

Growth and Yield Response of Carrot (*Daucus carota* L.) to Integrated Nutrient Management in the Forest-Savannah Transitional Zone of Ghana

Abstract

Carrot is an important root vegetable valued for its nutritional and economic benefits; however, achieving optimal growth and yield in the Forest-Savanna transitional zone of Ghana remains a challenge due to variable soil fertility and limited nutrient availability. In view of this, two field experiments were conducted from September 2021 to December 2021 and from April 2022 to July 2022 at the multipurpose crop nursery field of Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Mampong Campus, to assess the effects of integrated nutrient management on the growth and yield of carrot (*Daucus carota* L.). The experiment was laid out in a Randomized Complete Block Design (RCBD) with six treatments, replicated four times. The treatments included: - (i) 300 kg/ha NPK (full NPK), (ii) 20 t/ha chicken manure (full CM), (iii) 225 kg/ha NPK + 5 t/ha CM ($\frac{3}{4}$ NPK + $\frac{1}{4}$ CM), (iv) 150 kg/ha NPK + 10 t/ha CM ($\frac{1}{2}$ NPK + $\frac{1}{2}$ CM), (v) 75 kg/ha NPK + 15 t/ha CM ($\frac{1}{4}$ NPK + $\frac{3}{4}$ CM), and (vi) control (no fertilizer). The results indicated that full CM and full NPK significantly enhanced plant height and canopy development between 9 and 11 weeks after planting (WAP), compared with the control in both years. The combinations of $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM (2021) and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM (2022) produced the highest dry shoot weight from 9-11 WAP than the control. Dry root weight was also significantly greater under full CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatments from 9-11 WAP in both seasons compared to the control. The number of plants harvested, marketable roots, root length, root diameter, and total root yield were all higher under full CM, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM compared with the control. The 20 t/ha CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM recorded the highest yields (13.06 and 14.37 t/ha, respectively) for 2021 and 2022 and it is therefore recommended for adoption by farmers to achieve higher yields.

Keywords: Chicken manure; carrot; root yield; root length; root diameter

2010 Mathematics Subject Classification: 53C25; 83C05; 57N16

1 Introduction

Carrot (*Daucus carota* L.) is one of the most important herbaceous root vegetables in the Apiaceae family cultivated worldwide. Carrot is among the cool season crops that is utilized for the edible tap root and is adapted to temperate climates (Paparella *et al.*, 2024). Globally, carrots rank among the top 10 vegetables in terms of agricultural production (Kowalczyk & Kuboń, 2022). In 2020, the combined production of carrots and turnips reached 40.24 million tonnes and increased to approximately 41.67 million tonnes in 2021, reflecting their significant horticultural and economic importance (Sherin *et al.*, 2024). The crop is cultivated on approximately 1.2 million hectares worldwide, with an average yield of about 36 tonnes per hectare (FAOSTAT, 2022). Carrots are cultivated in over 100 countries, across temperate, subtropical, and tropical climates, with adaptability enhanced by the development of diverse varieties. China is by far the largest producer, contributing more than 45-50% of total world production. Other significant producers include Uzbekistan, Russia, the United States, Ukraine, Poland, and the United Kingdom. In Africa, Algeria is the leading producer with a production of about 420,000 metric tonnes (FAOSTAT, 2020). In Ghana, carrot is one of the important vegetable crops produced by many small-scale vegetable farmers for both domestic consumption and for sale. The Mampong Municipality is among the leading producers of vegetables, particularly carrot in Ghana. Carrot is a vegetable of high nutrient value and used in combination with other vegetables in preparing stews, soups, and salads. All carrots regardless of their colours are packed with variety of nutrients including fiber, potassium, vitamin C, vitamin A, and manganese. Additionally, carrots are relatively low in calories with 128 grams of raw carrots producing only 52 calories (Sharma *et al.*, 2025). However, purple-coloured carrots are nutritionally unique because of their high content of antioxidants called anthocyanin. The purple-coloured carrots contain 93-168 mg/100gm of anthocyanins with cyanidin acylated with ferulic and coumaric acid as the major forms of pigments (Pérez *et al.*, 2023). Carotene which is extracted from the roots of carrots is used in colouring margarine and for improving the colour of egg yolk when added to layers feed. The mature leaves and roots are used in the preparation of animal feed (Sah *et al.*, 2024). According to Mwetulundila & Indongo (2025) demand for carrots by consumers remain high especially in urban centers.

Several published research works on carrot production have confirmed that application of inorganic fertilizers to carrots increase growth, yield, and quality parameters, likewise the application of organic manure such as poultry manure, cow dung, compost etc. Choudhary *et al.* (2022) asserted that the application of 80 kg/ha N, 50 kg/ha P, and 50 kg/ha K significantly enhanced the growth and yield of carrot. Similarly, Dawuda *et al.* (2019) also reported that the application of 300 kg/ha NPK (20-10-10) promoted carrot growth and yield. Deekermue *et al.* (2024), recommended the application of 10-20 t/ha chicken manure for improved growth and yield of carrots. A study by Appiah *et al.* (2025) also indicated that the application of 10 t/ha chicken manure promoted effective crop growth and yield as compared to the control. However, because of ever increasing higher prices of inorganic fertilizers and loss of nutrients from inorganic fertilizers through leaching, and volatilization, farmers find it difficult to buy the quantities of inorganic fertilizers which will enable them to obtain maximum carrot yield and growth. In the same vein, the bulky nature of organic manure, high cost of transportation and the inability of farmers to get large quantities (Oluwagbemi *et al.*, 2021) for large scale carrot farming for maximum carrot growth and yield, has prompted this research work to evaluate the integrated management of organic and inorganic fertilizers for carrot production. The research will provide information on the best optimum levels of combination of organic manure (poultry manure) and inorganic fertilizers application (N.P.K. 15:15:15) to carrot farmers in Ghana. The objective of the study was to assess the growth and yield response of carrot to integrated nutrient management of chicken manure and inorganic fertilizer (NPK).

2. Material and Methods

2.1 Description of Experimental Site

The experiment was conducted from September, 2021 to December, 2021 (2021 minor season) and from April, 2022 to July, 2022 (2022 major season) at the Multipurpose nursery field of the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development located at Mampong in the Ashanti region of Ghana. Mampong-Ashanti (7°45'N, 1°24'W) lies at an altitude of 402 m above sea level and is located in the forest-savannah transition agro-ecological zone. The area has a bimodal rainfall pattern with the major rainy season in March to July and the minor rainy season from mid-August to November. The mean annual rainfall is between 800 and 1500mm, with monthly average rainfall of about 91.2mm (Geodatos, 2020). The average monthly temperature of the experimental site ranges from 25 to 32 °C, while the relative humidity ranges between 75% to 85% in the morning and decreases in the afternoon. There is a long dry harmattan season from December to March (Nkrumah *et al.*, 2019). The soils belong to the Bediese series (which are sandy loam, well-drained with a thin layer of organic matter, deep yellowish red, friable and free from stones according to CSIR-Soil Research Institute (1999), and are classified as Chromic Luvisol according to the FAO/UNESCO, Soil Classification (FAO/UNESCO, 2008). During the 2021 minor cropping season (September-December), total rainfall was 507.2 mm, with the highest amounts recorded in September and October. Average monthly temperatures ranged from 23.2°C to 32.5°C. In the 2022 major cropping season (April-July), total rainfall reached 580.0 mm, while average monthly temperatures ranged between 23.3°C and 31.7°C. Across both seasons, the average monthly relative humidity was 70% (Table 1).

Table 1. Climatic conditions at both experimental sites during the cropping seasons

Minor cropping season, 2021					Major cropping season, 2022				
Month	TMR (mm)	RH (%)	MT (°C)		Month	TMR (mm)	RH (%)	MT (°C)	
			Max.	Min				Max.	Min.
September	225.1	77	30.3	23.2	April	79.6	66	33.1	23.5
October	208.7	72	32.1	22.3	May	147.8	71	32.7	23.8
November	73.4	68	33.1	23.4	June	149.0	74	31.0	23.3
December	0.0	58	34.3	23.7	July	203.6	74	30.0	22.7
Total	507.2				Total	580.0			

(Ghana Meteorological Agency - Mampong Ashanti, 2021, 2022) TMR - Total monthly rainfall, RH - Relative humidity, TM - Monthly temperature

2.2 Manure Collection and Preparation

The chicken manure used for the study was collected from the poultry farm at AAMUSTED-Asante Mampong. The manure was heaped on a black polythene sheet and covered completely with a black polythene sheet to prevent them from losing their nutrients through run off water and volatilization. The manure was left for one month for complete decomposition before incorporation.

2.3 Land Preparation and Field Layout

The experimental field was marked out. The vegetation on the land was cleared using cutlass followed by lumbering. The field was ploughed and harrowed to a fine tilth to aid soil aeration, infiltration of water, and penetrability of carrot roots for optimum growth and yield. Beds or ridges of dimensions 1m by 2 m were raised after ploughing. The field was demarcated into four blocks with six beds per each. The plots were separated in 1.0 m paths and 2.0 m between blocks.

2.4 Soil, and Manure Sampling and Analysis

Initial soil samples were collected randomly from the field at a depth of about 0-30 cm using soil auger. The collected samples of soil were dried and bulked into composite samples prior to fertilizer application. The soil sample was air-dried and sieved through a 2.00 mm mesh to for both physical and chemical analysis. Chicken manure sample was collected and bulked after decomposition for nutrient analysis. Some of the parameters analyzed included: [pH (1:1 H₂O), organic matter (%), organic carbon (%), total N (%), available P and K (ppm), exchangeable cations: Ca, Mg, K, Na (me/100g), and exchangeable acidity: Al and H (me/100g), and particle size analysis. The analyses were conducted at the Soil Science Laboratory, Department of Crop and Soil Sciences, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi.

The pH was determined using a soil-to-water ratio of 1:2.5 for the soil sample and 1:10 for the chicken manure, as described by Miller & Keeney (1982). The percentage nitrogen (% N) was determined using the Kjeldahl method, as described by Bremner and Mulvaney (1982). The percentage of phosphorus (%P) in the soil sample was determined using the Bray-1 method, as reported by Bray and Kurtz (1945), while that of the chicken manure was determined as described by Motsa et al. (2008) and Moss (1961). The percentage potassium (%K) in the soil sample and chicken manure sample was determined using a flame photometer, as described by Okalebo et al. (2002). Exchangeable bases in the soil samples were determined using the ammonium acetate extraction method, following the procedure outlined by Chapman (1965). Exchangeable acidity (Al and H⁺) was determined using the titration method described by McLean (1965). The percentage of organic carbon (%C) in both the soil and chicken manure samples was determined using the Walkley-Black oxidation method, as described by Walkley and Black (1934). The percentage organic matter (%OM) of both the soil and chicken manure samples was determined by multiplying the percentage organic carbon (%C) by a factor of 1.724 (%OM = %C × 1.724), as described by Walkley and Black (1934).

The concentrations of calcium (Ca²⁺) and magnesium (Mg²⁺) in the chicken manure sample were determined using the EDTA (ethylenediaminetetraacetic acid) titration method, following the procedure outlined by Jackson (1962). The C: N ratio was calculated by dividing the percentage of organic carbon by the percentage

of total nitrogen, as described by Brady and Weil (2008). Particle size analysis was conducted using the hydrometer method as described by Gee and Bauder (1979).

2.5 Experimental Design and Treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) with six treatments and replicated four times. The six (6) treatments were: - (i) 300 kg/ha NPK (15-15-15) (Full NPK), (ii) 20 t/ha chicken manure (Full CM), (iii) 225 kg/ha NPK + 5 t/ha CM (3/4 NPK + 1/4 CM), (iv) 150 kg/ha NPK + 10 t/ha CM (1/2 NPK + 1/2 CM), (v) 75 kg/ha NPK + 15 t/ha CM (1/4 NPK + 3/4 PM), and (vi) No fertilizer (control).

2.6 Planting Materials, Planting and Management Practices

Carrots variety Bahia seeds were sourced from CSIR-Crops Research Institute in Kumasi, Ghana. The NPK fertilizer was sourced from Kyeiwaa Agrochemical Shop, located in the Asante Mampong Municipality. The carrot seeds were treated with a seed-dressing fungicide (seed power) at a rate of 10 g of seed mixed with 1 g of seed-dressing fungicide against seed-borne or soil-borne pathogens before sowing by drilling to a depth of 1 cm on 20 cm between rows on beds. The seeds were covered with palm fronds to prevent them from being washed away by heavy rains and also to prevent them from exposure to excessive heat from the sun. The palm fronds were removed from the seedlings two weeks after sowing to harden them. The seedlings were thinned to 10 cm within rows at two weeks after planting. Each plot measured 4 m wide x 2 m long. There were 4 rows per plot with 20 plants per row.

The chicken manure at different rates was incorporated into the beds two weeks before planting to allow proper decomposition and also to prevent the seedlings from dying as a result of the heat released by the decomposition of the poultry manure. The NPK fertilizer was applied to the seedlings one week after thinning using side placement. Forking was done three times at different intervals to loosen the soil for proper aeration, root development and also to enable the soil to retain the water for a long period of time after watering. Weeds were controlled manually using a hoe and hand pulling any time weed control was necessary in the field to prevent them from competing for nutrients, water, and sunlight and also to prevent them from harbouring pests. Watering was done twice a day, early in the morning and late in the evening for the first two months with an estimated 5 L of water per plot a day and it was later reduced to once in a day with an estimated amount of 2.5 L that is only morning for the last month to maturation. Earthening up was also done when necessary to prevent greening through a process called photomorphogenesis, protect the roots from pests, physical damage and promote proper root development.

2.7 Data Collected

Data were collected on vegetative growth and yield and yield components of carrot. Vegetative growth parameters were recorded using five randomly selected and tagged plants from the two harvestable central rows of each plot. Plant height (measured from the soil surface to the apex and were recorded in cm), number of leaves per plant were manually counted, and canopy spread (measured in two perpendicular directions across the widest leaves) were assessed at two-week intervals, beginning 4 weeks after planting (WAP), for four consecutive times. Dry matter accumulation was determined every two weeks after 4 WAP for four consecutive times. Two plants from the border rows of each bed were uprooted and cut into two parts namely: roots and shoots. A 200 g samples of each of shoots and roots were placed in separate paper envelopes with labels and dried in an oven at a temperature of 72 0C for 72 hours until the mass remained constant. The dry root and shoot weights were determined in grams (g) using an electronic weighing scale.

Yield and yield components parameters assessed included number of plants harvested, number of marketable roots, number of unmarketable roots, root length, root diameter, and total root yield (t/ha). Harvested roots were counted from the two central rows of each bed, with defective roots (cracked, nematode-infected, forked, malformed, or diseased) classified as unmarketable, while clean roots without any deformities were considered marketable. Five matured roots per plot were randomly sampled from the harvestable area (two central rows of each bed) for root length (measured with a meter rule) and root diameter (measured 2 cm below the crown using a digital vernier caliper), and the mean values were recorded in cm. The yield within the harvestable area of each plot was estimated in (t/ha) using the formula as described

below by Amanullah *et al.* (2019):

$$\text{Yield (t/ha)} = \frac{\text{Root yield (kg)}}{\text{Harvestable area (m}^2\text{)}} \times \frac{10,000\text{m}^2}{1,000} \tag{1}$$

2.8 Statistical Analysis

The data was analyzed using the analysis of variance (ANOVA) with GenStat Statistical Package. Treatment means were separated and compared using Fisher’s protected LSD at 5% probability.

3. Results

3.1 Soil, Chicken Manure, and Biochar Analysis

The initial soil analysis was interpreted using guide to interpretation of soil analytical data in Ghana (SRI, 2007). The soils used for the field experiments were all slightly acidic. The pH of the soils for both years was slightly acidic (Table 2). Available Phosphorus in the soil was moderate for both 2021 and 2022. Total Nitrogen in the soil was high for 2021, but moderate for 2022 (Table 2), Potassium was moderate for both 2021 and 2022. Calcium was low for both 2021 and 2022. Magnesium and Sodium were moderate for 2021 and 2022. Percentage organic carbon and percentage organic matter were all low for 2021 and 2022. Both soils used for the field experiments had a textural class of loamy sand with percentage 85.56% sand, 7.04% Clay and 7.40% Silt for 2021 and 84.74% sand, 7.84% Clay and 7.42% Silt for 2022 (Table 2).

Table 3 shows the nutrient composition of chicken manure used in studies. The nutrient composition of the chicken manure was interpreted using the reference ranges reported by Chastain *et al.* (2001). The manure contained moderate levels of total nitrogen and calcium, while total phosphorus, potassium, and magnesium were high. Organic carbon content was also high. The manure was slightly alkaline, with a pH of 7.16.

Table 2. Results of Initial Soil Analysis for 2021 and 2022

Year	pH (H ₂ O 1:1)	P mg/kg	N (%)	Exch. Bases (cmol/kg)				Exch. Acidity		% Org. C.	% Org. M.
				K	Ca	Mg	Na	Al	H		
2021	6.11	14.71	0.46	0.29	1.81	1.37	0.04	0.34	0.32	0.36	0.62
2022	6.03	12.69	0.15	0.26	1.75	1.23	0.05	0.38	0.41	0.42	0.73
Particle size analysis											
		% Sand		% Clay		% Silt				Textural class	
2021		85.56		7.04		7.40				Loamy sand	
2022		84.74		7.84		7.42				Loamy sand	

Table 3. Chemical properties of chicken manure used for the study

Total N (%)	Total P (%)	Total K (%)	Total Ca (%)	Total Mg (%)	% O. Carbon	pH	C: N
2.732	2.094	2.677	1.627	0.590	40.95	7.16	14.99

3.2 Vegetative growth

3.2.1 Plant height

The graphs show the effect of integrated nutrient management on carrot plant height over time in 2021 (A) and 2022 (B). In both years, plant height increased progressively from 5 weeks after planting (WAP) to 11 WAP across all treatments. In 2021, the performances of the treatments in terms of plant height were similar at 5 WAP. However, from at 7 WAP, full CM had the tallest plant height and was significantly ($P < 0.05$) different from all the other treatments (Fig. 1a). From 9 - 11 WAP full CM produced the tallest plants, followed closely by $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, while the control (no fertilizer) recorded the shortest plants. The control (no fertilizer) recorded the shortest plant height from 5 to 11 WAP (Fig. 1a). Plant height was not significantly ($P > 0.05$) influenced by the treatments from the 5 to 7 WAP in 2022. However, significant differences in plant height were evident from the 9 to 11 WAP in the 2022. At 9 and 11 WAP $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and full NPK recorded the tallest plant height, respectively while control recorded the shortest plant height (Fig. 1b). Full CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM recorded intermediate plant height.

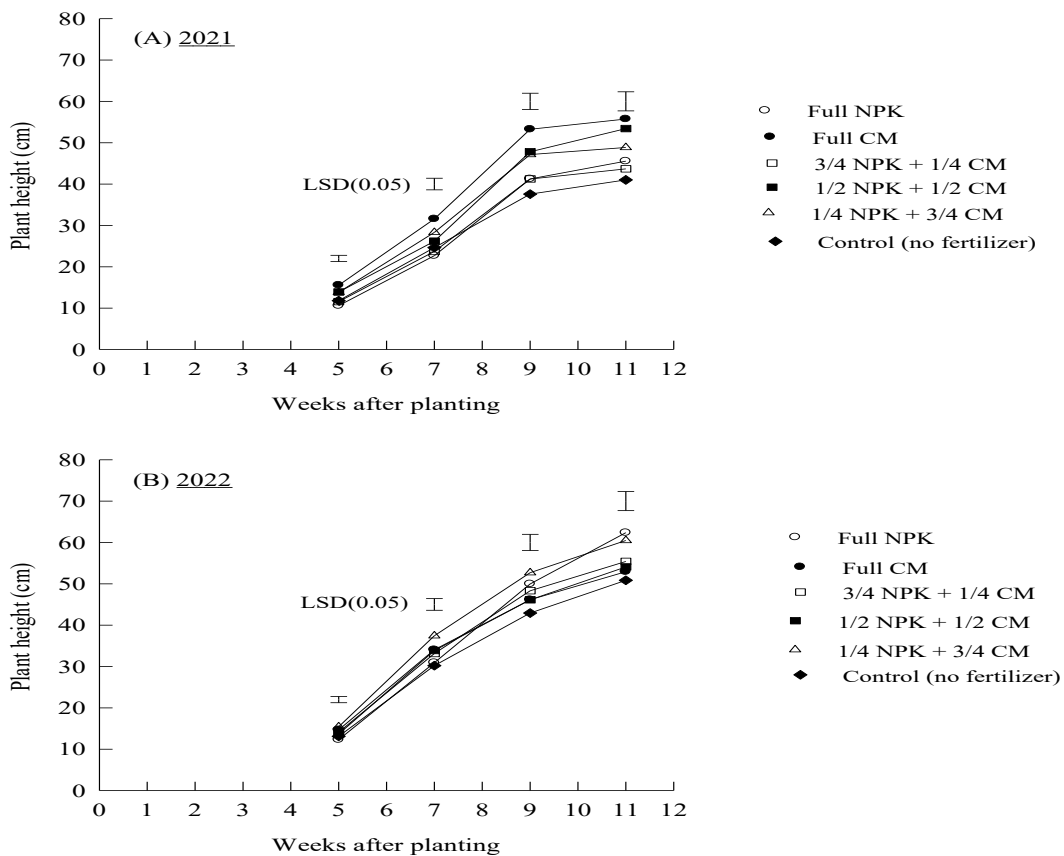


Fig 1. Effect of integrated nutrient management on plant height of carrot in 2021 and 2022

3.2.2 Canopy width

The canopy widths of the plants were statistically similar from the 5 to 7 WAP for both 2021 and 2022. The treatments significantly influenced canopy width from 7 to 11 WAP in both 2021 and 2022 (Fig. 2a and Fig. 2b). Full CM recorded the widest canopy width while control and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM recorded the least canopy width from 9 to 11 WAP in 2021. Full NPK, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM recorded intermediate canopy widths. There was no significant ($P>0.05$) difference between full CM and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, full NPK and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, and also between control and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM for 2021 (Fig. 2a). Similarly, in 2022, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and full NPK recorded the widest canopy width at 9 and 11 WAP, respectively while both full CM and control recorded the least canopy width during the same period.. The $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM treatments recorded intermediate canopy width (Fig. 2b).

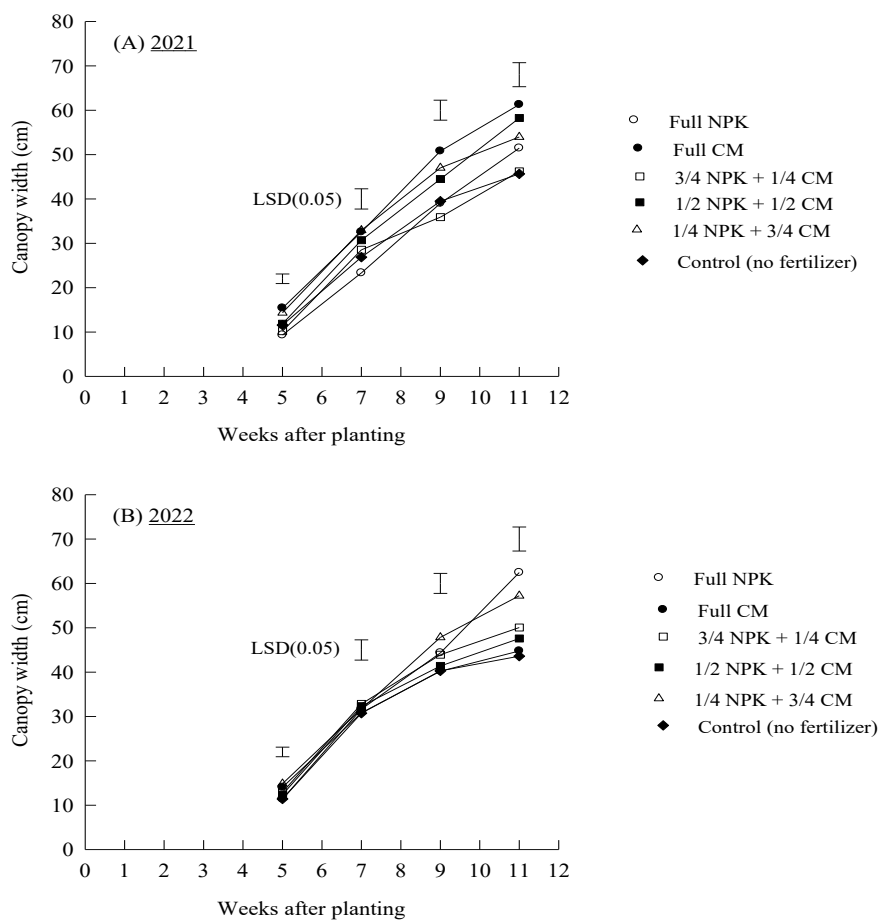


Fig 2. Effect of integrated nutrient management on canopy width of carrots in 2021 and 2022

3.2.3 Dry shoot weight

The dry shoot weight of the treatments was statistically similar from the 5 to 7 WAP for both seasons. The treatments performed differently after the 7th week for both years. Plants that received $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM produced the heaviest shoot dry weights at 9 and 11 WAP, respectively and they performed significantly better than full NPK and the control. Both full CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM recorded intermediate dry shoot weight at 11 WAP for 2021 (Fig. 3a). In 2022, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM recorded the heaviest dry shoot weight from 9 to 11 WAP whilst full NPK recorded the least dry shoot weight (Fig. 3b). There was a significant different between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and full NPK, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and full CM, control and full NPK and also between $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM and full NPK.

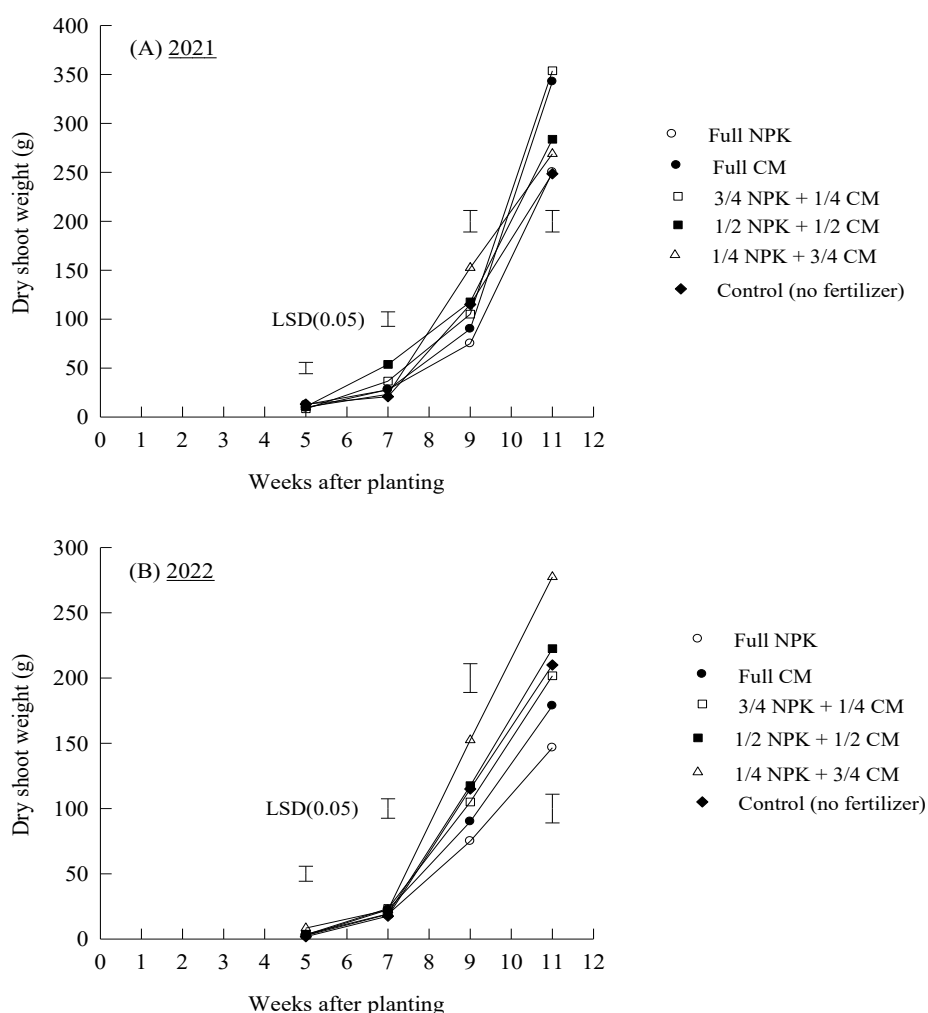


Fig. 3. Effect of integrated nutrient management on the dry shoot weight of carrot in 2021 and 2022

3.2.4 Dry root weight

In the 2021, all the treatments performed similarly until the 11th week where $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM recorded the heaviest dry root weight while $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM recorded the least dry root weight. The rest of the treatments recorded intermediate dry root weight. There was a significant difference between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM (Fig. 4a). There was no significant difference between full NPK, full CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and control at 11 WAP (Fig. 4a). In the 2022, the treatments performed similarly until 9th week where they started to perform differently. The $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM recorded the heaviest dry root weight which differed significantly from full NPK with the smallest dry root weight from 9 to 11 WAP (Fig. 4b). There was a significant difference between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, full CM, control and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM. The control and full NPK did not differ significantly from in dry root weight (Fig. 4b).

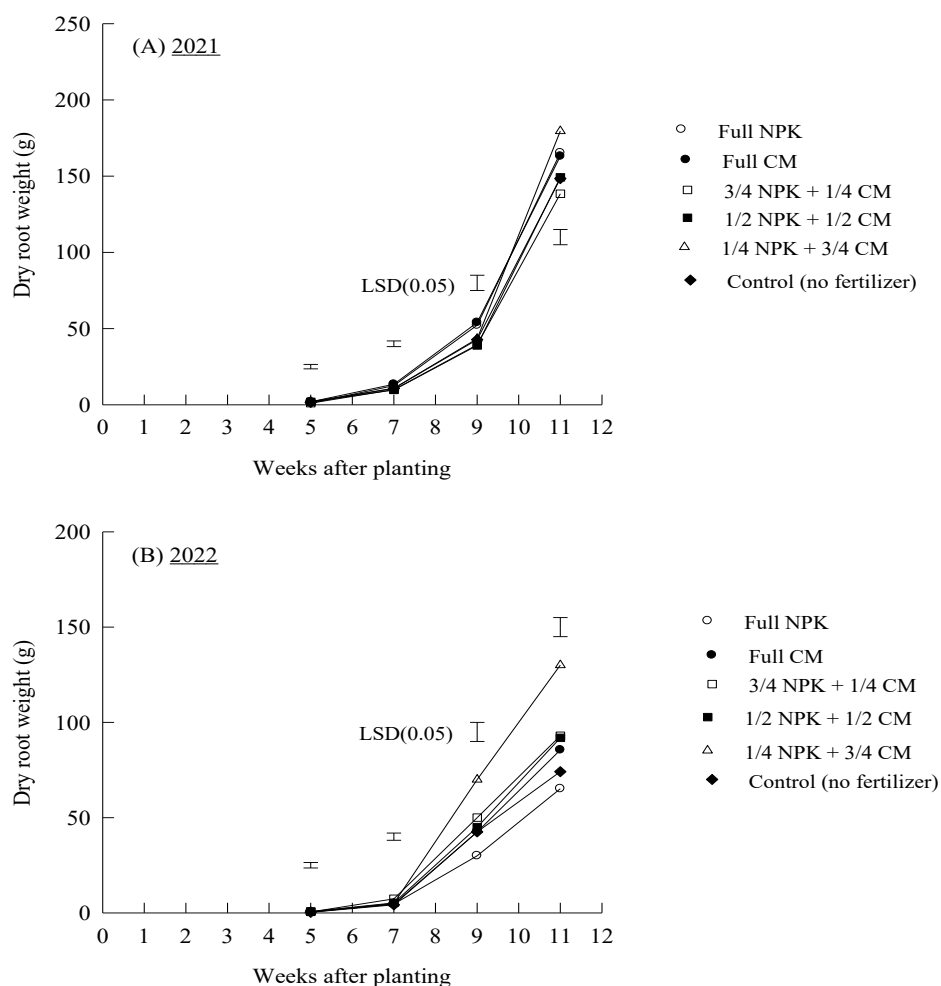


Fig 4. Effects of integrated nutrient management on the dry root weight of carrots in 2021 and 2022

3.3 Yield and Yield Components

3.3.1 Number of plants harvested

The effect of chicken manure (CM) and NPK on the number of plants harvested is presented in Table 4. In 2021, the $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatment produced the highest number of harvested plants (29.85), which was significantly greater than the lowest mean (22.50) recorded under full NPK. Both full CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM recorded 26.25 plants harvested and did not differ significantly ($P > 0.05$) from the highest value obtained under $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. In 2022, however, treatments had no significant ($P > 0.05$) effect on the number of harvested plants. Full CM produced the highest value, whereas full NPK recorded the lowest. Overall, more plants were harvested in 2022 compared to 2021, and a significant fertilizer \times season interaction ($P < 0.05$) was observed.

3.3.2 Number of marketable roots per plot

In 2021, the $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM treatment produced the highest number of marketable roots, which was significantly ($P < 0.05$) greater than the control and full NPK, both of which recorded the lowest values (Table 4). No significant ($P > 0.05$) differences were observed among full NPK, full CM, control, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. In 2022, treatments did not differ significantly ($P > 0.05$) in the number of marketable roots. However, full CM and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM recorded the highest mean (30 roots per plot), while full NPK produced the lowest (27 roots per plot). Significantly higher number of marketable roots per plots were recorded in 2022 than in 2021. Fertilizer \times season interaction had a significant effect ($P < 0.05$) on the number of marketable roots per plot.

Table 4. Effects of integrated nutrient management on number of plants harvested and the number of marketable roots per plot for 2021 and 2022

Treatment	Number of plants harvested			Number of marketable roots		
	2021	2022	Mean	2021	2022	Mean
Full NPK	22.50	34.00	28.25	11.25	27.00	19.13
Full CM	26.25	38.25	32.25	15.50	30.75	23.13
$\frac{3}{4}$ NPK + $\frac{1}{4}$ CM	26.25	36.75	31.5	13.00	29.75	21.38
$\frac{1}{2}$ NPK + $\frac{1}{2}$ CM	25.00	36.50	30.75	16.75	30.00	23.38
$\frac{1}{4}$ NPK + $\frac{3}{4}$ CM	29.85	36.00	32.93	14.75	29.75	22.25
No fertilizer (Control)	23.25	35.75	29.5	11.25	28.00	19.63
Mean	25.52	36.21		13.75	29.21	
CV (%)	17.74			22.55		
Fertilizer	LSD(0.05)=5.56, p=0.5877			LSD(0.05)=4.93, p=0.3874		
Year	LSD(0.05)=3.21 p <0.0001			LSD(0.05)=2.84, p <0.0001		
Fert x Year	LSD(0.05)=7.86, p =0.9140			LSD(0.05)=9.85, p =0.9799		

3.3.3 Number of non-marketable roots per plot

In 2021, the treatments significantly ($P < 0.05$) influenced the number of non-marketable roots per plot (Table 5). The highest value was recorded under $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, while the lowest was recorded by $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM. A significant difference ($P < 0.05$) was observed between $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, whereas the remaining treatments did not differ significantly. In 2022, treatment effects were not significant ($P > 0.05$); however, full CM produced the highest number of non-marketable roots, while $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM recorded the lowest (Table 5). Overall, more non-marketable roots were harvested in 2021 compared to 2022, and the fertilizer \times season interaction was significant.

3.3.4 Root length

Root length differed significantly ($P < 0.05$) among treatments in both 2021 and 2022. In 2021, full CM produced the longest roots, which were significantly longer than all other treatments, while $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM recorded the shortest root length. The remaining treatments (full NPK, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, and the control) showed intermediate values and did not differ significantly ($P > 0.05$) from each other or from $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM (Table 5). In 2022, the longest roots were obtained under $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, which differed significantly ($P < 0.05$) from all other treatments except $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM. The shortest root lengths were recorded under $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM and full NPK. Overall, root lengths in 2022 were significantly greater than those observed in 2021, and the fertilizer \times season interaction had a significant effect ($P < 0.05$) on root length.

Table 5. Effects of integrated nutrient management on number of unmarketable roots per plot and root length for 2021 and 2022

Treatment	Number of non-marketable roots			Root length (cm)		
	2021	2022	Mean	2021	2022	Mean
Full NPK	11.25	7.00	9.13	14.88	19.96	17.42
Full CM	10.75	7.50	9.13	17.02	20.12	18.57
$\frac{3}{4}$ NPK + $\frac{1}{4}$ CM	13.25	7.00	10.13	15.61	19.74	17.68
$\frac{1}{2}$ NPK + $\frac{1}{2}$ CM	8.25	6.00	7.13	14.65	22.12	18.39
$\frac{1}{4}$ NPK + $\frac{3}{4}$ CM	14.50	6.25	10.38	14.89	21.14	18.02
No fertilizer (Control)	12.00	6.25	9.13	15.35	20.31	17.83
Mean	11.66	6.67		15.40	20.57	
CV (%)	41.22			11.15		
Fertilizer	LSD(0.05)=3.99, p =0.5858			LSD(0.05)=2.04, p=0.8434		
Year	LSD(0.05)=2.25, p =0.0001			LSD(0.05)=1.2, p<0.0001		
Fert x Year	LSD(0.05)=5.51, p =0.6705			LSD(0.05)=2.89, p=0.3235		

3.3.5 Root diameter

The effect of chicken manure (CM) and NPK on root diameter is presented in Table 6. Treatments significantly ($P < 0.05$) influenced root diameter in both 2021 and 2022. In 2021, full CM produced the widest root diameter, while full NPK recorded the smallest. Both $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and the control recorded a diameter of 3.25 cm, which did not differ significantly ($P > 0.05$) from full NPK, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, but were significantly lower than full CM. In 2022, the widest root diameter was obtained under $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, which was significantly ($P < 0.05$) greater than the control that recorded the lowest value. The remaining treatments produced intermediate diameters, with no significant differences observed among full NPK, full CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and the control. Overall, root diameters were significantly wider in 2022 compared to 2021, and the fertilizer \times season interaction had a significant effect. The widest diameter was recorded under $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM in 2022, whereas the narrowest was observed under full NPK in 2021. Significantly wider diameters were recorded in the 2022 than in 2021. Fertilizer \times year interaction significantly influence root diameter.

3.3.6 Total root yield

The effect of chicken manure (CM) and NPK on total root yield is presented in Table 6. Treatments significantly ($P < 0.05$) influenced total root yield in both 2021 and 2022. In 2021, full CM produced the highest yield, while the control recorded the lowest. Full CM differed significantly ($P < 0.05$) from all other treatments except $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM. Yields under full CM were about four times greater than those of the control, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and full NPK, and approximately twice as high as those of $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM. In 2022, the highest total root yield was obtained with $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, which was significantly greater than the control that recorded the lowest yield. Significant ($P < 0.05$) differences were observed among $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, full CM, full NPK, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and the control. Overall, yields in 2022 were significantly higher than in 2021, although the fertilizer \times season interaction had no significant effect on total root yield.

Table 6. Effects of integrated nutrient management on root diameter and total root yield in 2021 and 2022

Treatment	Root diameter (cm)			Total root yield at harvest (t/ha)		
	2021	2022	Mean	2021	2022	Mean
Full NPK	2.99	3.91	3.45	10.17	13.90	12.04
Full CM	3.65	3.81	3.73	13.06	14.06	13.56
¼ NPK + ¼ CM	3.35	4.15	3.75	10.09	13.59	11.84
½ NPK + ½ CM	3.12	3.77	3.45	11.34	13.43	12.39
¼ NPK + ¾ CM	3.25	4.89	4.07	11.03	14.37	12.70
No fertilizer (Control)	3.25	3.61	3.43	9.93	11.95	10.94
Mean	3.27	4.02		10.93	13.55	
CV (%)	10.77			23.98		
Fertilizer	LSD(0.05)=0.40, p=0.0147			LSD(0.05)=1.89, p=0.1424		
Year	LSD(0.05)=0.23, p<0.0001			LSD(0.05)=1.09, p <0.0001		
Fert x Year	LSD(0.05)=0.56, p=0.0123			LSD(0.05)=84.5, p =0.6469		

3.4 Correlation matrix analysis

Correlation analysis was conducted to determine the relationship between total root yield and other agronomic traits. The results showed that total root yield had a negative, highly and significant correlation with dry root weight ($r = -0.64$, $p < 0.001$) (Table 7). In contrast, root yield exhibited strong positive and significant correlations with root diameter ($r = 0.65$, $p < 0.0001$), root length ($r = 0.74$, $p < 0.0001$), and number of plants harvested ($r = 0.77$, $p < 0.0001$). The strongest association was observed between total root yield and number of marketable roots ($r = 0.89$, $p < 0.0001$). Conversely, total root yield was negatively and significantly correlated with the number of non-marketable roots ($r = -0.56$, $p < 0.0001$) (Table 7).

Table 7. Combined correlation matrix analysis between vegetative and yield and yield components of carrot

	1	2	3	4	5	6	7
1. Number of plants harvested	1	0.89 P<0.0001	-0.16 P=0.281	0.44 P=0.0016	0.50 P=0.003	-0.40 P=0.0043	-0.16 P=0.281
2. Number of marketable roots		1	0.60 P<0.0001	0.59 P<0.0001	0.61 P<0.0001	-0.56 P<0.0001	0.89 P<0.0001
3. Number of non-marketable roots			1	-0.50 P=0.0003	-0.42 P=0.0029	0.50 p=0.0003	-0.56 P<0.0001
4. Root length				1	0.64 P<0.0001	-0.55 P<0.0001	-0.50 P=0.0001
5. Root diameter					1	-0.80 P=0.2319	0.65 P<0.0001
6. Dry root weight						1	-0.56 P<0.0001
7. Total root yield							1

NB: Numbers in the horizontal columns correspond with the numbers and variables in the vertical columns.

4. Discussion

4.1 Plant growth parameters

The results of this study showed that the integrated nutrient management had a significant effect on the growth and yield of carrot plants. However, the superior plant height and canopy widths observed with full CM and full NPK from 9- 11 WAP for 2021 and 2022, respectively compared to the control can be attributed to their ability to supply macronutrients (N, P and K) needed for healthy growth and development of plants. Chicken manure also serves as a rich source of beneficial microorganisms which, together with native soil microbes, enhance nutrient release by improving soil porosity and facilitating the infiltration of nutrients essential for healthy carrot growth (Djoufack *et al.*, 2025). The ability of chicken manure to conserve soil moisture might have increased nutrient solubility and uptake by the carrot roots and subsequently influencing the height and canopy width. The results of this study are similar to the previous work done by Amartei *et al.* (2022), who reported full PM and integrated nutrient management $\frac{1}{2}$ CD + $\frac{1}{2}$ PM recorded the tallest carrot plant and widest canopy width. The control recorded the shortest plant height for 2021 and 2022, presumably because of insufficient amount of essential nutrients in the soil to sustain the healthy growth and development of the carrot.

The full CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM recorded the heaviest dry shoot weight at 11 WAP for 2021, while $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM recorded the largest dry shoot weight at 11 WAP for 2022. These results might be attributed to the slow release of nutrients by organic manure which made more nutrients available to the plant for uptake leading to higher accumulation of assimilate at the shoot at the vegetative growth stage. This may be attributed to the fact that, while the inorganic fertilizer supplied essential nutrients for proper growth development, the chicken manure complemented it by providing additional elements, including growth-promoting factors, that supported overall plant growth (Djoufack *et al.*, 2025). The tendency of the CM to improve the physical and chemical properties of soil such as pH, exchangeable acidity and bases, water holding capacity, bulk density, and organic matter content might have created favourable micro-climatic conditions for plant growth. The significantly higher dry root weight recorded by $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM from 9 - 11 WAP across both years might be as a result of higher rate of nutrient availability and decrease in nutrient loss by the combined application of NPK and CM. These results are in accordance with the previous work done by (Kiran *et al.*, 2022) who reported that NPK + poultry manure produced the highest biomass per plant for carrot.

4.2 Yield and yield components

The significantly higher number of plants harvested recorded by $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM as compared to full NPK in 2021 might be due to high nutrient availability and absorption by plants as a result of integrated nutrient management of inorganic and organic fertilizers. This combination might have improved photosynthesis rate in the source (leaves) and might have also increased the survival rate of plants till harvesting. Full NPK recording the lowest number of plants harvested in both years might be due to insufficient nutrient availability at the vegetative stage of the plant because inorganic fertilizers are readily available to plants once applied and the nutrient might have been used up at seedling and vegetative stages. According to Ano and Ekefan (2023), while chemical fertilizers supply readily available nutrients, a considerable portion can be lost through leaching caused by rainfall, thereby reducing nutrient uptake efficiency. Moreover, their use may decrease soil porosity and promote compaction, which can negatively affect carrot growth.

The application of $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM in 2021 and full CM in 2022 produced the highest number of marketable roots as compared to full NPK. Again, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM produced the least number of non-marketable roots across both seasons. This might be attributed to improved nutrient availability and uptake, which enhanced photosynthetic activity in the leaves and facilitated efficient assimilate translocation to the roots. These conditions favoured the development of healthy, well-formed roots. Again, the reduced microbial competition for nutrients under combined NPK and chicken manure application could have led higher number of marketable roots. These results are consistent with the findings of Adeleye *et al.* (2024), who reported that the integration of 300 kg/ha NPK with 10 t/ha poultry manure (PM) consistently increased the number of marketable roots. The full CM recording the highest number of non-marketable roots might be due to higher nematode infestation rate which affected the quality of the root due to increased activities of microorganisms

as a result of high levels of applications of CM in both years and high amount of rainfall in 2022.

Carrot root length and diameter are important criterions contributing to yield. In 2021, full CM recorded the widest root diameter and longest root length while $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM recorded the least root diameter and length. In 2022, combination of $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM produced the largest root diameter and length, respectively, while the control and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM had the least root diameter and length. The superior root diameter and length observed under full CM, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM across both seasons can be attributed to the higher nutrient availability derived from full CM and its combined application with NPK fertilizer. These results may also be linked to improvements in soil physicochemical properties, such as enhanced structure, porosity, and cation exchange capacity, induced by organic manure and the readily available nutrients supplied by inorganic fertilizer during the initial growth stages (Ma *et al.*, 2023). Furthermore, the greater nutrient retention is likely due to the binding effect of organic matter, which minimizes nutrient losses and ensures a more sustained supply for carrot growth and development. This might have increased vegetative growth of plants (leaves), photosynthesis rate and translocation of assimilate from the leaves to the roots. These findings support previous research indicating that combining chicken manure with mineral fertilizer enhances plant growth more effectively than applying either fertilizer alone (Ning *et al.*, 2022). The results are similar to the previous report by Sah *et al.* (2020) and Poku *et al.* (2020).

This study has shown that the highest total root yield was obtained after using full CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. This could be attributed to higher concentrations of essential nutrients (micro and macronutrients) supplied by full CM and its combined application with NPK which might have improved vegetative growth of plant (leaves), photosynthesis rate of source (leaves) and translocation of assimilate from the source to the sink (roots). The high nitrogen content in chicken manure, as a fundamental component of chlorophyll and amino acids, likely enhanced photosynthetic activity and protein synthesis. This improvement in photosynthesis facilitated greater assimilation and translocation of photosynthates to the roots, thereby contributing to increased root biomass and overall yield (Dawuda *et al.*, 2019). The results are similar to the findings of Deekermue *et al.* (2024) and Djoufack *et al.* (2025) in carrots. The lowest total root yield produced by control (no fertilizer) might be due to low concentration of essential nutrients in the soil which affected the photosynthesis and translocation rate of plants and led to poor yield of total root weight.

4.3 Correlation matrix analysis

The correlation analysis indicated that carrot yield was strongly and positively associated with root diameter, root length, number of plants harvested, and particularly the number of marketable roots, which showed the highest correlation with total yield ($r = 0.89$, $p < 0.0001$). This finding suggests that these traits are critical yield components in carrot production. This is consistent with Meghashree *et al.* (2018), who identified marketable root number and root size traits as the most reliable predictors of carrot yield. Similarly, Wilkinson *et al.* (2020) found a significant positive correlation between plant height and various vegetative and yield components in sweet potato. In contrast, the negative correlations of yield with dry root weight at 11 WAP and the number of non-marketable roots suggest that early root desiccation and deformities adversely affect productivity.

5. Conclusion

The study demonstrated that carrot vegetative growth parameters, including plant height and canopy width, were significantly enhanced by the application of full chicken manure (CM) and full NPK compared to the control. Hence, the use of full CM and full NPK during the minor and major cropping seasons, respectively, is recommended for optimum vegetative development. Similarly, dry shoot and root weights were maximized under full CM, full NPK, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, indicating the importance of both sole and integrated nutrient applications for balanced growth. The highest improvements in yield-related traits such as number of plants harvested, root diameter, root length, number of marketable roots, and total root yield were achieved with full CM, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM. Therefore, integrating CM with NPK ($\frac{1}{4}$ NPK + $\frac{3}{4}$ CM), alongside full CM application, is strongly recommended to farmers as a sustainable strategy for achieving optimal carrot growth and yield.

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