of fertiliser relied on planting density. The interaction of Variety \times Fertiliser \times Spacing ($V \times N \times S$) was significant at both growth stages, indicating that optimal plant height was attained through particular combinations of all three variables. The aggregated data verified that the 30×30 cm spacing reliably promoted the tallest plants for various variety-fertiliser combinations, especially when using Supergro fertiliser.

3.3 Number of Leaves per Plant

The combined evaluation of leaf count during the 2023 and 2024 growing seasons indicated that the application of organic fertiliser was the main factor affecting this growth metric, whereas differences in variety and spacing by themselves had no considerable impact (Table 3.3). The primary impact of variety was not significant ($p > 0.05$) in both the separate year analysis and the overall assessment. This suggests that the 'Yellow' and 'Brown' tiger nut types generated a statistically comparable quantity of leaves during the growth cycle under the research conditions. Conversely, the use of organic fertilisers produced a notable and active effect. The joint analysis validated notable differences at both 6 and 8 Weeks After Planting (WAP). At 6 WAP, Agri-Life generated the highest quantity of leaves (51.3), substantially surpassing Supergro (46.1), while the control group was in between. At 8 WAP, the rankings changed; Agri-Life (56.0) and Supergro (54.8) showed a notably higher leaf count than the control (54.3), emphasising the ongoing advantages of fertiliser use for vegetative development.

Plant spacing, did not have a significant impact on the number of leaves per plant in any year or in the overall analysis ($p > 0.05$). This indicates that the plant's compensatory strategies for leaf development were consistent among the various planting densities examined. Notable two- and three-way interactions offered greater insight into the connections among the factors. The interaction between Variety and Fertiliser ($V \times N$) was notable at 6 and 8 WAP in the joint analysis. This verified the pattern noted in 2023, where the 'Yellow' type reacted most favorably to Supergro, while the 'Brown' type reached its peak leaf count using Agri-Life.

The interaction between Variety and Spacing ($V \times S$) was significant at 8 WAP in the overall analysis. This corresponds with the 2024 findings, indicating that the ideal spacing for leaf output varied by variety, with 'Yellow' excelling at 15×30 cm and 'Brown' at 15×15 cm. Additionally, the interaction between Fertiliser and Spacing ($N \times S$) was significant at 6 WAP in the combined analysis, suggesting that the effectiveness of each fertiliser was affected by the planting density. The intricate interaction of Variety \times Fertiliser \times Spacing ($V \times N \times S$) was also significant at both 6 and 8 WAP in the overall analysis. This highlights that the greatest leaf totals were reached via particular combinations. For example, the merged data confirmed that 'Yellow' with Agri-Life at a close spacing resulted in the highest leaf count at

6 WAP, whereas the 'Yellow' with Supergro at the broader 30 x 30 cm spacing generated the greatest leaf quantity by 8 WAP.

3.4 Leaf Area

The combined analysis of leaf area during the 2023 and 2024 growing seasons indicated that fertiliser use and planting density had a notable impact on leaf growth, whereas varietal variations were minimal (Table 3.4). The primary impact of variety was not significant ($p > 0.05$) in either season alone or in the overall analysis, suggesting that 'Yellow' and 'Brown' varieties yielded statistically comparable leaf areas during the growth phase.

Table 3.2: Effect of Variety, Spacing, and Liquid Organic Fertilisers on Plant Height (cm)

Treatment	2023		2024		Combined	
	6 WAP	8 WAP	6 WAP	8 WAP	6 WAP	8 WAP
Variety (V)						
Yellow	19.7	20.3	20.3	20.7	20.0	20.5
Brown	20.0	19.2	20.7	21.2	20.4	20.2
Significance	NS	NS	NS	NS	NS	NS
SE\pm	-	-	-	-	0.22	0.35
P-value	> 0.05	> 0.05	> 0.05	> 0.05	0.285	0.585
Organic Fertilisers (N)						
Supergro	18.3	23.5a	20.7	23.7a	19.5b	23.6a
Agri-Life	20.9	20.0b	21.5	21.8b	21.2a	20.9b
Control	20.9	18.4b	20.6	21.4b	20.8a	19.9c
Significance	NS	*	NS	*	*	*
LSD (0.05%) / SE\pm	-	2.95	-	1.99	LSD: 0.85	LSD: 1.10
P-value	> 0.05	0.008	> 0.05	0.012	0.015	< 0.001
Spacing (S)						
15 x 15 cm	21.8a	21.0a	21.8	22.0	21.8a	21.5a
15 x 30 cm	16.3b	17.2b	20.6	22.0	18.4b	19.6b
30 x 30 cm	21.4a	22.0a	21.8	23.2	21.6a	22.6a
Significance	*	*	NS	NS	*	*
LSD (0.05%) / SE\pm	2.41	2.94	-	-	LSD: 1.20	LSD: 1.45
P-value	0.010	0.015	> 0.05	> 0.05	< 0.001	< 0.001
Interaction						
V x N	NS	NS	NS	NS	NS	NS
V x S	NS	*	NS	NS	NS	*
N x S	NS	*	*	*	*	*
V x N x S	NS	*	*	*	*	*
CV %	13.08	6.67	9.48	7.99	10.85	8.05

Means with the letter(s) are not statistically different at a 5% level of probability. * = Significant at a 5% level of probability. NS = Not significant at a 5% level of probability. Weeks After Planting = WAP. V. = Variety. N = Organic fertiliser. S = Spacing

Table 3.3: Effect of Variety, Spacing, and Liquid Organic Fertilisers on the Number of Leaves per Plant

Treatment	2023		2024		Combined	
	6 WAP	8 WAP	6 WAP	8 WAP	6 WAP	8 WAP
Variety (V)						
Yellow	51.1	50.4	56.4	59.1	53.8	54.8
Brown	45.2	51.0	51.8	59.4	48.5	55.2
Significance	NS	NS	NS	NS	NS	NS
SE\pm	-	-	-	-	1.85	1.92
P-value	> 0.05	> 0.05	> 0.05	> 0.05	0.058	0.865
Organic Fertilisers (N)						
Supergro	44.3b	49.8	47.8b	59.8a	46.1b	54.8ab
Agri-Life	46.9b	54.2	55.6a	57.8a	51.3a	56.0a
Control	53.7a	57.2	44.6b	51.4b	49.2ab	54.3b
Significance	*	NS	*	*	*	*
LSD (0.05%) / SE\pm	6.81	-	5.71	5.83	LSD: 3.95	LSD: 1.95
P-value	0.015	> 0.05	0.003	0.008	0.010	0.025
Spacing (S)						
15 x 15 cm	47.6	50.6	48.4	54.1	48.0 a	52.4 a
15 x 30 cm	45.3	52.9	46.1	53.4	45.7 a	53.2 a
30 x 30 cm	47.0	54.7	45.4	54.6	46.2 a	54.7 a
Significance	NS	NS	NS	NS	NS	NS
SE\pm	-	-	-	-	1.25	1.40
P-value	> 0.05	> 0.05	> 0.05	> 0.05	0.365	0.485
Interaction						
V x N	*	*	NS	NS	*	*
V x S	NS	*	NS	*	NS	*
N x S	*	NS	NS	NS	*	NS
V x N x S	*	*	NS	NS	*	*
CV %	1.85	9.04	12.18	10.63	10.20	8.95

Means with the letter(s) are not statistically different at a 5% level of probability. * = Significant at a 5% level of probability. NS = Not significant at a 5% level of probability. Weeks After Planting = WAP. V. = Variety. N = Organic fertiliser. S = Spacing.

Application of organic fertiliser showed highly significant effects ($p \leq 0.05$) on leaf area growth in each season as well as in the overall analysis. Both Supergro and Agri-Life fertilisers consistently resulted in much larger leaf areas compared to the control treatment throughout all measurement periods. In the joint analysis, Supergro and Agri-Life demonstrated statistically comparable performance at both 6 WAP (12.2 cm² for each) and 8 WAP (13.1 cm² and 12.9 cm², respectively), while both significantly surpassed the control (10.1 cm² at 6 WAP and 11.3 cm² at 8 WAP). Plant spacing exhibited notable effects ($p \leq 0.05$) in the aggregated analysis at both 6 and 8 WAP. At 6 WAP, the spacing of 15 × 15 cm resulted in the highest leaf area (12.0 cm²), which was significantly larger than the 15 × 30 cm (11.3 cm²) and 30 × 30 cm (11.4 cm²) spacings. At 8 WAP, the spacings of 15 × 15 cm

(12.5 cm²) and 15 × 30 cm (12.6 cm²) resulted in markedly larger leaf areas compared to the 30 × 30 cm spacing (12.1 cm²).

The combined analysis showed significant two-way and three-way interactions among variety, fertiliser, and spacing, indicating that optimal leaf area depended on specific factor combinations. At both 6 and 8 WAP, the significant Variety × Fertiliser interaction highlighted distinct varietal preferences, with 'Yellow' performing best with Supergro and 'Brown' with Agri-Life. Fertiliser performance also varied with planting density, as reflected by the significant Fertiliser × Spacing interaction, while the significant Variety × Spacing interaction at 6 WAP demonstrated differing varietal responses to spacing. Overall, maximum leaf area was generally attained at 15 × 15 cm spacing, with the optimal variety–fertiliser combination within that spacing influenced by the growth stage.

3.5 Net Assimilation Rate (NAR)

The combined assessment of Net Assimilation Rate (NAR) across the 2023 and 2024 growing seasons indicated that both variety and fertiliser significantly influenced photosynthetic efficiency, while spacing showed no consistent main effect (Table 3.5). Variety had a significant effect in the pooled analysis at 6 WAP ($p \leq 0.05$), with the Brown variety (10.3 g m⁻² day⁻¹) exhibiting higher NAR than the Yellow variety (9.1 g m⁻² day⁻¹). By 8 WAP, however, this varietal difference diminished, as both varieties displayed statistically similar NAR values.

The use of organic fertiliser showed very significant impacts ($p \leq 0.05$) on NAR in each season separately and in the overall analysis. Supergro consistently yielded the highest NAR values during all measurement periods, reaching 10.8 g/m²/day at 6 WAP and 11.4 g/m²/day at 8 WAP in the overall analysis. Agri-Life demonstrated moderate performance, whereas the control group reliably produced the lowest NAR values (8.8 g/m²/day at 6 WAP and 9.9 g/m²/day at 8 WAP). Plant spacing did not demonstrate notable main effects ($p > 0.05$) in any single season or the combined analysis, suggesting that planting density by itself did not consistently affect the net assimilation rate throughout the growing seasons.

Significant interaction effects revealed important relationships among the studied factors. The Fertiliser × Spacing (N × S) interaction was significant at 8 WAP in the combined analysis, consistent with the 2023 results, where Supergro and Agri-Life produced the highest NAR at 15 × 15 cm spacing, while the control treatment performed best at 30 × 30 cm spacing. Similarly, the three-way interaction of Variety × Fertiliser × Spacing (V × N × S) was significant at 8 WAP in the combined analysis, indicating that maximum photosynthetic efficiency was achieved through specific combinations of these factors. Overall, the pooled results showed that optimal NAR was generally attained at 15 × 15 cm spacing, although the most effective variety–fertiliser combinations varied with season and growth stage.

3.6 Relative Growth Rate (RGR)

Across both cropping seasons, the combined analysis indicated that variety, fertiliser, and spacing significantly influenced Relative Growth Rate (RGR), with notable interaction effects (Table 3.6). While no significant varietal differences were observed at 6 WAP, the main effect of variety became significant by 8 WAP ($p \leq 0.05$), with the 'Brown' variety achieving a higher mean RGR (2.9 g/g/day) compared to 'Yellow' (2.5 g/g/day) in the later growth phase. The application of organic fertiliser showed highly significant effects ($p \leq 0.05$) on RGR in each season and in the overall analysis. Supergro and Agri-Life fertilisers both yielded statistically comparable RGR values that were notably greater than the control

treatment throughout all measurement intervals. In the joint assessment, Supergro and Agri-Life recorded RGR values of 2.8 g/g/day at 8 WAP, while the control had 2.3 g/g/day.

Plant spacing had noteworthy impacts ($p \leq 0.05$) at 8 WAP in the overall analysis, with the 15×15 cm spacing resulting in the highest RGR ($2.8 \text{ g g}^{-1} \text{ day}^{-1}$), followed by 15×30 cm (2.7 g/g/day), whereas the 30×30 cm spacing produced the lowest RGR (2.6 g/g/day). Notable interaction effects offered valuable insights into the connections among factors. The interaction between Variety and Fertiliser ($V \times N$) was significant at 8 WAP in the combined analysis, validating the 2024 trend, where 'Yellow' showed the best response to Supergro while 'Brown' reached peak RGR with Agri-Life. The interaction between Fertiliser and Spacing ($N \times S$) was significant at 6 WAP in the combined analysis, indicating that the efficacy of fertiliser relied on planting density. The two organic fertilisers were most effective at an intermediate spacing of 15×30 cm, whereas the control treatment exhibited varying optimal spacing needs. The joint analysis indicated that although the three-way interaction ($V \times N \times S$) lacked significance, the persistent two-way interactions throughout the seasons

Table 3.4: Effect of Variety, Spacing and Organic Fertilisers on the Leaf Area (cm^2)

Treatment	2023		2024		Combined	
	6 WAP	8 WAP	6 WAP	8 WAP	6 WAP	8 WAP
Variety (V)						
Yellow	10.9	12.4	11.3	12.5	11.1a	12.5a
Brown	11.4	12.1	11.8	12.8	11.6a	12.5a
Significance	NS	NS	NS	NS	NS	NS
SE\pm	-	-	-	-	0.18	0.15
P-value	> 0.05	> 0.05	> 0.05	> 0.05	0.072	0.895
Organic Fertilisers (N)						
Supergro	11.9a	12.7a	12.5a	13.4a	12.2a	13.1a
Agri-Life	11.5a	12.7a	12.8a	13.0a	12.2a	12.9a
Control	9.9b	11.4b	10.2b	11.1b	10.1b	11.3b
Significance	*	*	*	*	*	*
LSD (0.05%) / SE\pm	1.04	0.97	1.26	1.07	LSD: 0.65	LSD: 0.58
P-value	0.008	0.006	0.005	0.007	< 0.001	< 0.001
Spacing (S)						
15 x 15 cm	11.9a	12.7a	12.1	12.2	12.0a	12.5a
15 x 30 cm	10.8b	12.7a	11.8	12.4	11.3b	12.6a
30 x 30 cm	10.6b	11.4b	12.1	12.8	11.4b	12.1b
Significance	*	*	NS	NS	*	*
LSD (0.05%) / SE\pm	1.13	0.97	-	-	LSD: 0.72	LSD: 0.61
P-value	0.012	0.015	> 0.05	> 0.05	0.008	0.025
Interaction						
V x N	*	*	NS	NS	*	*
V x S	NS	NS	*	NS	*	NS
N x S	*	*	NS	NS	*	*
V x N x S	*	*	*	*	*	*
CV %	7.19	5.99	11.29	12.07	9.45	9.15

Means with the letter(s) are not statistically different at a 5% level of probability. * = Significant at a 5% level of probability. NS = Not significant at a 5% level of probability. Weeks After Planting = WAP. V. = Variety. N = Organic fertiliser. S = Spacing.

Table 3.5: Effect of Variety, Spacing and Organic Fertilisers on the Net Assimilation Rate (NAR) (g/m²/day)

Treatment	2023		2024		Combined	
	6 WAP	8 WAP	6 WAP	8 WAP	6 WAP	8 WAP
Variety (V)						
Yellow	9.0	10.0	9.1	10.4	9.1b	10.2a
Brown	10.1	10.5	10.4	10.8	10.3a	10.7a
Significance	*	NS	NS	NS	*	NS
LSD (0.05%) / SE±	0.99	-	-	-	LSD: 0.45	SE±: 0.25
P-value	0.035	> 0.05	> 0.05	> 0.05	0.028	0.185
Organic Fertilisers (N)						
Supergro	10.4a	10.9a	11.1a	11.8a	10.8a	11.4a
Agri-Life	9.9a	10.3b	11.1a	11.4a	10.5a	10.9b
Control	8.1b	9.9b	9.4b	9.8b	8.8b	9.9c
Significance	*	*	*	*	*	*
LSD (0.05%) / SE±	1.07	0.77	1.13	0.99	LSD: 0.52	LSD: 0.42
P-value	0.008	0.015	0.006	0.009	< 0.001	< 0.001
Spacing (S)						
15 x 15 cm	9.9	11.0	10.1	10.1	10.0a	10.6a
15 x 30 cm	9.4	10.0	9.8	10.8	9.6a	10.4a
30 x 30 cm	9.4	9.7	9.4	11.8	9.4a	10.8a
Significance	NS	NS	NS	NS	NS	NS
SE±	-	-	-	-	0.28	0.35
P-value	> 0.05	> 0.05	> 0.05	> 0.05	0.215	0.685
Interaction						
V x N	NS	NS	NS	NS	NS	NS
V x S	NS	NS	NS	NS	NS	NS
N x S	NS	*	NS	NS	NS	*
V x N x S	NS	*	NS	*	NS	*
CV %	15.63	7.58	9.05	10.36	12.45	8.95

Means with the letter(s) are not statistically different at a 5% level of probability. * = Significant at a 5% level of probability. NS = Not significant at a 5% level of probability. Weeks After Planting = WAP. V. = Variety. N = Organic fertiliser. S = Spacing.

highlight the need to account for variety-specific fertiliser reactions and spacing optimisation to attain the highest relative growth rate in tiger nut farming.

3.7 Fresh Nuts (kg/Plot)

The combined analysis of fresh nut yield across the 2023 and 2024 cropping seasons showed that organic fertiliser application was the primary factor influencing productivity, while variety and spacing alone had no significant effects (Table 3.7). Variety did not have a significant effect ($p > 0.05$) in either individual season or in the pooled analysis, indicating that the Yellow and Brown varieties produced statistically similar yields per plot. In contrast, organic fertiliser significantly increased yield ($p \leq 0.05$) in both seasons and overall, with Supergro and Agri-Life markedly outperforming the control. In the combined analysis,

Supergro recorded the highest yield of 23.0 kg/plot, followed by Agri-Life at 21.7 kg/plot, both significantly exceeding the control (15.3 kg/plot). Plant spacing did not have a significant main effect ($p > 0.05$) on fresh nut yield in any season or in the combined analysis, suggesting that planting density alone did not consistently influence final nut production per plot.

Significant interaction effects provided additional insight into the relationships among the factors. The Variety \times Fertiliser ($V \times N$) interaction was significant in each year and in the combined analysis ($p \leq 0.05$), confirming a consistent trend in which the Yellow variety responded best to Supergro, while the Brown variety achieved maximum yield with Agri-Life.

Table 3.6: Effect of Variety, Spacing and Liquid Organic Fertilisers on the Relative Growth Rate (RGR) (g/g/day)

Treatment	2023		2024		Combined	
	6 WAP	8 WAP	6 WAP	8 WAP	6 WAP	8 WAP
Variety (V)						
Yellow	1.3	2.5b	1.3	2.5b	1.3a	2.5b
Brown	1.3	2.8a	1.4	2.9a	1.4a	2.9a
Significance	NS	*	NS	*	NS	*
SE\pm / LSD (0.05%)	-	0.27	-	0.26	SE \pm : 0.05	LSD: 0.18
P-value	> 0.05	0.018	> 0.05	0.015	0.085	0.008
Organic Fertilisers (N)						
Supergro	1.4a	2.7a	1.4a	2.9a	1.4a	2.8a
Agri-Life	1.2a	2.9a	1.4a	2.7a	1.3a	2.8a
Control	1.1b	2.2b	1.2b	2.3b	1.2b	2.3b
Significance	*	*	*	*	*	*
LSD (0.05%)	0.18	0.27	0.19	0.26	LSD: 0.12	LSD: 0.19
P-value	0.012	0.009	0.010	0.011	0.006	< 0.001
Spacing (S)						
15 x 15 cm	1.4	2.9a	1.4	2.6	1.4a	2.8a
15 x 30 cm	1.4	2.6ab	1.4	2.7	1.4a	2.7ab
30 x 30 cm	1.3	2.4b	1.3	2.8	1.3a	2.6b
Significance	NS	*	NS	NS	NS	*
SE\pm / LSD (0.05%)	-	0.31	-	-	SE \pm : 0.06	LSD: 0.22
P-value	> 0.05	0.022	> 0.05	> 0.05	0.215	0.025
Interaction						
V x N	NS	NS	NS	*	NS	*
V x S	NS	NS	NS	NS	NS	NS
N x S	*	NS	*	NS	*	NS
V x N x S	NS	NS	NS	NS	NS	NS
CV %	14.69	13.28	13.90	15.79	14.25	14.45

Means with the letter(s) are not statistically different at a 5% level of probability. * = Significant at a 5% level of probability. NS = Not significant at a 5% level of probability. Weeks After Planting = WAP. V. = Variety. N = Organic fertiliser. S = Spacing.

Furthermore, the three-way interaction of Variety \times Fertiliser \times Spacing ($V \times N \times S$) was significant in the combined analysis ($p \leq 0.05$), indicating that optimum nut yield depended on specific combinations of these factors. The pooled results supported the 2023 findings, showing that the highest yields were generally obtained at 15×15 cm spacing, where the appropriate variety–fertiliser combination played a key role in enhancing productivity.

3.8 Fresh Biomass Yield (kg/plot)

The combined analysis of fresh biomass production for the 2023 and 2024 growing seasons revealed that variety and organic fertiliser had significant effects, whereas planting density and all interaction effects were not significant (Table 3.8). Variety had a highly significant impact ($p \leq 0.05$) in both individual seasons, with the Brown type consistently outperforming the Yellow type, producing 8.6 kg/plot compared to 6.9 kg/plot, representing a 24.6% advantage in fresh biomass yield.

Organic fertiliser application also significantly influenced biomass yield ($p \leq 0.05$) across both seasons. Supergro and Agri-Life markedly increased biomass production relative to the control, with Supergro yielding the highest (11.5 kg/plot) followed by Agri-Life (11.0 kg/plot), both significantly exceeding the control (7.1 kg/plot), reflecting a 62–69% increase in yield. Plant spacing had no significant main effect ($p > 0.05$) on fresh biomass yield in either season, as all three spacing configurations (15×15 cm, 15×30 cm, and 30×30 cm) produced statistically similar biomass, ranging from 9.2 to 9.7 kg/plot. Importantly, no significant interaction effects were observed among variety, fertiliser, or spacing in either season or in the combined analysis ($p > 0.05$). This indicates that the superior performance of the Brown variety and the positive effects of organic fertilisers were consistent across all treatment combinations, regardless of planting density or other factors.

3.9 Nut Yield (t/ha)

The combined evaluation of nut yield for the 2023 and 2024 growing seasons showed that organic fertiliser was the primary factor influencing productivity, with some significant interaction effects among management factors (Table 3.9). Variety alone had no significant effect ($p > 0.05$) in either season or in the combined analysis, as the Yellow and Brown varieties produced statistically similar yields, averaging 27.4 t/ha and 27.8 t/ha, respectively. Organic fertiliser, however, significantly increased nut yield ($p \leq 0.05$), with both Supergro and Agri-Life outperforming the control. Supergro recorded the highest yield (30.3 t/ha), followed by Agri-Life (29.5 t/ha), compared to 25.5 t/ha for the control, representing yield increases of 18.8% and 15.7%, respectively. Plant spacing had no significant main effect ($p > 0.05$) on nut yield in any season, with all three spacing configurations producing similar

results ranging from 27.2 to 28.1 t/ha. The observed interaction effects provided useful insights for optimising management practices.

The interaction between Fertiliser and Spacing ($N \times S$) was significant ($p \leq 0.05$) in the overall analysis, confirming the 2023 trend where Supergro excelled at the 15×15 cm spacing, whereas the control treatment was more effective at the larger 30×30 cm spacing. The interaction of Variety \times Fertiliser \times Spacing ($V \times N \times S$) was likewise significant ($p \leq 0.05$) in the overall analysis, indicating that optimal nut yield occurred with particular combinations of all three elements. The combined data corroborated the 2023 findings, showing that optimal yields were obtained with the 'Yellow' variety combined with Supergro fertiliser at the 15×15 cm spacing configuration.

Table 3.7: Effect of Variety, Spacing and Organic Fertilisers on the Fresh Nuts (kg/Plot)

Treatment	2023	2024	Combined
Variety (V)			
Yellow	18.3	20.7	19.5a
Brown	18.8	21.6	20.2a
Significance	NS	NS	NS
SE±	-	-	0.45
P-value	> 0.05	> 0.05	0.285
Organic Fertilisers (N)			
Supergro	21.6a	24.4a	23.0a
Agri-Life	20.2a	23.1a	21.7a
Control	13.8b	16.8b	15.3b
Significance	*	*	*
LSD (0.05%)	2.19	3.26	1.95
P-value	< 0.001	< 0.001	< 0.001
Spacing (S)			
15 x 15 cm	19.0	20.6	19.8a
15 x 30 cm	18.7	20.4	19.6a
30 x 30 cm	17.9	20.9	19.4a
Significance	NS	NS	NS
SE±	-	-	0.35
P-value	> 0.05	> 0.05	0.685
Interaction			
V x N	*	*	*
V x S	NS	NS	NS
N x S	NS	NS	NS
V x N x S	*	NS	*
CV %	5.16	6.23	5.75

Means with the letter(s) are not statistically different at a 5% level of probability. * = Significant at a 5% level of probability. NS = Not significant at a 5% level of probability. V. = Variety. N = Organic fertiliser. S = Spacing.

Table 3.8: Effect of Variety, Spacing and Organic Fertilisers on the Fresh Biomass Yield (kg/plot)

Treatment	2023	2024	Combined
Variety (V)			
Yellow	6.3b	7.5b	6.9b
Brown	7.8a	9.3a	8.6a
Significance	*	*	*
LSD (0.05%)	0.54	0.79	0.45
P-value	0.008	0.005	0.003
Organic Fertilisers (N)			
Supergro	10.9a	12.1a	11.5a
Agri-Life	10.1a	11.8a	11.0a
Control	6.6b	7.5b	7.1b
Significance	*	*	*
LSD (0.05%)	1.73	2.15	1.35
P-value	0.006	0.004	< 0.001
Spacing (S)			
15 x 15 cm	9.0	9.4	9.2 a
15 x 30 cm	9.3	9.4	9.4a
30 x 30 cm	9.6	9.8	9.7a
Significance	NS	NS	NS
SE±	-	-	0.25
P-value	> 0.05	> 0.05	0.425
Interaction			
V x N	NS	NS	NS
V x S	NS	NS	NS
N x S	NS	NS	NS
V x N x S	NS	NS	NS
CV %	11.35	9.87	10.55

Means with the letter(s) are not statistically different at a 5% level of probability. * = Significant at a 5% level of probability. NS = Not significant at a 5% level of probability. V. = Variety. N = Organic fertiliser. S = Spacing.

Table 3.9: Effect of Variety, Spacing Distance, and Organic Fertilisers on the Nut Yield (t/ha)

Treatment	2023	2024	Combined
Variety (V)			
Yellow	26.3	28.4	27.4a
Brown	26.8	28.7	27.8a
Significance	NS	NS	NS
SE±	-	-	0.35
P-value	> 0.05	> 0.05	0.425
Organic Fertilisers (N)			
Supergro	29.8	30.8a	30.3a
Agri-Life	28.5	30.4a	29.5a
Control	25.2	25.8b	25.5b
Significance	NS	*	*
LSD (0.05%) / SE±	-	1.87	LSD: 1.25
P-value	> 0.05	0.012	0.008
Spacing (S)			
15 x 15 cm	27.9	28.3	28.1a
15 x 30 cm	27.0	28.4	27.7a
30 x 30 cm	25.5	28.9	27.2a
Significance	NS	NS	NS
SE±	-	-	0.55
P-value	> 0.05	> 0.05	0.485
Interaction			
V x N	NS	NS	NS
V x S	NS	NS	NS
N x S	*	NS	*
V x N x S	*	NS	*
CV %	12.25	9.49	10.78

Means with the letter(s) are not statistically different at a 5% level of probability. * = Significant at a 5% level of probability. NS = Not significant at a 5% level of probability. V. = Variety. N = Organic fertiliser. S = Spacing.

4.0 Discussion

4.1 Soil Fertility Changes and Implications for Tiger Nut Productivity

Pre-planting soil analysis indicated a highly acidic sandy loam, with a pH of 4.4, very low organic matter (0.99%), minimal total nitrogen (0.012%), limited available phosphorus (4.50 mg/kg), and a moderate cation exchange capacity (CEC) of 6.55 Cmol kg⁻¹, all substantially below optimal levels for tiger nut cultivation. Post-harvest evaluations after the two-year trial revealed notable improvements: soil pH increased to 6.2, organic carbon rose to 1.45%, total nitrogen reached 0.093%, available phosphorus increased to 7.05 mg/kg, and exchangeable cations (Na 0.34, K 1.63, Mg 1.80, Ca 2.68 Cmol kg⁻¹) improved, with CEC rising to 8.55 Cmol kg⁻¹. These results demonstrate that the combined application of organic liquid fertilisers (Supergro and Agri-Life) with basal poultry manure effectively reduced soil acidity and restored fertility. The findings indicate that integrated management of organic

fertilisers, plant spacing, and variety selection significantly influences the growth, physiological efficiency, and yield of tiger nut in the Federal Capital Territory, Abuja, with the joint assessment of the 2023 and 2024 seasons providing strong evidence to support improved agricultural practices.

4.2 Growth and Physiological Responses to Management Practices

Plant height exhibited varying responses to spacing arrangements, with the combined analysis indicating that both 15×15 cm and 30×30 cm spacings resulted in significantly taller plants compared to the 15×30 cm configuration. This pattern indicates intricate plant reactions to density: the 15×15 cm spacing might have triggered crowding effects that encouraged upward growth, whereas the 30×30 cm spacing permitted ideal resource access without competitive stress. This observation is consistent with results from Baloch *et al.* (2012) and Abu & Odo (2017) in eggplants, where decreased spacing encouraged increased height, probably due to changes in light penetration and internal auxin levels. The organic fertilisers, especially Agri-Life, consistently improved vegetative growth metrics. Agri-Life yielded the tallest plants throughout both seasons, while the organic treatments notably enhanced leaf production and growth. The joint analysis showed that Supergro and Agri-Life enhanced leaf area by about 15-18% relative to the control, leading to a more effective photosynthetic system. This improved leaf development resulted in better physiological performance, with Supergro reaching the highest Net Assimilation Rate (10.9 g/m²/day) and Agri-Life showing a superior Relative Growth Rate (2.9 g/g/g/day) in the combined results.

4.3 Yield Components and Final Productivity

The organic fertilisers showed significant effectiveness in enhancing yield aspects. The joint analysis revealed that both Supergro and Agri-Life notably enhanced the number of fresh nuts per plot (21.6 and 20.2, respectively), fresh biomass production (10.9 kg and 10.1 kg per plot), and total nut yield (29.8 t/ha and 28.5 t/ha) in comparison to the unfertilized control. These enhancements indicate yield increases of 18.8% with Supergro and 15.7% with Agri-Life compared to the control treatment. The advantages of organic fertilisers can be linked to their diverse benefits. According to Neweke and Nsoanya (2013), organic amendments enhance the physical properties of soil and sustain organic matter levels, while poultry manure-derived products, similar to those utilised in this research, offer slow nutrient release and promote advantageous soil microbiota. This is consistent with research by Rajapaksa *et al.* (2024) regarding tomato plants and Alamene *et al.* (2022) with fluted pumpkins, showing that organic solutions regularly improved crop performance.

4.4 Varietal Performance and Interaction Effects

The brown variety consistently surpassed the yellow variety in biomass production (7.8 kg/plot compared to 6.3 kg/plot in combined analysis), although differences in final nut yield between the varieties were not significant. This discovery highlights the intricate connection between vegetative development and reproductive yield in tiger nut, indicating that although the brown variety allocates more resources to vegetative parts, both varieties can produce comparable nut yields with proper management. Notable interaction effects highlighted the significance of customised management strategies. The steady $V \times N$ interaction observed throughout both seasons and the combined analysis revealed variety-specific responses to fertiliser, with 'Yellow' excelling with Supergro and 'Brown' with Agri-Life. Additionally, the notable interactions of $N \times S$ and $V \times N \times S$ seen in the overall analysis indicated that the best yields necessitated particular combinations of all three elements. The greatest yields

were consistently obtained at the 15 × 15 cm spacing, although specific fertiliser needs varied by variety.

4.5 Physiological Mechanisms and Crop Efficiency

The improved performance under organic fertilisation can be understood through physiological mechanisms. According to Yao *et al.* (2016) and Liu *et al.* (2023), canopy apparent photosynthesis (CAP) provides a comprehensive measure of crop growth efficiency, integrating genetic, environmental, and management factors. The organic treatments in this study likely enhanced specific leaf area, leaf nitrogen content, and leaf area index; key determinants of photosynthetic efficiency identified by Feng & Dietze (2013) and Fang *et al.* (2023). The relationship between photosynthetic capacity and yield formation follows the principles outlined by Tan *et al.* (2017) and Simkin *et al.* (2020), where dry matter accumulation and photosynthetic capacity serve as primary determinants of yield. The current study demonstrates that organic fertilisers enhance this relationship by improving both the source (photosynthetic apparatus) and sink (nut development) capacities simultaneously.

4.6 Implications for Sustainable Tiger Nut Production

The findings have significant implications for sustainable tiger nut production in Nigeria and similar ecologies. The consistent performance of organic fertilisers addresses both productivity and environmental sustainability concerns, as highlighted by Vilarrasa-Nogué *et al.* (2019) regarding reduced soil pollution from inorganic fertilisers. Furthermore, the economic importance of tiger nut, as emphasised by Maduka & Ire (2018) and Arafat *et al.* (2009), underscores the value of these optimised production practices. The ability to enhance yield through improved management rather than genetic modification alone provides accessible strategies for smallholder farmers to increase productivity and contribute to food security. The minimal varietal effects on most growth parameters, consistent with Ogundare *et al.* (2015), suggest that sound agronomic practices can transcend genetic limitations, allowing farmers to achieve high yields with available varieties while maintaining the beneficial proximate composition that makes tiger nut valuable for addressing hunger and malnutrition.

5.0 Conclusion and Recommendations

This two-year study conclusively demonstrates that an integrated management strategy is paramount for maximising tiger nut productivity in Abuja's challenging soils. The application of organic fertilisers, particularly Supergro, was the cornerstone of this success, boosting the final nut yield to 30.3 t/ha, an 18.8% increase over unfertilized plots. This approach also dramatically improved soil health, correcting severe acidity by raising the pH from 4.4 to 6.2 and significantly enhancing key nutrients like nitrogen and phosphorus.

For optimal results, farmers should pair a high-density 15 × 15 cm spacing with Supergro organic fertiliser. While the choice of tiger nut variety alone had a limited impact, a goal-oriented selection is advised: the Yellow variety is superior for nut yield, whereas the Brown variety produces 24.6% more fresh biomass. Agri-Life organic fertiliser is a highly effective alternative. Together, these practices offer a complete system that enhances crop performance, builds long-term soil fertility, and ensures sustainable, profitable production.

Based on the comprehensive research findings, the following integrated management practices are recommended for optimal tiger nut production in Abuja and similar regions: To maximise nut yield and profitability, farmers should adopt a high-density planting system at 15 × 15 cm spacing combined with Supergro organic fertiliser application. For specific production goals: cultivate the Yellow variety paired with Supergro fertiliser for maximum

nut yield (achieving up to 30.3 t/ha), while the Brown variety is recommended for superior biomass production (yielding 24.6% more fresh biomass). Agri-Life organic fertiliser serves as an effective alternative to Supergro. These organic practices simultaneously improve soil health, having demonstrated the capacity to correct soil acidity from pH 4.4 to 6.2 while enhancing soil organic matter and nutrient status. Continued organic matter management is essential to maintain soil pH within the optimal 5.5-6.5 range for sustainable long-term productivity.

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