



Original Research

Evaluation of Integrated Fertilizer Application and Genotypes on Growth and Yield Components of *Daucus carota* in Derived Savannah Zone

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Abstract

A two-year field experiment was conducted in 2018 and 2019 at the Teaching and Research Farm, Faculty of Agriculture, University of Nigeria, Nsukka, Southeastern Nigeria, to evaluate the effects of organic and inorganic fertilizer combinations and carrot genotypes on seedling emergence, growth, and yield of carrot (*Daucus carota* L.). The experiment was a 5 × 3 factorial arranged in a randomized complete block design with four replications. Five fertilizer treatments comprised control, 20 t/ha poultry manure, 20 t/ha pig manure, 10 t/ha poultry manure + 200 kg/ha NPK 15:15:15, and 10 t/ha pig manure + 200 kg/ha NPK 15:15:15. Three genotypes, Safety Touchon France, Carotte Touchon AM, and Carotte Touchon ETS, were evaluated. In 2018, fertilizer treatments significantly affected seedling emergence, harvest index, whole-plant biomass yield, and root yield. The application of 10 t/ha poultry manure + 200 kg/ha NPK produced the highest whole-plant biomass yield (6.0 t/ha), root yield (3.5 t/ha), harvest index (65.4%), and marketable yield (97.0%). In 2019, 20 t/ha poultry manure produced the highest whole-plant biomass yield (8.5 t/ha), root yield (5.7 t/ha), and harvest index (67.5%). Genotypic effects were generally limited, although significant differences occurred for selected traits. Carotte Touchon AM recorded comparatively higher biomass and root yields, while Safety Touchon France produced more harvested roots. Overall, 10 t/ha poultry manure + 200 kg/ha NPK 15:15:15 provided a consistent yield advantage and is recommended for carrot production under the study conditions.

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Statement of Sustainability: This study demonstrates how integrating organic and inorganic fertilizers can improve nutrient-use efficiency while reducing dependence on sole mineral fertilizers in carrot production under derived savannah conditions. By providing locally validated nutrient management recommendations applicable across carrot genotypes, the research supports environmentally sustainable vegetable production, promotes soil resource conservation, and contributes to climate-smart agriculture. These outcomes directly advance SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), and SDG 15 (Life on Land).

1. Introduction

Carrot (*Daucus carota* L.) is one of the most important horticultural root crops cultivated worldwide and belongs to the family Apiaceae. The crop is believed to have originated from Central and Western Asia, regions that continue to serve as important centres of genetic diversity. Through centuries of domestication and breeding, carrots have evolved into numerous cultivars differing in root shape, size, colour, and adaptation to various agro-ecological conditions. The commonly cultivated orange carrot is particularly valued because of its high β -carotene content, a precursor of vitamin A, while other cultivars exhibit purple, yellow, red, or white pigmentation due to variations in phytochemical composition. Carrot roots are rich sources of dietary fibre, minerals, antioxidants, vitamins, and bioactive compounds that contribute significantly to human nutrition and health (Sharma, 2018; Ikram et al., 2024).



Consumption of carrot has been associated with reduced risks of vitamin A deficiency, certain cancers, and cardiovascular diseases due to its antioxidant properties. Globally, carrot production continues to increase because of growing consumer demand for nutritious foods and the crop's adaptability to diverse climatic conditions. In Nigeria, carrot cultivation has expanded beyond traditional production areas into the derived savannah and humid zones, where the crop contributes to household nutrition and income generation. However, achieving optimum yield and marketable root quality remains a challenge due to poor soil fertility and inadequate nutrient management practices. The growth and productivity of carrots are highly dependent on the availability of essential nutrients in balanced proportions. Nutrient deficiencies or imbalances can adversely affect germination, vegetative growth, root enlargement, and final yield. Fertilizer management therefore plays a critical role in maximizing crop performance and maintaining soil productivity. Soil testing remains an important tool for determining site-specific nutrient requirements and guiding fertilizer recommendations; however, crop responses to fertilizers often vary with soil type, climatic conditions, genotype, and agronomic management practices (Singh et al., 2024; Akhil et al., 2025). Carrot is particularly sensitive to soil physical and chemical conditions because its edible portion develops below ground. The crop requires deep, loose, well-drained soils that permit proper root elongation and enlargement. Since carrot seeds are small and directly sown in the field, good soil tilth and adequate nutrient supply are necessary for uniform emergence and stand establishment. In many tropical regions, including southeastern Nigeria, declining soil fertility due to continuous cultivation, erosion, and nutrient depletion has become a major limitation to sustainable vegetable production. Consequently, improving nutrient use efficiency through appropriate fertilizer management has become essential for enhancing carrot productivity while minimizing environmental degradation.

Organic nutrient sources have received considerable attention in sustainable agriculture because of their capacity to improve both soil fertility and soil health. Organic manures such as poultry manure and pig manure supply essential macro- and micronutrients while also contributing organic matter that enhances soil structure and biological activity. The application of organic manure improves aggregation, cation exchange capacity, water-holding capacity, and buffering capacity of soils, thereby creating favourable conditions for root growth and nutrient uptake (Adekiya et al., 2020; Liu, 2024). In highly weathered tropical soils, the incorporation of organic materials is particularly beneficial because these soils are often characterized by low organic matter content and poor nutrient retention. Nevertheless, the nutrient composition of organic manures varies considerably depending on animal source, feed composition, storage conditions, and handling methods, which in turn influence nutrient availability and crop response (Ndambi et al., 2019). While poultry manure is generally rich in nitrogen and phosphorus, pig manure often contains substantial amounts of organic carbon and other nutrients. The effectiveness of these organic amendments therefore depends not only on their nutrient content but also on application rate, timing, and interaction with environmental factors. Inorganic fertilizers, especially compound fertilizers such as NPK formulations, provide readily available nutrients that can rapidly satisfy crop nutrient requirements and significantly improve growth and yield. However, long-term reliance on inorganic fertilizers alone may lead to soil acidification, nutrient imbalances, reduced soil biological activity, and environmental pollution through nutrient leaching and runoff (Nadarajan & Sukumaran, 2021; Amartei et al., 2022). As a result, integrated nutrient management approaches that combine organic amendments with mineral fertilizers have been increasingly promoted as sustainable strategies for maintaining soil fertility and improving crop productivity. Several studies have demonstrated that combining organic manures with inorganic fertilizers enhances nutrient use efficiency, improves soil quality, and increases crop yields compared with the sole application of either source (Debele, 2021; Kiran et al., 2022; Rangasami et al., 2024). The gradual nutrient release from organic materials complements the immediate nutrient availability provided by inorganic fertilizers, thereby ensuring sustained nutrient supply throughout the crop growth cycle. Such integrated systems are particularly relevant in tropical agriculture, where soils are often nutrient-deficient and prone to rapid degradation under continuous cultivation.

Despite the recognized benefits of integrated nutrient management, optimum fertilizer combinations for carrot production under derived savannah conditions remain insufficiently documented. Excessive application of nitrogen or organic manure may promote luxuriant vegetative growth at the expense of root development, resulting in forked, cracked, or deformed roots with reduced market value (Deekermue et al., 2024). Furthermore, carrot genotypes may differ in nutrient requirements, growth characteristics, and yield potential, leading to variable responses to fertilizer application across environments and seasons. Information on genotype $\times$ fertilizer interactions under southeastern Nigerian conditions is particularly scarce. Understanding these interactions is important for developing location-specific nutrient recommendations that maximize productivity while ensuring sustainable soil management. Therefore, this study was conducted to evaluate the effects of integrated organic and inorganic fertilizer application on the growth and yield components of selected carrot genotypes in the derived savannah zone of southeastern Nigeria. It was hypothesized that integrated fertilizer application would enhance carrot growth and yield compared with sole nutrient sources, and that genotypes would differ in their responses to fertilizer treatments.

2. Materials and Methods

2.1. Site Description and Treatment Preparation

Field studies evaluated the effect of five fertilizer levels on the growth and yield of three genotypes of carrots grown in the field for two (2) cropping seasons (June to September) 2018 and 2019 at the Teaching and Research Farm of the Department of Crop Science,



Faculty of Agriculture, University of Nigeria, Nsukka. Nsukka is located in the derived savannah zone at latitude 06°44'83"N, and longitude 07°51'39"E, with an altitude of 447.26 m above sea level. Nsukka has a humid tropical climate, with a mean rainfall of 1400 mm per annum distributed over six months (April - September). The monthly minimum temperature ranges from 19°C to 23°C, while the monthly maximum temperature ranges from 27°C to 34°C. The relative humidity varies from 37% to 63% (UNN Meteorological station, 2019). The soil of the experimental site had a sandy clay loam texture and a pH of 4.8. The soil organic carbon was 1.5%, while available phosphorus and total nitrogen were 30.8 mg/kg and 0.14%, respectively. Exchangeable calcium was 2.2 cmol/kg, exchangeable potassium was 1.40 cmol/kg, and exchangeable magnesium was 0.13 cmol/kg.

2.2. Experimental Design and Treatment Application

The experiment was laid out as a 5 × 3 factorial experiment in a Randomized Complete Block Design replicated four times (4). The factors were five (5) fertilizer levels (control, 0 t/ha, 20 t/ha poultry manure, 20 t/ha pig manure, 10 t/ha poultry manure + 200 kg/ha N: P: K 15:15:15, 10 t/ha pig manure + 200 kg/ha N: P: K 15:15:15) and three (3) carrot genotypes (Safety Touchon France, Carotte Touchon AM, and Carotte Touchon ETS). The field area measuring 50 m × 25 m was ploughed, harrowed, and ridged. The experimental field was divided into plots measuring 3.0 m × 1.5 m, with 1.5 m-long ridges spaced 1.0 m apart. Twenty carrot seeds were sown within the plots. Growth parameters were recorded from four randomly selected and tagged plants in each plot throughout the experiment, while yield parameters were determined using all harvestable plants within the net plot at maturity. The required rates of organic manure were thoroughly incorporated into the soil on the designated ridges one month before planting. Planting was carried out in June. NPK 15:15:15 was applied at the rate of 200 kg ha⁻¹ at eight weeks after planting as a supplementary mineral fertilizer treatment. The application timing was intended to supply readily available nutrients during the active vegetative and root-development stages of the carrot crop following the initial incorporation of organic manure. The NPK fertilizer was applied uniformly to the designated plots by band placement beside the plant rows, taking care to avoid direct contact with the carrot plants, and was lightly incorporated into the soil. No separate basal application of NPK fertilizer was made.

Data collected included days to seedling emergence, percentage seedling emergence, number of harvested roots, whole-plant biomass yield (t/ha), root yield (t/ha), percent marketable yield (%), root uniformity, harvest index (%), number of marketable roots, and number of sorting groups. Days to seedling emergence were recorded as the number of days from sowing until approximately 50% of the seedlings had emerged. Percentage seedling emergence was calculated as the proportion of emerged seedlings relative to the number of seeds sown.

At harvest, all roots from the net plot were collected and counted to obtain the number of harvested roots. Root yield and whole-plant biomass yield were determined by weighing harvested roots and the entire above- and below-ground biomass, respectively, and converting the values to tonnes per hectare.

Marketable roots were defined as healthy, well-developed roots that were free from branching, cracking, pest or disease damage, and severe deformities, and were of acceptable size and shape for commercial sale. Percent marketable yield was calculated as:

Percent marketable yield (%) = (Weight of marketable roots / Total root yield) × 100.

Harvest index was determined as the proportion of economic yield (root yield) to total biological yield using the formula:

Harvest Index (%) = (Root yield / Whole plant biomass yield) × 100.

Root uniformity was assessed visually at harvest based on the consistency of root size, shape, and appearance within each experimental plot, with higher values indicating greater uniformity among harvested roots. Harvested roots were also sorted into commercially recognized size categories (small, medium, and large) according to root length and diameter. The number of sorting groups represented the total number of size categories present within each treatment, while the number of marketable roots was obtained by counting all roots meeting the predefined marketability criteria.

2.3. Data Analysis

Data collected on the growth and yield parameters of carrot were subjected to analysis of variance (ANOVA) appropriate for a factorial experiment in a Randomized Complete Block Design (RCBD) using SAS 9.4 (SAS Institute Inc., Cary, NC, USA).

The statistical model used was: $Y_{ijk} = \mu + R_i + F_j + G_k + (FG)_{jk} + \epsilon_{ijk}$

(where Y_{ijk} is the observed value of the response variable, μ is the overall mean, R_i is the effect of the i th replication/block, F_j is the effect of the j th fertilizer treatment, G_k is the effect of the k th genotype, $(FG)_{jk}$ is the interaction effect between fertilizer treatment and genotype, and ϵ_{ijk} is the random experimental error.)

Analysis of variance was performed separately for each year. Where the ANOVA indicated significant treatment effects, treatment means were separated using Fisher's Least Significant Difference (F-LSD) at the 5% probability level ($p \leq 0.05$). The F-LSD value was calculated from the appropriate error mean square and error degrees of freedom from the ANOVA. Differences between means were considered statistically significant when the absolute difference between two treatment means exceeded the corresponding F-LSD value.



3. Results and Discussion

3.1 Effects of Fertilizer Levels and Genotypes on Seedling Emergence of Carrot

The percentage emergence of carrot seedlings in 2018 was generally higher in fertilizer-amended plots than in the control, although the main effect of fertilizer level was not significant on most assessment dates (Table 1). A significant difference ($p \leq 0.05$) among fertilizer treatments occurred on the ninth day after planting, when the combined application of 10 t ha⁻¹ poultry manure (PM) + 200 kg ha⁻¹ NPK 15:15:15 recorded the highest emergence (63.9%) compared with the other fertilizer treatments. Numerically, this treatment also produced the highest emergence during the early assessment period (7–13 days after planting), whereas 20 t/ha poultry manure recorded the highest values from the 15th to the 23rd day. The control consistently recorded the lowest numerical emergence. These results indicate that fertilizer application did not consistently produce statistically significant differences in final emergence, although integrated nutrient application tended to promote earlier establishment.

The relatively higher emergence observed in the fertilized treatments agrees with Adeleye et al. (2024), who reported improved carrot establishment under integrated poultry manure and NPK fertilization compared with unfertilized plots. Eze et al. (2024) similarly reported improved stand establishment of carrot following poultry manure application. However, because fertilizer effects were not significant on most emergence dates in the present study, the observed numerical differences should not be interpreted as evidence of a strong fertilizer effect on emergence. The response may instead reflect differences in the early soil environment created by the amendments. Organic manure can contribute nutrients and improve soil physical conditions, while mineral fertilizer provides readily available nutrients; however, these potential mechanisms were not directly measured in the present experiment and are therefore not established as the cause of the observed emergence pattern.

Genotype significantly affected seedling emergence on some assessment dates in 2018. Safety Touchon France recorded the highest percentage emergence during the early period (7–11 days after planting), whereas Carotte Touchon AM recorded relatively higher emergence from the 13th to the 23rd day. Carotte Touchon ETS generally recorded the lowest values across the assessment period. The differences among genotypes indicate that emergence performance was partly genotype-dependent. Such variation is consistent with Nascimento et al. (2008), who demonstrated differences among carrot genotypes in germination performance under high-temperature conditions. Loarca et al. (2024) likewise reported substantial genetic variation in early shoot growth and stand establishment among carrot germplasm. Thus, the emergence differences observed in the present study may reflect inherent genetic differences among the tested cultivars, although the physiological basis of these differences was not investigated.

Table 1. Main effects of fertilizer levels and genotypes on the percentage of carrot seedling emergence in 2018.

Treatments	Number of days after planting								
	7	9	11	13	15	17	19	21	23
<i>Fertilizers</i>									
Control, 0 t/ha	31.9	34.7	69.2	79.2	80.6	81.9	84.4	84.4	88.6
20 t/ha Pig M	37.5	45.8	75.0	84.7	84.7	84.7	87.5	87.5	88.9
20 t/ha PM	48.6	54.2	88.9	88.9	94.4	94.4	98.6	98.6	98.6
10 t/haPM+200 kg/ha NPK	61.1	63.9	90.3	90.3	93.1	93.1	95.8	95.8	95.8
10 t/haPigM+200 kg/ha NPK	51.9	53.3	79.2	80.6	81.9	81.9	88.9	88.9	93.1
LSD _(0.05)	NS	1.7	NS	NS	NS	NS	NS	NS	NS
<i>Genotypes</i>									
Safety Touchon France	60.0	63.3	92.5	94.2	95.0	95.8	99.2	99.2	99.2
Carotte Touchon AM	46.7	52.5	91.2	95.0	95.8	95.8	96.7	99.2	99.2
Carotte Touchon ETS	20.0	23.3	63.3	65.0	70.0	70.0	83.3	83.3	86.7
LSD _(0.05)	1.3	1.3	1.2	1.0	0.9	0.9	0.7	0.7	0.6

PM: Poultry manure, Pig M: pig manure, N: P: K 15:15:15; NS: Not Significant.

In 2019, neither fertilizer level nor genotype significantly affected percentage seedling emergence (Table 2). Nevertheless, plots receiving organic manure alone or in combination with 200 kg ha⁻¹ NPK generally recorded higher numerical emergence than the control. The absence of significant treatment effects in 2019, despite numerical differences, indicates that environmental conditions during the second season may have reduced treatment-related variation in seedling establishment. Carotte Touchon ETS generally recorded lower emergence values than the other genotypes, although this pattern was not consistent on every assessment date. The contrasting significance between years emphasizes that genotype and fertilizer effects on emergence may vary with prevailing field conditions.

3.2 Effects of Fertilizer Levels and Genotypes on Growth and Yield Components in 2018

Fertilizer application significantly ($p \leq 0.05$) affected harvest index, whole-plant biomass yield, and root yield per hectare in 2018 (Table 3). The combined application of 10 t/ha poultry manure + 200 kg ha⁻¹ NPK 15:15:15 produced the highest whole-plant



biomass yield (6.0 t/ha), root yield (3.5 t/ha), harvest index (65.4%), percentage marketable yield (97%), root uniformity score (2.8), and number of marketable roots (34.4). In contrast, 10 t ha⁻¹ pig manure + 200 kg ha⁻¹ NPK 15:15:15 produced the highest number of harvested roots (38.8) and number of sorting groups (9.3). The control generally recorded the lowest values for the major yield parameters, although it did not necessarily produce the lowest number of harvested roots or root uniformity.

Table 2. Main effect of fertilizer levels and genotypes on the percentage emergence of carrot seedlings grown in 2019.

Treatments	Number of days after planting							
	7	9	11	13	15	17	19	21
<i>Fertilizers</i>								
Control, 0 t/ha	54.2	54.2	77.3	77.3	77.3	87.5	87.5	93.8
20 t/ha PM	70.8	73.6	87.5	87.5	95.8	100.0	100.0	100.0
20 t/ha PigM	58.3	61.1	80.6	81.9	90.3	95.8	95.8	98.6
10 t/haPM + 200kg/ha NPK	75.0	75.0	95.8	95.8	98.6	100.0	100.0	100.0
10 t/haPigM + 200kg/ha NPK	72.28	75.0	95.8	95.8	98.6	100.0	100.0	100.0
LSD_(0.05)	NS	NS	NS	NS	NS	NS	NS	NS
<i>Genotypes</i>								
Safety Touchon France	66.7	66.7	72.2	77.3	93.9	95.7	97.5	98.8
Carotte Touchon AM	66.7	68.3	86.3	84.2	89.2	97.5	98.8	99.2
Carotte Touchon ETS	65.0	68.3	83.7	86.7	93.3	97.5	97.5	97.5
LSD_(0.05)	NS	NS	NS	NS	NS	NS	NS	NS

PM: Poultry manure, Pig M: pig manure, N: P: K 15:15:15; NS: Not Significant.

The superior biomass and root yield obtained with 10 t ha⁻¹ poultry manure + 200 kg ha⁻¹ NPK 15:15:15 demonstrates the potential benefit of combining organic and inorganic nutrient sources. The root yield obtained under this treatment was 3.5 t/ha, compared with the lower values recorded under the other fertilizer treatments. Kiran et al. (2022) similarly reported increased carrot growth and yield following integration of NPK fertilizer with organic manure. The present finding is also consistent with the report of Adeleye et al. (2024), who observed improved carrot performance under combined poultry manure and NPK application. The response may be associated with the complementary nutrient supply provided by the two fertilizer sources; however, because nutrient uptake and soil nutrient dynamics were not measured in this study, the specific mechanism responsible for the higher yield cannot be conclusively established.

Table 3. Main effects of fertilizer levels and genotype on carrot growth and yield components in 2018.

Treatments	NHR	RU	NSG	NMR	HI	MY	WPBYH	RYH
					(%)	(%)	t/ha	t/ha
Fertilizers								
Control, 0 t/ha	33.8	2.2	7.2	21.1	46.4	68.3	2.4	1.8
20 t/ha PM	32.7	2.5	8.5	26.7	58.4	82.7	5.0	2.7
20 t/ha Pig M	34.6	2.4	7.9	33.4	55.5	95.6	5.5	3.4
10 t/ha PM+200 kg/ha NPK	35.5	2.8	8.6	34.3	65.4	97	6.0	3.5
10 t/ha Pig M+200 kg/ha NPK	38.8	2.7	9.3	30.8	59.4	87.9	5.1	2.9
LSD _(0.05)	NS	NS	NS	NS	10.5	NS	0.55	0.5
Genotypes								
Safety Touchon France	36.0	2.9	7.8	29.5	57.1	84.4	4.8	3.0
Carotte Touchon AM	34.8	2.8	8.1	30.7	57.4	88.3	4.9	3.1
Carotte Touchon ETS	32.1	2.4	9.1	27.6	56.6	86.1	4.7	3.0
LSD _(0.05)	NS	NS	NS	NS	0.42	NS	0.13	NS

PM: Poultry manure, Pig M: pig manure, N: P: K 15:15:15; NHR: Number of harvested roots; RU: Root uniformity; NSG: Number of sorting groups; NMR: Number of marketable roots; HI: Harvest Index, MY: percent marketable yield; WPBYH: Whole plant biomass yield per hectare; RYH: Root yield per hectare; NS: Not Significant.

The significant improvement in harvest index under the integrated treatment is particularly important because harvest index represents the proportion of total plant biomass allocated to the harvested root. The value of 65.4% recorded under 10 t ha⁻¹ poultry manure + 200 kg ha⁻¹ NPK indicates effective partitioning of biomass towards the economic yield component. The 97% marketable yield obtained under the same treatment further demonstrates its potential for improving the proportion of roots suitable for market. Similar benefits of integrated organic and inorganic nutrient management have been reported by Kiran et al. (2022) and Amartey et al. (2022), who found that appropriate combinations of organic manure and mineral fertilizers enhanced carrot yield and yield-related characteristics.



Genotypic differences were significant for harvest index and whole-plant biomass yield in 2018, while other measured yield components did not differ significantly. Carotte Touchon AM recorded the highest number of marketable roots (30.7), harvest index (57.4%), percentage marketable yield (88.3%), whole-plant biomass yield (4.9 t/ha), and root yield (3.1 t ha⁻¹). Safety Touchon France produced the highest number of harvested roots (36.0) and root uniformity score (2.9), whereas Carotte Touchon ETS recorded the highest number of sorting groups. These differences indicate that the genotypes did not respond identically across all production traits. Loarca et al. (2024) similarly reported genetic variation among carrot germplasm for traits associated with establishment and shoot growth, supporting the importance of genotype in determining crop performance.

3.3 Effects of Fertilizer Levels and Genotypes on Growth and Yield Components in 2019

Fertilizer treatments significantly affected harvest index, whole-plant biomass yield, root yield, and marketable yield in 2019, whereas the other measured growth and yield components were statistically similar among fertilizer treatments (Table 4). The highest whole-plant biomass yield (8.5 t/ha), root yield (5.7 t/ha), and harvest index (67.5%) were recorded with 10 t/ha poultry manure + 200 kg ha⁻¹ NPK 15:15:15. These values were considerably higher than those obtained in 2018 under the same treatment, particularly for root yield, which increased from 3.5 to 5.7 t/ha. This year-to-year variation demonstrates that fertilizer response was not constant across seasons and may have been influenced by differences in environmental conditions.

The strong performance of the integrated poultry manure and NPK treatment in 2019 aligns with the 2018 results and reinforces the potential of integrated nutrient management for carrot production under the study conditions. Kiran et al. (2022) reported improved carrot yield following combined application of organic manure and NPK fertilizer, while Amartey et al. (2022) also found that integrated organic and inorganic nutrient management significantly affected carrot growth and yield. The consistency of the response across the two seasons provides stronger evidence for the agronomic potential of the integrated treatment than would be obtained from either season alone.

However, the 2019 results also demonstrate that the response to individual organic fertilizer sources differed from that observed in 2018. The manuscript should therefore distinguish between the highest-performing treatment in each year rather than assuming that one fertilizer treatment was universally superior. The observed variation is particularly relevant for practical fertilizer recommendations because the effectiveness of an amendment can vary across seasons and production environments.

Table 4. Main effect of fertilizer levels and genotypes on the growth and yield components of carrots harvested in 2019.

Effect	NHR	RU	NSG	NMR	HI	MY	WPBYH	RYH
					%	%	t/ha	t/ha
<i>Fertilizers</i>								
Control, 0 t/ha	35.6	3.4	7.8	25.7	52.2	72.5	2.0	1.1
20 t/ha PM	36.0	2.8	9.3	36.0	65.5	100.0	8.2	5.2
20 t/haPigM	34.4	2.2	9.8	31.8	65.6	91.0	4.8	3.2
10 t/haPM + 200 kg/ha NPK	36.0	3.0	11.3	36.0	67.5	100.0	8.5	5.7
10 t/haPigM + 200 kg/ha NPK	36.0	2.5	9.3	36.0	65.0	100.0	5.6	3.6
LSD _(0.05)	NS	NS	NS	NS	9.8	7.8	2.4	1.4
<i>Genotypes</i>								
Safety Touchon France	36.1	2.6	9.9	33.8	61.2	93.2	5.9	3.8
Carotte Touchon AM	35.3	2.7	10.0	33.2	66.0	93.5	6.1	3.9
Carotte Touchon ETS	35.4	3.1	8.7	32.3	62.3	91.4	5.4	3.6
LSD _(0.05)	NS	NS	NS	NS	NS	NS	0.26	NS

PM: Poultry manure, Pig M: pig manure, N: P: K 15:15:15, NHR: Number of harvested roots, RU: Root uniformity, NSG: Number of sorting groups, NMR: Number of marketable roots, HI: Harvest Index, MY: percent marketable yield, WPBYH: Whole plant biomass yield per hectare, RYH: Root yield per hectare, NS: Not Significant.

Genotype had limited effects on the measured growth and yield components in 2019. Significant differences were detected for whole-plant biomass yield, with Carotte Touchon AM producing the highest biomass yield (6.1 t/ha), root yield (3.9 t/ha), harvest index (66.0%), and marketable yield (93.5%). Safety Touchon France recorded the highest number of harvested roots and number of marketable roots, but had the lowest root uniformity score (2.6) and harvest index (61.2%). These results indicate that no single genotype was consistently superior for every measured trait. Carotte Touchon AM showed an advantage in biomass and root production, whereas Safety Touchon France performed better for root number.

The relatively small differences among genotypes for most yield traits in 2019 are consistent with the observation that genotype effects were generally limited in the present study. Nevertheless, the numerical superiority of Carotte Touchon AM for root and biomass yield suggests that genotype selection remains relevant when the production objective is maximum yield. Pusuluri et al. (2024) emphasized the importance of cultivar differences in carrot production and demonstrated that cultivar characteristics can influence growth and yield responses to crop management. Similarly, studies on nutrient demand have shown that nutrient



requirements can vary among carrot cultivars according to their yield potential (Aquino et al., 2015). Therefore, fertilizer recommendations should consider both nutrient availability and the productivity characteristics of the cultivar being grown.

Across both years, the results demonstrate that fertilizer management had a stronger and more consistent influence on major yield attributes than genotype. The integrated application of 10 t/ha poultry manure + 200 kg ha⁻¹ NPK 15:15:15 was particularly effective, producing the highest root yield in both years, although the magnitude of the response differed between seasons. In 2018, the treatment produced 3.5 t/ha root yield, while in 2019 it produced 5.7 t/ha. The increase of approximately 63% between the two seasons highlights the importance of seasonal conditions when evaluating fertilizer performance. The results therefore support the use of integrated nutrient management rather than reliance on either organic or inorganic fertilizer alone under the conditions of the study.

The findings also have economic and environmental implications. Although fertilizer application improved yield, increasing fertilizer inputs indiscriminately may increase production costs and create environmental risks. Luz et al. (2009) reported that fertilizer use constitutes a substantial component of carrot production costs, while Smoleń and Sady (2009) demonstrated that nitrogen management can influence both yield and the quality-related composition of carrot roots. Consequently, the objective should not simply be to maximize fertilizer application but to identify combinations that provide an appropriate balance between yield, marketable production, and input cost. The present results suggest that 10 t/ha poultry manure combined with 200 kg ha⁻¹ NPK 15:15:15 provides a promising nutrient management option for carrot production at the study location, particularly because it produced the highest root yield in both seasons.

Overall, the results show that fertilizer management substantially influenced carrot productivity, particularly the economically important root yield, biomass production, harvest index, and marketable yield. Genotypic effects were comparatively smaller and were expressed mainly in selected traits such as biomass yield, harvest index, and root number. The absence of consistently superior performance by one genotype across all parameters indicates that cultivar selection should depend on the specific production objective. More importantly, the repeated high performance of the integrated poultry manure and NPK treatment across the two seasons provides evidence supporting its use under the conditions of Nsukka. Nevertheless, because soil nutrient uptake, nutrient-use efficiency, and economic returns were not directly assessed, further studies should evaluate these parameters before making broader recommendations on fertilizer optimization.

4. Conclusion

The two-year field evaluation demonstrated that fertilizer management had a greater influence on carrot growth and yield than genotype under the derived savannah conditions of Nsukka, Southeastern Nigeria. Organic and inorganic fertilizer treatments generally improved seedling establishment and yield-related characteristics compared with the unfertilized control. The combination of 10 t/ha poultry manure with 200 kg ha⁻¹ NPK 15:15:15 produced the most consistent performance, particularly for whole-plant biomass yield, root yield, harvest index, and marketable yield. In 2018, this treatment produced 6.0 t/ha whole-plant biomass, 3.5 t/ha root yield, and 97.0% marketable yield, while in 2019 it produced high yield performance, although 20 t ha⁻¹ poultry manure recorded the highest values for some yield attributes. Genotypic differences were generally limited, although Carotte Touchon AM showed comparatively high biomass and root yield, while Safety Touchon France performed better for some root-number traits. Based on the overall response across the two seasons, 10 t ha⁻¹ poultry manure combined with 200 kg ha⁻¹ NPK 15:15:15 is recommended as an effective nutrient-management option for carrot production in the study environment. Further studies should evaluate the economic returns and nutrient-use efficiency of this fertilizer combination under different soil and seasonal conditions.

Author Contributions

Chizaram-Ndubuaku, Chiamaka Adaeze, Ebido, Nancy Ekene; Writing – original draft, Chizaram-Ndubuaku, Chiamaka Adaeze; Writing – review & editing, Ebido, Nancy Ekene. Chiamaka Adaeze Chizaram-Ndubuaku: Data curation, Funding acquisition, Investigation, Methodology, Resources, Software, Visualization, Writing – original draft, Writing – review & editing; Nancy Ekene Ebido: Methodology, Software, Visualization, Writing – review & editing; Kayode Paul Baiyeri: Conceptualization, Methodology, Supervision, Validation.

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Declarations

Conflicts of Interest: The authors declare that there are no conflicts of interest regarding the publication of this paper.

Institutional/Ethical Approval: Standard research ethics were followed in the conduct of this investigation. Farmers were not required to participate, and all respondents gave their full consent before any data were collected. Sensitive or private information was not revealed. Since this study used non invasive survey based data collection, formal institutional ethical approval was not necessary.

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