

**AKENTEN APPIAH-MENKA UNIVERSITY OF
SKILLS TRAINING AND ENTREPRENEURIAL
DEVELOPMENT**

**EFFECTS OF INTEGRATED NUTRIENT MANAGEMENT ON
GROWTH, YIELD AND NUTRITIONAL QUALITY OF
CARROTS (*Daucus carota* L.)**

**FRANCIS AGYAPONG
MASTER OF PHILOSOPHY CROP SCIENCE (AGRONOMY)**

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**BY
FRANCIS AGYAPONG
(8201970016)**

**A THESIS IN THE DEPARTMENT OF CROP AND SOIL SCIENCES
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THE REQUIREMENTS FOR THE AWARD OF DEGREE OF MASTER OF
PHILOSOPHY CROP SCIENCE (AGRONOMY)**

MAY, 2025

DECLARATION

Candidate's declaration

I hereby declare that this thesis, with the exception of quotations and references contained in published works which have been duly acknowledged; is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Name: Francis Agyapong

Signature:

Date:

Supervisors' Declaration

We hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of thesis as laid down by the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development.

Prof. Harrison Kwame Dapaah (Principal Supervisor)

Signature:

Date:

Rev. Kwame Nkrumah Hope (Co-Supervisor)

Signature:

Date:

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DEDICATION

This work is dedicated to my lovely, caring late mother Madam Afia Kwaago.

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ABSTRACT

Two experiments were conducted from September to December 2021 and from April to July 2022 at the Multipurpose Crop Nursery Field of Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED), Mampong Campus. The objective was to assess the effects of combining inorganic fertilizer with chicken manure on the growth, yield, nutritional qualities, and profitability of carrot production. The study was conducted using a Randomized Complete Block Design (RCBD) with six treatment options, each replicated four times. The treatments included: (i) 300 kg/ha of NPK (15-15-15) fertilizer (Full NPK), (ii) 20 t/ha of poultry manure (Full PM), (iii) 225 kg/ha NPK combined with 5 t/ha PM ($\frac{3}{4}$ NPK + $\frac{1}{4}$ PM), (iv) 150 kg/ha NPK plus 10 t/ha PM ($\frac{1}{2}$ NPK + $\frac{1}{2}$ PM), (v) 75 kg/ha NPK with 15 t/ha PM ($\frac{1}{4}$ NPK + $\frac{3}{4}$ PM), (vi) Control treatment with no fertilizer applied. The results showed that vegetative growth parameters of the carrots such as plant height, canopy width, and number of leaves per plant were significantly improved with the application of full chicken manure (CM) and full NPK compared to the control. Additionally, dry shoot weight, fresh root weight, and dry root weight were higher in treatments with full CM, full NPK, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM than in the control group. Application of full chicken manure (CM), $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM resulted in increased root diameter, root length, number of plants harvested, number of marketable roots, and total root yield compared to the control. Root yield in these treatments was 14–41% higher than that of the control. The nutritional qualities of carrots including crude protein, iron, calcium, reducing sugars, total oxalates, total carotenoids, carbohydrates, and moisture content were generally higher in treatments with full chicken manure (CM) and full NPK compared to the control. The economic analysis revealed that applying 20 t/ha of poultry manure (PM) was the most profitable option in 2021, yielding the highest benefit-cost ratio (2.56) and marginal rate of return (MRR) of 641.57%. In 2022, the combination of 75 kg/ha NPK + 15 t/ha PM proved more profitable, recording the highest MRR of 708.44%. During the minor season, 20 t/ha PM produced the highest yield (4.06 t/ha), along with the best benefit-cost ratio and MRR, and is therefore recommended to farmers for improved yield and profitability in carrot production during that season. In contrast, the application of 75 kg/ha NPK combined with 15 t/ha poultry manure resulted in the highest yield (14.37 t/ha) and marginal rate of return (MRR) of 708.44% during the major season. This treatment is therefore recommended for farmers to adopt in order to achieve higher yields and increased profitability in carrot production during the major season.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Carrot (*Daucus carota* L.) is a widely cultivated herbaceous root vegetable belonging to the Apiaceae family. It is classified as a cool-season crop, primarily grown for its edible taproot, and is best suited to temperate climates (Rubatzky *et al.*, 1999). Globally, China is the largest producer, contributing over 21 million metric tonnes, which accounts for approximately 55% of total world production. In Africa, Algeria leads in carrot production, yielding around 420,000 metric tonnes (FAOSTAT, 2019). In Ghana, carrot is a significant vegetable crop cultivated by many small-scale farmers for both household consumption and commercial purposes. The Mampong Municipality is known as one of the leading carrot-producing areas in the country. Carrot is highly prized for its nutritional value and is commonly incorporated 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, manganese, etc. Additionally, carrots are relatively low in calories with 128grams of raw carrots producing only 52 calories (Kubala, 2019).

However, purple-coloured carrots are nutritionally unique because of their high content of antioxidants called anthocyanin. Purple carrots contain between 93–168 mg/100g of anthocyanins, primarily in the forms of cyanidin acylated with ferulic and coumaric acids (Assous *et al.*, 2014). Carotene, extracted from carrot roots, is commonly used to colour margarine and enhance egg yolk pigmentation when included in poultry feed. Additionally, the mature leaves and roots are also used in the formulation of animal feed (Kahahgi, 2004). Consumer demand for carrots remains high, particularly in urban areas, and the crop's export potential has been acknowledged by the Ministry of Food and Agriculture since 2002 (MoFA, 2000).

1.2 Problem Statement and Justification

Several studies on carrot production have demonstrated that applying either full doses of inorganic fertilizers or organic manures like poultry manure, cow dung, or compost can significantly improve growth, yield, and quality. Dawuda *et al.* (2011) recommended applying 70–120 kg/ha of nitrogen, 30–35 kg/ha of phosphorus, and 0–55 kg/ha of potassium to achieve high carrot yields. Similarly, Norman (1992) recommended the application of 300-450 kg/ha of NPK (15:15:15) before planting to enhance growth and yield in Ghana. Kahangi (2004) recommended applying 10–20 t/ha of poultry manure to enhance carrot growth and yield in tropical regions. 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.

Similarly, the bulky nature of organic manure, its high transportation cost, and the difficulty farmers' face in sourcing sufficient quantities for large-scale carrot production have necessitated this research. The study aims to evaluate the combined application of organic and inorganic fertilizers in carrot production. Specifically, the study seeks to identify the optimal combination of poultry manure and NPK (15:15:15) fertilizer that enhances carrot growth and yield in Ghana. Furthermore, the research will offer insights to farmers on how supplementing inorganic fertilizers with organic manure can help reduce the overall cost of fertilizer use in carrot production.

1.3 Objectives of the Study

1.3.1 Main Objective

The main objective of the study was to assess the effect of combining inorganic fertilizer with organic manure specifically chicken manure for carrot production.

1.3.2 Specific Objectives

The specific objectives of the study were to;

- a. Assess the effect of integrating inorganic fertilizer and organic manure on the growth of carrots.
- b. Assess the effects of combining inorganic fertilizer and organic manure on the yield and yield components of carrot.
- c. Examine how the integration of inorganic fertilizers and organic manure affects the nutritional quality of carrots.
- d. Assess the profitability of integrating inorganic fertilizer and organic manure in carrot production.

CHAPTER TWO: LITERATURE REVIEW

2.1 Origin and Distribution of Carrot

Cultivated carrot is one of the most significant root vegetables grown globally and ranks third among the world's succulent vegetables (Yamaguchi, 1983). It originated from the wild carrot, which initially had white roots. The wild carrot (*Daucus carota*), also known as Queen Anne's lace, is native to Eurasia. Domestication of carrot is believed to have occurred in Central Asia around 1000 AD. The transformation of wild ancestors through human selection during domestication laid the groundwork for modern agriculture (Zohary & Hopf, 2000; Gleumin & Bataillon, 2009). Banga (1963) noted that the earliest domesticated carrots around 900 AD in Central Asia were purple and yellow in color. Archaeological findings of prehistoric carrot seeds suggest that the plant was initially used for medicinal purposes or as a spice before its roots were cultivated for consumption (Andrews, 1949; Brothwell & Brothwell, 1969).

The orange-rooted carrot is currently the most widely cultivated carrot variety across the world. According to Lorizzo et al. (2016), these orange carrots originated from yellow-rooted domesticated types. Historical records suggest that orange carrots first appeared in Spain and Germany during the 15th century and quickly became the dominant variety (Stolarczyk & Janick, 2011). Their popularity was attributed to their sweeter taste and the fact that they did not stain cooking utensils or water, unlike the purple varieties.

White-rooted carrots, often used as animal feed, still exist today. Vavilov and Dorofeev (1992) identified Asia Minor and the inner Asiatic regions as the primary centers of cultivated carrot origin. Stolarczyk and Janick (2011) further noted that Afghanistan was the primary center of carrot diversity, followed by Turkey. The earliest known cultivation

of carrots for their storage roots is believed to have taken place in the Afghanistan region around 1,100 years ago (Mackevic, 1929). Supporting this, Lorizzo et al. (2013) provided molecular evidence indicating Central Asia as the origin of domesticated carrots. Their study used single nucleotide polymorphisms (SNPs) to examine the genetic structure and evolutionary relationships between wild and cultivated carrots, revealing a clear genetic distinction between the two groups. Combining historical accounts with molecular findings, Central Asia is widely accepted as the center of carrot domestication.

2.2 Botany of Carrot

Carrot (*Daucus carota*) is a significant vegetable, ranked third among succulent vegetables worldwide (Yamaguchi, 1983). In Ghana, carrot is regarded as an exotic vegetable with high value and strong demand in urban markets, and it also holds potential as an export crop (MoFA, 2002). Carrot (*Daucus carota* L.) is a biennial herbaceous plant belonging to the Apiaceae family. In tropical regions, it is typically grown as an annual crop for its edible, fleshy roots (De Lannoy, 2001). During the first year, the plant develops leaves that can grow up to 50 cm tall, while in the second year, it produces flowers and stems, reaching a final height of 120 to 150 cm.

However, in some cases, the stem may develop during the first year. This typically happens when the fleshy roots exceed a diameter of 0.5 cm, the stem has prematurely developed at least eight leaves, and the plant has been exposed to cooler winter temperatures for approximately two months. Low temperatures are known to trigger floral induction in woody plants, frequently leading to a reduction in vegetative growth (Jackson and Sweet, 1972). For instance, floral induction in sweet orange has been triggered by exposure to low temperatures (Moss, 1969). This process of exposing carrots to cold

temperatures is referred to as vernalization. Vernalization plays a crucial role in the induction of flowering and subsequent seed production in plants. The requirement for vernalization is closely linked to the cultivation zone. In temperate regions, plants need exposure to low temperatures ranging from 0 to 10 °C for approximately two months. In contrast, in tropical and subtropical areas, the upper temperature limit for vernalization is around 15 °C, and the required duration is shorter. Carrot leaves develop one per node along the stem and are characterized as long, compound, finely divided, oblong, and dimorphic. The lower leaves are significantly larger, more elongated, deeply lobed, and may be either toothed or smooth, whereas the upper leaves are smaller and less dissected. During the first year, the leaves form a characteristic rosette, while in the second year, they grow alternately along the flowering stem. Leaf color in cultivated carrots ranges from grey-green to deep green.

The anatomical development of carrot roots has been detailed by Esau (1940). The carrot's taproot system originates from the hypocotyl, with secondary lateral roots emerging from the xylem. The root color varies, presenting as orange, violet, white, or yellow, depending on the pigments present. Typically, carrot roots exhibit a cylindrical shape with either blunt or pointed tips (Banga, 1963; Simon *et al.*, 2008).

2.3 Varieties of Carrots

Carrot varieties are categorized based on two main factors: their temperature response for flowering and the shape of their roots. Regarding temperature requirements for flowering, carrots are divided into two groups: (i) temperate or European varieties, and (ii) Asiatic or tropical varieties. In terms of root shape, carrot varieties fall into three categories: (i) long-rooted, (ii) short stump-rooted, and (iii) half-long rooted. European carrot varieties, for

instance, share a set of common characteristics within these classifications. The temperate or European carrot varieties are characterized by the following features:

- (i) They are biennial crops that require exposure to low temperatures (4–10 °C) for floral induction.
- (ii) They typically produce long, red-colored roots with white or creamy cores.
- (iii) These varieties are rich in lycopene, a valuable antioxidant.
- (iv) They generally do not produce seeds in tropical regions or plains without vernalization.

Common examples of temperate carrot varieties include Pusa Yamdagini, Jeno, Emperor, Chantenay, Danvers, Early Nantes, Nantes, Nantes Half Long, Ooty, and Solan Rachna.

Nantes: It is a European carrot variety grown mainly for its root production. It only produces seeds after undergoing vernalization, which involves exposure to low temperatures. The roots are moderately long, slim, and uniformly cylindrical with a blunt end and a small, thin tail. They have a deep orange colour with a red cortex and are best suited for cultivation during cooler months.

Chantenay: This is a well-regarded European carrot variety known for its suitability for canning and storage. The roots are 11–15 cm long with a diameter of 3–5 cm, tapering to a blunt end. They have a deep orange cortex and core. Notable examples include Royal Chantenay and Red Cored Chantenay.

Pusa Yamdagini: Developed from a cross between EC 9981 and Nantes Half Long, this variety takes approximately 86–130 days to produce harvestable, long, orange-coloured roots.

Solan Rachna: This variety features attractive, round roots with medium-sized tops. The roots are orange-coloured, medium in length (18–21 cm), and soft in texture. It matures within 100–108 days and yields an average of 225–250 q/ha. The roots are rich in carotene, containing 15.14 mg per 100 g of edible portion.

Long-rooted varieties: These carrot roots typically grow to 25 cm or more in length and are generally tapering. They perform best in comparatively light soils.

Half-long rooted varieties: The root length of these varieties usually does not exceed 20 cm. The roots are cylindrical in shape with straight or sloping shoulders, as seen in varieties like Nantes. Others, such as Chantenay and Emperor, have blunt or semi-blunt tips.

Short stump-rooted varieties: These are well-suited for cultivation in heavy soils. Examples include Oxheart, which is heart-shaped; Early Scarlet Horn, which is oval-shaped; and French Forcing, which has a round shape.

2.4 Soil and Climatic Requirements

For optimal carrot growth and yield, the top 75 cm of soil should be uniform and free from obstructions such as stones and debris that can hinder root development. Carrots thrive best in loose, well-structured soils rich in organic matter. They do not perform well in highly acidic conditions or soils excessively high in nitrogen. While carrots are often cultivated in sandy soils, silt loam is considered ideal due to its excellent water-holding capacity and drainage properties. Well-drained sandy loam soils also tend to produce straighter and more uniform roots. In contrast, heavy soils containing rocks or compacted layers often lead to short, forked, or misshapen roots. Although carrots can grow in both

acidic and alkaline soils, they prefer neutral to slightly acidic conditions, with an optimal pH range of 5.5 to 7.0.

Carrot is primarily a cool-season crop but can also perform well in warmer climates. The optimal temperature range for carrot growth is between 15°C and 20°C, which also promotes the development of desirable root color and flavor (Gardner *et al.*, 1985). Carrots need a consistent water supply throughout their growing period. On average, they require about 25 mm of water per week, though this may increase to 50 mm under hot and dry conditions. Inadequate water can lead to the development of long, thin roots, malformed or woody-textured carrots, and cracked roots. On the other hand, excessive watering may result in short, thick roots, pale coloration, and an increased risk of root rot or fungal infections (Richard, 2008).

2.5 Nutritional Values of Carrots

Carrots are highly nutritious and widely consumed as part of the human diet. Among thirty-nine fruits and vegetables, carrots rank tenth in nutritional value (Alasalvar *et al.*, 2001). Carrot roots can be eaten raw in salads or cooked and processed in stews and soups (Anjum & Amjad, 2002). The increasing popularity of orange-rooted carrots is largely due to their high provitamin A content (Dias, 2012). Carrots are rich in carotenoids and anthocyanins, which are key antioxidants present in the roots. The black or purple color in certain carrot varieties is attributed to anthocyanins, which are recognized for their antioxidant properties (Chrong *et al.*, 2007). Carotenoids, found predominantly in yellow and orange-fleshed carrots, include alpha- and beta-carotene, which are significant sources of provitamin A. A study conducted in five European countries found that carrots

accounted for 60% to 90% of the total dietary β -carotene intake in humans (Maiani *et al.*,2009).

Moreover, carrots are rich in carbohydrates, proteins, and various vitamins. Their nutritional composition includes: carbohydrates (9.58 g/100 g), protein (0.93 g/100 g), total sugars (4.74 g/100 g) comprising sucrose (3.59 g), glucose (0.59 g), and fructose (0.55 g). They also contain vitamin C (5.9 mg/100 g), vitamin B1 (0.07 mg), B2 (0.06 mg), B3 (0.93 mg), B6 (0.138 mg), and vitamin E (0.66 mg) (USDA, 2012). Carrots are also a rich source of lutein, a carotenoid responsible for pigmentation in plants. Yellow-rooted carrot varieties, in particular, have high lutein content. Lutein plays a vital role in preventing macular degeneration, an age-related eye condition that affects the macula and leads to blurred central vision (Dias, 2012).

Additionally, carrots especially red-coloured varieties are high in lycopene, a powerful antioxidant. Red carrot roots have been reported to contain lycopene concentrations as high as 10 mg/100 g, which is even greater than that found in tomatoes (Grassmann *et al.*,2007). Carrots also serve as good sources of dietary fiber and essential minerals such as molybdenum, magnesium, manganese, and potassium. According to Khanum *et al.* (2000), fresh carrots contain approximately 1.65% soluble dietary fiber and 4.1% insoluble fiber. Magnesium is essential for bone development, protein synthesis, new cell formation, muscle and nerve function, blood clotting, and energy production (Guerrera *et al.*,2009). It also supports insulin secretion and function (Bartlett & Eperjesi, 2008). Potassium and magnesium contribute to healthy muscle function.

2.6 Effects of Organic Manure on Growth and Yield of Carrots

Organic manures are naturally derived materials applied by farmers to supply essential nutrients to crops. These include various types such as farmyard manure, green manure, compost made from crop residues and farm waste, vermicompost, oil cakes, and biological wastes like animal bones and slaughterhouse by-products. The use of organic manures not only provides nutrients but also improves the physical, chemical, and biological properties of the soil. Additionally, they enhance the soil's moisture retention capacity, leading to increased crop productivity while preserving the quality of the produce (Maheswarappa *et al.*,1999). Organic manures supply essential nutrients, enhance soil structure, increase microbial populations, and help maintain crop quality (Wong *et al.*,1999; Nehra *et al.*,2001; Dauda *et al.*,2008).

While organic manures contain lower nutrient levels than inorganic fertilizers, they play a crucial role in soil fertility and productivity because they supply growth-promoting substances like enzymes and hormones alongside essential nutrients (Bhuma, 2001). Numerous studies have reported that organic manures improve crop growth and yield. For example, Premsekhar and Rajashree (2009) found that applying 20 t/ha of farmyard manure to okra resulted in the highest yield of 10.39 t/ha compared to other treatments. These findings align with those of Nehra *et al.* (2001) and Sanwal *et al.* (2007). The increased yield is attributed to the enhancement of the soil's physical and biological properties, which improves nutrient availability and subsequently promotes better crop growth and productivity. Bio-slurry, the by-product of anaerobic decomposition of organic matter, is considered a high-quality organic fertilizer (Islam, 2006). During anaerobic fermentation, about 25 to 30% of the organic matter is converted into biogas, while the remaining material becomes bio-slurry manure. This residual manure is rich in both

macro- and micronutrients (Isam, 2006; Thu, 2007). Positive yield responses to bio-slurry application have been reported in various vegetable crops such as okra (Shahbaz, 2011), maize, and cabbage (Karki, 2001). In carrot production, the use of decomposed bio-slurry has been shown to enhance growth and yield. Specifically, applying 7.8 t/ha of bio-slurry increased yields by 8.8% in the first season and 23.5% in the second season compared to the control. Additionally, leaf number, plant height, dry weights of shoots and roots, and root volume were generally higher under the 7.8 t/ha treatment. Total soluble solids in carrot roots from this treatment were also greater, increasing by 12.7% in season one and 13.2% in season two compared to the control.

The study recommends 7.8 t/ha of bio-slurry manure for enhanced yield and quality of carrot (Jaetzold and Schmidt, 1983). According to Sylvester *et al.* (2014), application of 10 t/ha chicken manure to carrots improved the growth and yield compared to the control treatment. Sole application of chicken manure at rate 10 t/ha recorded plant height of 43.70 cm and leaf length of 43.46 cm compared to control treatment of plant height 34.12 cm and leaf length of 34.69 cm. The results also indicated that marketable root yield was statistically similar between control (5.6 t/ha) and chicken manure alone (5.7 t/ha). The cost benefit analysis also indicates that sole application of chicken manure performed better than the control. Sole chicken manure recorded 1.75 as against 1.12 for control (Sylvester *et al.*, 2014).

2.7 Effects of Inorganic Fertilizers on Growth and Yield of Carrots

Inorganic fertilizers are chemically synthesized products that supply essential nutrient elements required for crop growth. These fertilizers are industrially produced with precise amounts of key nutrients such as nitrogen, phosphorus, and potassium, but their misuse

can lead to air, water, and soil pollution (Youssef and Eissa, 2014). The majority of chemical fertilizers used in agriculture are NPK formulations, which are rich in nitrogen, phosphorus, and potassium. In addition to these primary nutrients, chemical fertilizers may also provide secondary nutrients like sulfur, magnesium, and calcium to the soil or plants. Common examples of inorganic fertilizers used in crop production include NPK 15:15:15, urea, and ammonium sulfate. The importance of inorganic fertilizers is well documented, as numerous studies have demonstrated their positive impact on crop growth, yield, and quality. Shah and Rajendra (2014) reported that the application of inorganic fertilizer to rice significantly increased growth and yield compared to the control. Plants treated with inorganic fertilizer reached an average height of 84.7 cm at 105 days after planting, compared to 78.7 cm in the control group, representing a 7.09% increase. Similarly, the average number of grains per plant was 610 in the fertilized group, marking a 7.98% increase over the control.

Inorganic fertilizers play a crucial role in crop production, accounting for approximately 50% of total agricultural output in Bangladesh (BARC, 1997). In carrot production, the application of NPK fertilizers also positively influenced yield and yield components. The highest marketable yield was obtained with the application of NPK at rates of 140 kg N, 40 kg P, and 80 kg K per hectare (Hossain, 2005). Urea applied at 200 kg/ha produced the tallest plants, the greatest number of leaves, along with cracked and branched roots, and the highest fresh shoot weight. However, applying nitrogen at 150 kg/ha resulted in the longest root length, largest root diameter, highest fresh root weight, and maximum yield of 53.37 t/ha (Haque, 1999).

However, the indiscriminate use of inorganic fertilizers can negatively impact the soil's physical, chemical, and biological properties, potentially causing environmental issues and health risks due to toxic residues. Sharangi and Paria (1995) reported that NPK fertilizer application increased plant height in carrots. Their results showed that the maximum root length was achieved with the application of 150 kg/ha N, followed by 200 kg/ha N. Similar trends were observed for root diameter, fresh root weight, gross yield, and marketable yield. The highest gross yield (47.35 t/ha) and marketable yield (39.00 t/ha) were recorded at 150 kg/ha N, likely due to the combined positive effects on root length, diameter, and fresh weight. The increases in gross and marketable yields at 150 kg/ha N were 115.9% and 115.3% higher, respectively, compared to 100 kg/ha N.

These findings suggest that applying 150 kg N/ha significantly supports proper root growth and development through optimal nutrient uptake. Similar significant effects of nitrogen levels on carrots were also reported by Polach (1982) and Abdel Razik (1996). The poorest yield performance was observed at 100 kg/ha of nitrogen, as this rate was insufficient to meet the crop's nutrient demands, leading to weak root growth and development. Regarding root characteristics, the highest incidence of branched roots was recorded at 200 kg N/ha, aligning with the observations made by Orphanos and Krentzos (1988). Moreover, the incidence of cracked and rotten roots increased with rising nitrogen levels, a trend similarly reported by Bose and Som (1990).

2.8 Effects of Combination of Organic and Inorganic Fertilizers on Growth and Yield of Carrots

Organic fertilizers release nutrients more slowly than inorganic fertilizers, which helps to prevent the rapid fluctuations in plant growth often associated with synthetic inputs.

Beyond providing nutrients, organic fertilizers improve soil structure, reduce erosion, and are typically more cost-effective than chemical fertilizers (Siavoshi *et al.*,2011). However, research has shown that neither organic nor inorganic fertilizers alone can sustainably boost crop productivity over the long term (Satyanarayana *et al.*,2002). Prolonged use of inorganic fertilizers, particularly nitrogen-based ones, can degrade soil health and may contribute to pest issues by increasing the survival and fitness of certain pest species (Siavoshi *et al.*,2011).

Relying solely on organic fertilizers may not fully meet plant nutrient requirements due to their relatively low nutrient concentrations. However, combining organic fertilizers with chemical fertilizers can enhance microbial activity in the soil, improve nutrient use efficiency (Moharana *et al.*,2012), and increase the availability of nutrients for plant uptake. Integrated fertilizer management, which involves the use of both organic and inorganic fertilizers, has been shown to positively influence the growth and yield of okra. Palm *et al.* (1997) emphasized the importance of integrating both sources as essential for sustainable okra production.

Similarly, Mario *et al.* (1989) reported that applying a combination of organic and inorganic fertilizers improves fruit yield and ensures a more balanced nutrient supply to the crop. Ayoola and Makinde (2007) reported that the combined application of organic and inorganic fertilizers in cowpea production resulted in significantly higher yields compared to the use of either fertilizer type alone. Similarly, Mehedi *et al.* (2012) observed positive effects of integrated fertilizer management involving urea and cow dung on carrot growth and yield. Their results showed that applying 150 kg N/ha combined with 15 t/ha of cow dung resulted in the longest root length of 15.67 cm. The same treatment

also produced the highest fresh root weight of 127.98 g, followed by 118.24 g and 95.31 g from other combinations using similar fertilizer rates. The combined use of inorganic nitrogen fertilizer and organic manure produced the thickest carrot roots, with a maximum diameter of 4.59 cm, followed by 4.39 cm and 4.14 cm from treatments with 150 kg N/ha and 15 t/ha cow dung, respectively. These results align with findings by Prarraga *et al.* (1995), who reported that incorporating organic matter with NPK fertilizers increased root diameter in carrots. The lowest incidences of root defects—branched roots (5.63%), cracked roots (6.72%), and rotten roots (3.13%)—were also recorded under the treatment combining 150 kg N/ha and 15 t/ha cow dung.

Similarly, Sissay *et al.* (2007) observed enhanced carrot growth and yield performance from the combined application of organic and inorganic fertilizers. Yield and yield components were significantly improved by pre-harvest application of both urea and organic amendments. Notably, the combined application of 309 kg/ha “Orga” and 274 kg/ha urea resulted in a 46% increase in carrot yield compared to the control. Increasing rates of combined “Orga” and urea also led to progressive improvements in yield components, with the highest yield achieved at the 309 kg/ha “Orga” + 274 kg/ha urea treatment.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of Experimental Location / Site

The experiments were conducted during the 2021 minor cropping season (September to December) and the 2022 major season (April to July) at the Multipurpose Crop Nursery Research Fields of Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED), located at Mampong in the Ashanti Region of Ghana. Mampong-Ashanti (7°45'N, 1°24'W) is situated at an elevation of 402 meters above sea level within the forest-savannah transition agro-ecological zone. The area experiences a bimodal rainfall pattern, with the major rainy season occurring from March to July and the minor season from mid-August to November. Annual rainfall ranges from 800 mm to 1500 mm, with an average monthly rainfall of approximately 91.2 mm (Ghana Meteorological Service Department, 2008).

The average monthly temperature at the experimental site ranges from 25°C to 32°C, while relative humidity varies between 75% and 85% in the morning and decreases during the afternoon. The area experiences a prolonged dry Harmattan season from December to March (Ghana Meteorological Service Department). The soil at the site belongs to the Bediese series, characterized as sandy loam, well-drained, with a thin layer of organic matter. It is deep, yellowish-red, friable, and free from stones (CSIR-Soil Research Institute, 1999). According to the FAO/UNESCO Soil Classification system, the soil is classified as Chromic Luvisol (FAO/UNESCO, 1988).

3.2 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 poultry 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 CM)
- (vi) No fertilizer (control)

3.3 Land Preparation

The land was initially cleared manually using cutlasses, followed by the removal of tree stumps through lumbering. The field was then ploughed and harrowed to achieve a fine tilth, which improved soil aeration, water infiltration, and root penetration—conditions essential for optimal carrot growth and yield. After land preparation, raised beds measuring 1 m by 2 m were constructed.

3.4 Manure Preparation and Application

Poultry manure was obtained from the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED) poultry farm at the Mampong Campus. The manure was heaped on a black polythene sheet and fully covered with another sheet to prevent nutrient loss through runoff and volatilization. It was left to decompose for one month to ensure complete breakdown. The manure was then applied at varying rates and thoroughly incorporated into the soil beds two weeks prior to planting.

This allowed sufficient time for decomposition and minimized the risk of seedling damage from the heat generated during the decomposition process.

3.5 Planting Materials

Carrot seeds of the variety 'Bahia' were procured from Kyeiwaa Agrochemicals, a reputable agrochemical shop located in Mampong, in the Ashanti Region of Ghana.

3.6 Sowing

Carrot seeds were treated with a seed-dressing fungicide at a ratio of 10 g of seed to 1 g of fungicide to protect against seed- and soil-borne pathogens. The seeds were sown by drilling at a depth of 1 cm, with rows spaced 20 cm apart on raised beds. After sowing, palm fronds were placed over the seeds to prevent them from being washed away by heavy rains and to shield them from excessive heat. The palm fronds were removed two weeks later to help harden the seedlings. Three weeks after planting, the seedlings were thinned to a spacing of 10 cm by 20 cm. Each plot measured 4 m wide by 2 m long.

3.7 Cultural and Management Practices

NPK 15:15:15 fertilizer was applied to the seedlings one week after thinning using side placement, following the treatment plan. The soil was loosened by forking three times at different intervals to improve aeration, support root development, and help retain moisture after watering. Weeds were controlled manually through hoeing and hand pulling whenever necessary to prevent competition for nutrients, water, and sunlight, as well as to reduce pest habitat. Watering was done twice daily early morning and late evening with about 5 liters per plot per day during the first two months. In the final month leading to maturity, watering was reduced to once daily in the morning, with approximately 2.5 liters

per plot, especially during the minor season planting from September to December 2021. Earthing up was carried out as needed to prevent greening caused by photomorphogenesis, protect roots from pests and physical damage, and promote proper root development.

3.8 Soil and Chicken Manure Analysis

Soil samples were randomly collected from ten different points in the field at a depth of 0-30 cm using a soil auger. The samples were air-dried, combined, and sent to the KNUST Soil Science laboratory for initial analysis. The tests conducted included pH (1:1 soil to water ratio), organic matter (%), total nitrogen (%), available phosphorus and potassium (ppm), exchangeable cations (Ca, Mg, K, Na in me/100g), and exchangeable acidity (Al and H in me/100g).

Decomposed chicken manure samples were also collected, bulked, and analyzed at the same laboratory for pH (1:10 manure to water ratio), organic matter (%), total nitrogen (%), total phosphorus (%), total potassium (%), total calcium (%), total magnesium (%), C:N ratio, and particle size.

Soil pH was determined using a soil-to-water ratio of 1:2.5, while chicken manure pH used a 1:10 ratio, following A.L. et al. (1982). Nitrogen content (%N) for both soil and manure was determined using the Kjeldahl method (Bremner & Mulvaney, 1982). Soil phosphorus (%P) was measured via the Bray-1 method (Bray & Kurtz, 1945), and phosphorus in manure was analyzed according to Motsa et al. (2008) and Moss (1961). Potassium (%K) in both soil and manure was measured with a flame photometer (Okalebo *et al.*, 2002).

Exchangeable bases in soil were extracted using ammonium acetate (Chapman, 1965), while exchangeable acidity (Al and H⁺) was determined by titration (McLean, 1965).

Organic carbon (%C) was measured by the Walkley-Black oxidation method (Walkley & Black, 1934), and organic matter (%OM) was calculated by multiplying %C by 1.724. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) concentrations in manure were measured using EDTA titration (Jackson, 1962). The C:N ratio was calculated by dividing organic carbon by total nitrogen, as described by Brady and Weil (2008). The hydrometer method, as described by Gee and Bauder (1979), was used to conduct the particle size analysis.

3.9.1 Plant Height

The height of five tagged plants was measured every two weeks, starting at 4 weeks after planting (WAP), for a total of four measurements. Plant height was recorded in centimeters using a meter rule, measuring from the soil surface to the apex (topmost part) of the plant.

3.9.2 Number of Leaves per Plant

The number of leaves on each of the five tagged plants was counted every two weeks, beginning at 4 weeks after planting (WAP), for four consecutive assessments.

3.9.3 Canopy Width

Canopy width was measured by determining the distance between the widest spreading leaves on opposite sides of each plant in two perpendicular directions using a meter rule. Measurements were taken every two weeks, starting from 4 weeks after planting (WAP), for four consecutive times.

3.9.4 Dry Matter Accumulation

Dry matter accumulation was measured every two weeks, starting 4 weeks after planting (WAP), for four consecutive intervals. Two seedlings were carefully uprooted from the

inner border rows of each bed and separated into roots and shoots. The fresh weights of the roots and shoots were measured in grams (g) using an electronic balance. The samples were then placed in labeled envelopes and oven-dried at 80°C for three days until a constant weight was achieved. Thereafter, the dry weights of the roots and shoots were recorded in grams (g) using the same electronic balance.

3.9.5 Root Length

The length of five mature roots, harvested from the two central rows of each bed, was measured using Vernier calipers. Measurements were recorded in centimeters (cm).

3.9.6 Root Diameter

The diameter of five mature roots, harvested from the two central rows (harvestable area) of each bed, was measured using Vernier calipers. Root diameter was recorded in centimeters (cm).

3.9.7 Number of Plants Harvested from the Harvestable Area

The total number of harvested plants was determined by counting all plants harvested from the two central rows of each bed, designated as the harvestable area.

3.9.8 Number of Harvested Roots

The total number of roots harvested was counted from the harvestable area, (the two central rows of each bed).

3.9.9 Number of Cracked Roots

Roots showing cracks were identified, counted, and recorded as cracked roots within the harvestable area.

3.9.10 Number of Deformed Roots

Roots exhibiting deformities such as disease symptoms or pest infestations were counted and recorded from the two central rows of each bed (harvestable area).

3.9.11 Number of Forked Roots

Forked roots within the harvested roots were counted and documented.

3.9.12 Total Fresh Root Yield (Weight)

The total fresh root yield was measured by weighing all harvested roots from the two central rows (harvestable area) of each bed, with the weight recorded in grams (g).

3.9.13 Number of Marketable Roots

Harvested roots were sorted based on size, shape, color, and defect absence. Only roots that were straight, smooth, medium-sized, and free from cracks, diseases, pests, or deformities were counted and recorded as marketable roots.

3.9.14 Number of Non-Marketable Roots

Harvested roots were sorted by size, shape, color, and presence of defects such as forked, cracked, undersized, diseased, greened, or pest-damaged. Those showing any of these defects were counted and recorded as non-marketable roots.

3.9.15 Organoleptic Determination (Sweetness)

To assess sweetness, harvested roots from each of the six treatments were bulked and coded. Random samples from each coded group were cut into 2 cm by 2 cm cubes. These cubes were boiled in 350 ml of distilled water for five minutes on a gas stove set to the same heat intensity. During boiling, 2.0 g of salt was added to each sample. A panel of 30 members (15 males and 15 females) aged between 9 and 60 years tasted the six boiled samples in sequence. After tasting each sample, panelists rinsed their mouths before proceeding to the next. Samples were rated on a scale of 1 to 5, where 1 = highly unpalatable, 2 = slightly unpalatable, 3 = bland, 4 = slightly palatable, and 5 = highly palatable.

3.9.16 Nutritional Analysis

Proximate analysis was conducted at the KNUST Food Science Department laboratory on samples of harvested roots. The analysis included measurements of crude protein, moisture, carbohydrates, total carotenoids, total oxalates, reducing sugars, calcium, and iron content.

3.9.17 Partial Budget Analysis

Partial budget analyses for 2021 and 2022 were performed to evaluate the economic viability of each treatment. The following cost information was used:

- Price of 1 bag (50 kg) of NPK 15-15-15 fertilizer: GHC 440.00
- Price of 1 bag (40.35 kg) of chicken manure: GHC 10.00
- Labor cost per man-day: GHC 80.00
- 8 man-days required for fertilizer application (both inorganic and organic)
- Price of 1 bag (44.2 kg) of carrot roots: GHC 250.00

3.10 Data Analysis

Data collected were analyzed using analysis of variance (ANOVA) in Genstat (2018) version. Treatment means were separated using Fisher's LSD at a 5% significance level. Pearson's correlation coefficient was employed to assess the strength and direction of the relationships between total root yield and various variables, including fresh root weight, dry root weight, root diameter, root length, number of plants harvested, number of marketable roots, and number of non-marketable roots. Correlation coefficients range from -1 to +1, where 0 indicates no correlation. A positive correlation indicates that as one variable increases, the other also tends to increase, while a negative correlation indicates an inverse relationship. Organoleptic test data were also statistically analyzed using Genstat (2018) version.

CHAPTER FOUR: RESULTS

4.1 Initial Soil Analysis for 2021 and 2022

The initial soil analysis was interpreted following the guidelines provided in the Guide to Interpretation of Soil Analytical Data in Ghana (SRI, 2007) (see Appendix 1). The soils used in the field experiments for both 2021 and 2022 were slightly acidic, as indicated by their pH values (Table 4.1). Available phosphorus levels were moderate in both years. Total nitrogen content was high in 2021 but decreased to moderate in 2022 (Table 4.1). Potassium concentrations remained moderate across both years, while calcium levels were consistently low. Magnesium and sodium contents were moderate for both sampling periods. Both percentage organic carbon and organic matter were low in 2021 and 2022. The textural classification of the soils was loamy sand, with the 2021 soil comprising 85.56% sand, 7.04% clay, and 7.40% silt, while the 2022 soil contained 84.74% sand, 7.84% clay, and 7.42% silt (Table 4.1).

Table 4.1. Results of initial soil analysis for 2021 and 2022

Year				Exch. Bases (cmol/kg)				Exch.		%	%
	pH (H ₂ O)	P mg/kg	N (%)	K	Ca	Mg	Na	Acidity (cmol/kg)		Org. C.	Org. M.
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			

4.1.1 Chicken Manure Analysis for 2021 and 2022

The results of the chicken manure analysis were interpreted based on the nutrient content ranges reported by Chastain et al. (2001). Total nitrogen levels were moderate in both 2021 and 2022. Total phosphorus, potassium, and magnesium concentrations were high for both years. Calcium content was moderate across the two seasons. The percentage of organic carbon was also high in both years. Additionally, the chicken manure used in the field experiments for both 2021 and 2022 was slightly alkaline.

Table 4.2 Chicken manure analysis for 2021 and 2022

Year	Total N (%)	Total P (%)	Total K (%)	Total Ca (%)	Total Mg (%)	% O. Carbon	pH	C: N
2021	2.732	2.094	2.677	1.627	0.590	40.95	7.16	14.99
2022	2.732	2.094	2.677	1.627	0.590	40.95	7.16	14.99

4.2 Climatic Data

Total rainfall recorded during the experimental period was 507.2 mm in 2021 and 580.0 mm in 2022, with monthly averages of 126.8 mm and 145.0 mm, respectively. In 2021, the highest monthly rainfall occurred in September (225.1 mm), while the lowest (0.0 mm) was recorded in December. For 2022, the highest rainfall was in July (203.6 mm), and the lowest was in April (79.6 mm). The average maximum temperature during the period was 32.5°C in 2021 and 31.7°C in 2022. The highest maximum temperature in 2021 was 34.3°C (December), and the lowest was 30.3°C (September). In 2022, the highest maximum temperature was 33.1°C (April), while the lowest was 30.0°C (July).

Average minimum temperatures were 23.15°C in 2021 and 23.3°C in 2022. The highest minimum temperature in 2021 was 23.7°C (December), and the lowest was 23.2°C (September). In 2022, the highest minimum temperature was 23.8°C in May, while the lowest was 22.7°C in July.

Table 4.3 Climatic Data

Month	Total rainfall (mm)	Temperature (°C)		Relative humidity (%)
		Max.	Min.	
2021				
September	225.1	30.3	23.2	77
October	208.7	32.1	22.3	72
November	73.4	33.1	23.4	68
December	0.0	34.3	23.7	58
Total	507.2			
Average	126.8	32.5	23.15	68.75
2022				
April	79.6	33.1	23.5	66
May	147.8	32.7	23.8	71
June	149.0	31.	23.3	74
July	203.6	30	22.7	74
Total	580			
Average	145	31.7	23.3	71.25

4.3 Plant Height

In 2021, plant height did not vary significantly among treatments from 5 to 7 weeks after planting (WAP). However, from 7 to 11 WAP, significant differences were observed. The treatment with full chicken manure (Full CM) produced the tallest plants, while the control

(no fertilizer) consistently recorded the shortest (Figure 4.1a). Treatments with Full NPK, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM showed intermediate plant heights. Statistical analysis revealed significant differences between Full CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and the control. Additionally, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM differed significantly from $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and Full NPK differed significantly from Full CM. No significant differences were observed between Full NPK, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and the control, nor between $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM (Figure 4.1a). Significant differences were observed between Full NPK and the control, and between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and the control. However, there were no significant differences between Full NPK and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. Similarly, no significant differences were observed among $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, Full CM, and the control (Figure 4.1b).

A significant difference in plant height was observed between the two years. An interaction between year and fertilizer treatment was also evident. In 2021, Full CM produced the tallest plants, followed by $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. Conversely, in 2022, Full NPK resulted in the tallest plants, followed by $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM. In 2022, plant height did not differ significantly among treatments from 5 to 9 WAP. However, significant differences emerged between 9 and 11 WAP. Full NPK recorded the tallest plants, whereas the control again recorded the shortest (Figure 4.1b). Intermediate plant heights were observed under 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.

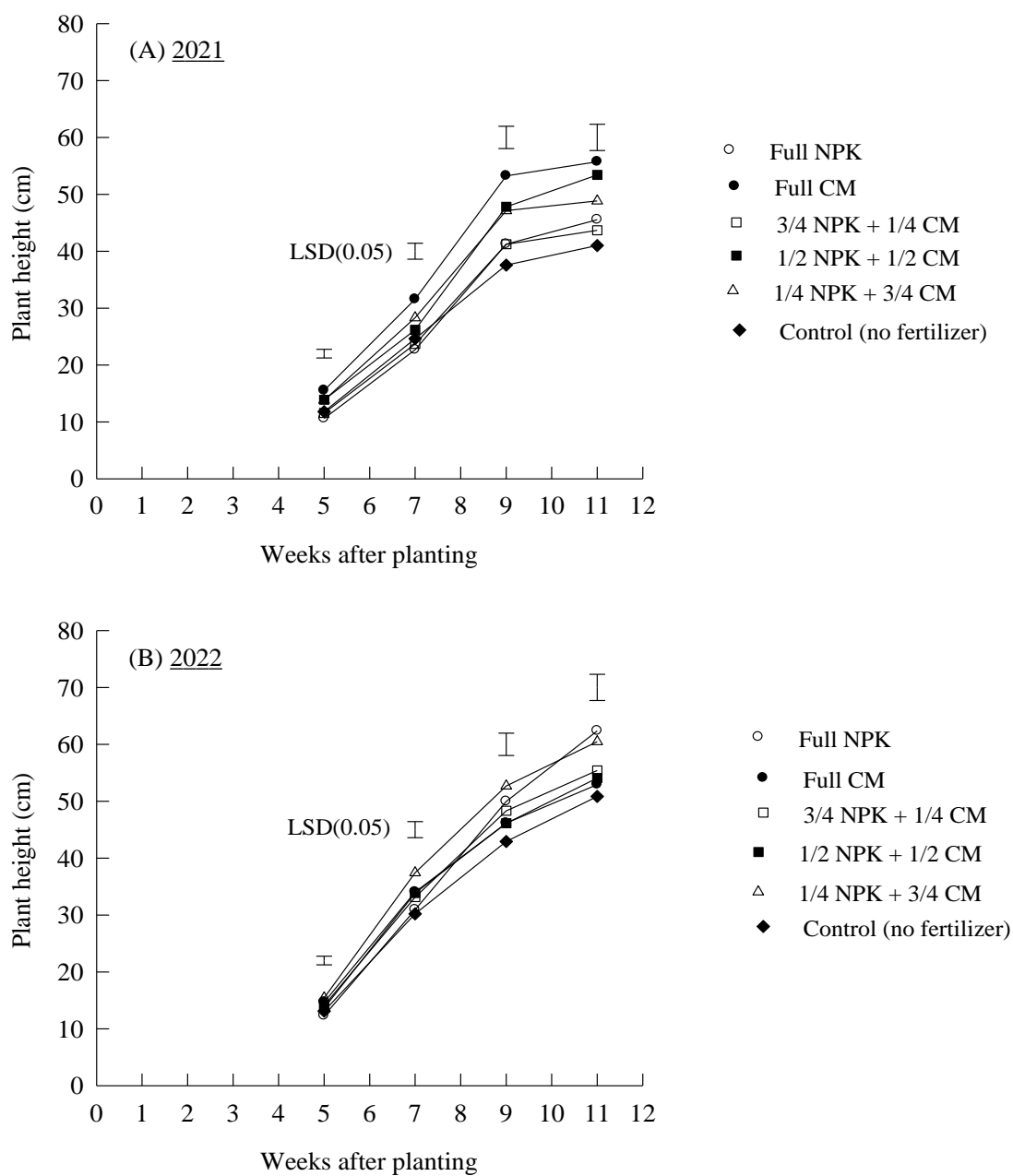


Figure 4.1. Effect of integrated nutrient management on plant height of Carrots in 2021 and 2022

4.4 Canopy Width

From 5 to 7 weeks after planting (WAP), canopy width across all treatments showed no significant differences in both 2021 and 2022. However, from 7 to 11 WAP, treatment effects became more distinct in both years (Figure 4.2a and 4.2b).

In 2021, the Full CM treatment recorded the widest canopy width, while the Control and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM treatments recorded the narrowest. Intermediate canopy widths were observed for Full NPK, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. Statistically, Full CM was significantly different from both the Control and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM. Similarly, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM differed significantly from the Control and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM. However, no significant differences were observed between Full CM and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, between Full NPK and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, or between the Control and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM (Figure 4.2a).

In 2022, the Full NPK treatment produced the widest canopy width, while both Full CM and the Control recorded the narrowest canopies. The treatments $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM showed intermediate values. Significant differences were observed between Full NPK and both the Control and Full CM. However, there were no significant differences between Full NPK and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. Likewise, no significant differences were observed among $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, Full CM, and the Control (Figure 4.2b).

There was no significant difference in canopy width between years. However, a year-by-treatment interaction was observed. In 2021, Full CM produced the widest canopy, followed by $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. In contrast, in 2022, Full NPK recorded the widest canopy, followed by $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM (Figures 4.2a and 4.2b).

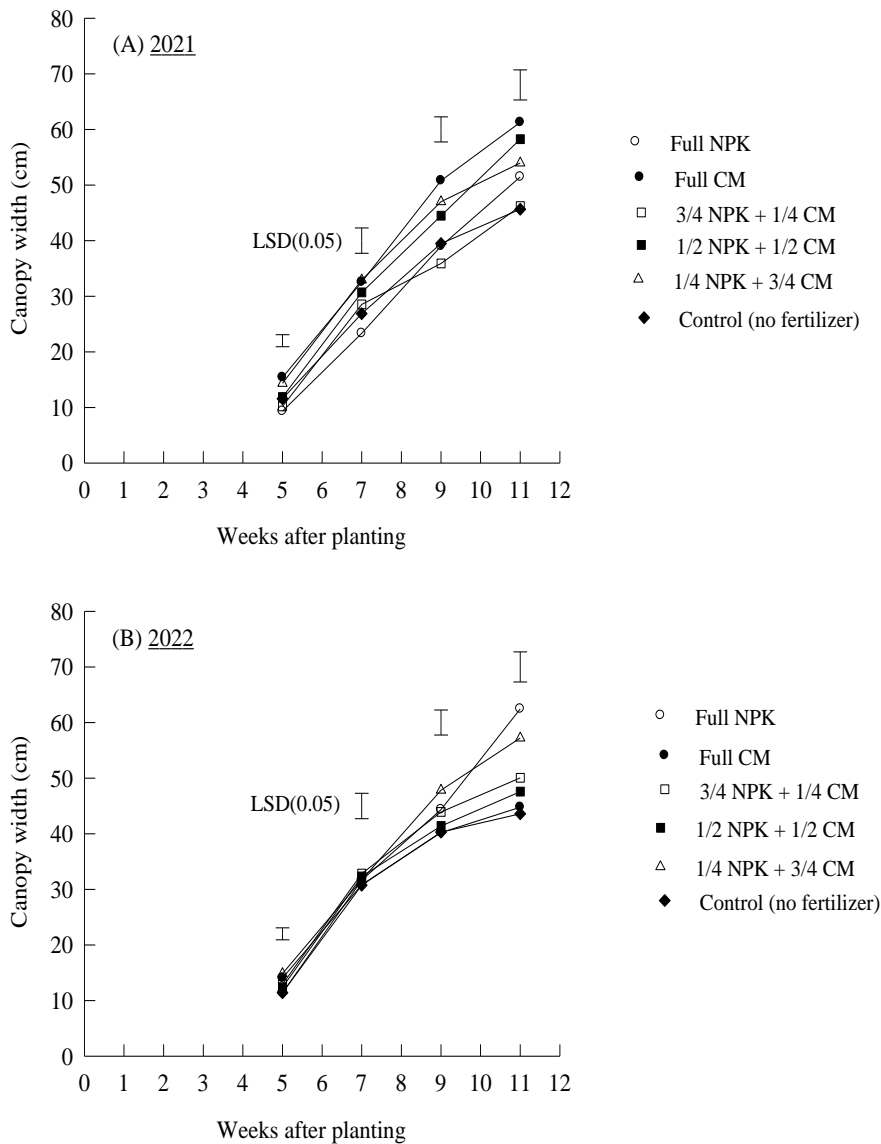


Figure 4.2. Effect of integrated nutrient management on canopy width of Carrots in 2021 and 2022

4.5 Dry Shoot Weight

Dry shoot weight across treatments showed no significant differences from 5 to 7 weeks after planting (WAP) in both 2021 and 2022. However, from the 7th week – 11week, clear differences among treatments emerged in both years.

In 2021, the highest dry shoot weights were recorded under Full CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM treatments, while the lowest were observed in the Full NPK and Control treatments (Figure 4.3a). Intermediate dry shoot weights were recorded for $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. Statistically, both Full CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM differed significantly from Full NPK and the Control. Significant differences were also observed between the groups Full CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. However, no significant differences were found between Full CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, between $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, or between the Control and Full NPK (Figure 4.3a).

In 2022, the $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatment recorded the highest dry shoot weight, while Full NPK recorded the lowest (Figure 4.3b). Significant differences were observed between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and Full NPK, as well as between $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and Full CM, and between the Control and Full NPK. Additionally, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM was significantly different from Full NPK. However, no significant differences were found among $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, the Control, and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM (Figure 4.3b). A significant difference in dry shoot weight was observed between the two years. There was also a notable interaction between year and fertilizer treatment. In 2021, Full CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM recorded the highest dry shoot weights, followed by $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. In contrast, in 2022, the highest dry shoot weight was observed under $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, followed by $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM.

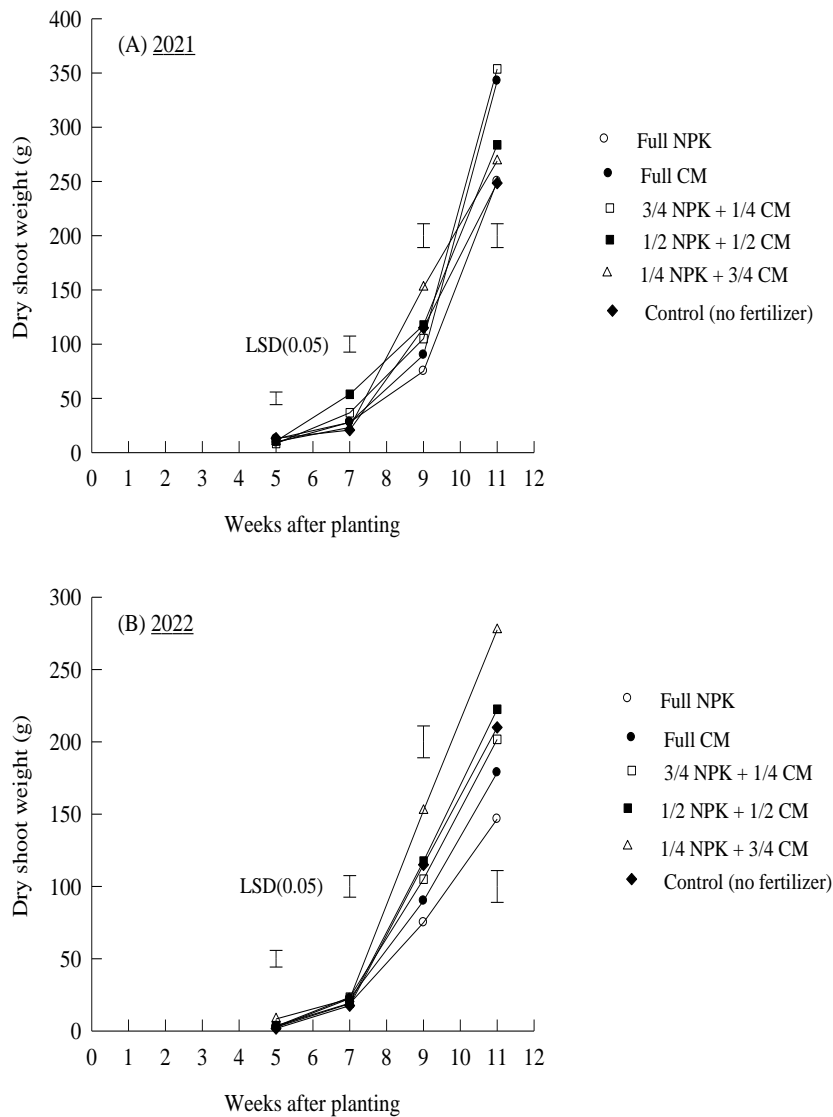


Figure 4.3. Effect of integrated nutrient management on the dry shoot weight of carrot

4.6 Fresh root weight

In 2021, there were no significant differences in fresh root weight among treatments from 5 to 9 weeks after planting (WAP). However, from the 9th week to 11week, significant difference between treatments was evident. The Full CM treatment recorded the highest

fresh root weight, while the Control recorded the lowest (Figure 4.4a). Intermediate fresh root weights were observed under $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, Full NPK, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM.

Statistical analysis showed significant differences between Full CM and Full NPK, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, Control, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. However, no significant differences were found among $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, Full NPK, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. Similarly, there were no significant differences between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and the Control (Figure 4.4a).

In 2022, treatments showed similar performance until the 9th week, after which significant differences emerged. The $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and Full NPK treatments recorded the highest fresh root weights, while Full CM recorded the lowest (Figure 4.4b). Significant differences were observed between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and both Full CM and the Control, as well as between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM. Additionally, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM differed significantly from the Control. However, there were no significant differences between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and Full NPK, nor among $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, the Control, and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM (Figure 4.4b).

A significant difference was observed between years. A significant interaction between year and fertilizer treatment was also observed. In 2021, Full CM produced the highest fresh root weight, followed by Full NPK and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, with $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM ranking next. However, in 2022, both $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and Full NPK recorded the highest fresh root weights, followed by $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, while the Control and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM treatments had the lowest values (Figures 4.4a and 4.4b).

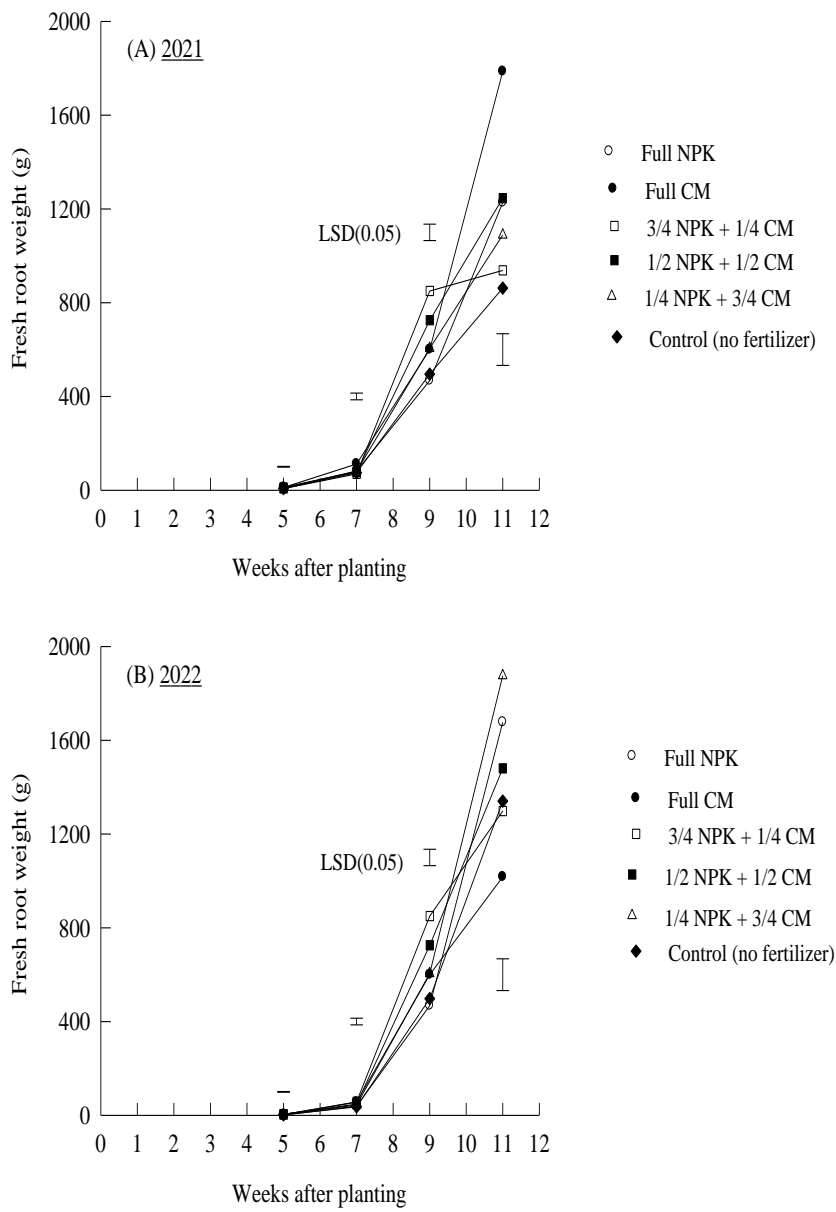


Figure 4.4. Effect of integrated nutrient management on the fresh root weight of Carrot for 2021 and 2022

4.7 Dry root weight

In 2021, all treatments showed similar dry root weights up to the 11th week after planting. At 11 WAP, the $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatment recorded the highest dry root weight, while $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM recorded the lowest (Figure 4.5a). The remaining treatments, full NPK, full CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and the Control showed intermediate values. A significant difference was observed between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM. However, there were no significant differences among Full NPK, Full CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and the Control (Figure 4.5a).

In 2022, treatment effects were similar until the 9th week, after which differences became evident. The $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatment again recorded the highest dry root weight, while Full NPK recorded the lowest (Figure 4.5b). Significant differences were observed between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and all other treatments, including Full NPK, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, Full CM, the Control, and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM. Additionally, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM differed significantly from both the Control and Full NPK. No significant differences were found among $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, Full CM, and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM. Similarly, no significant difference was observed between the Control and Full NPK (Figure 4.5b).

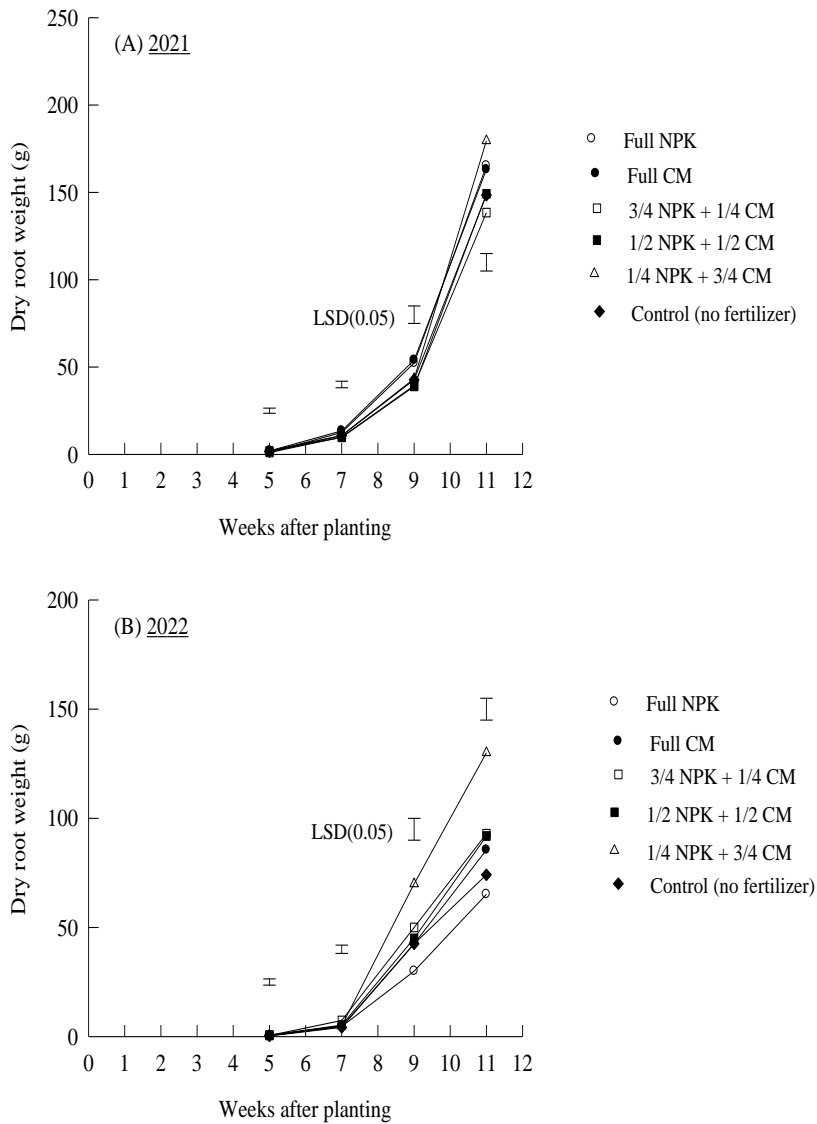


Figure 4.5. Effects of integrated nutrient management on the dry root weight of Carrots for 2021 and 2022

4.8 Number of leaves per plant

In 2021, the Full CM treatment recorded the highest number of leaves per plant, while both the Control and Full NPK treatments recorded the lowest (Figure 4.6a). A significant difference was observed between Full CM and the Control. However, there was no

significant difference between Full NPK and the Control. Similarly, no significant differences were observed among Full CM, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM (Figure 4.6a).

In 2022, Full NPK produced the highest number of leaves per plant, while the Control recorded the lowest (Figure 4.6b), with a significant difference between these two treatments. However, no significant differences were observed among the other treatments. A significant difference was also noted between the two years, along with a significant interaction between year and fertilizer treatment. In 2021, Full CM had the highest number of leaves per plant, whereas Full NPK and the Control recorded the lowest. Conversely, in 2022, Full NPK recorded the highest leaf count, while the Control remained the lowest (Figures 4.6a and 4.6b).

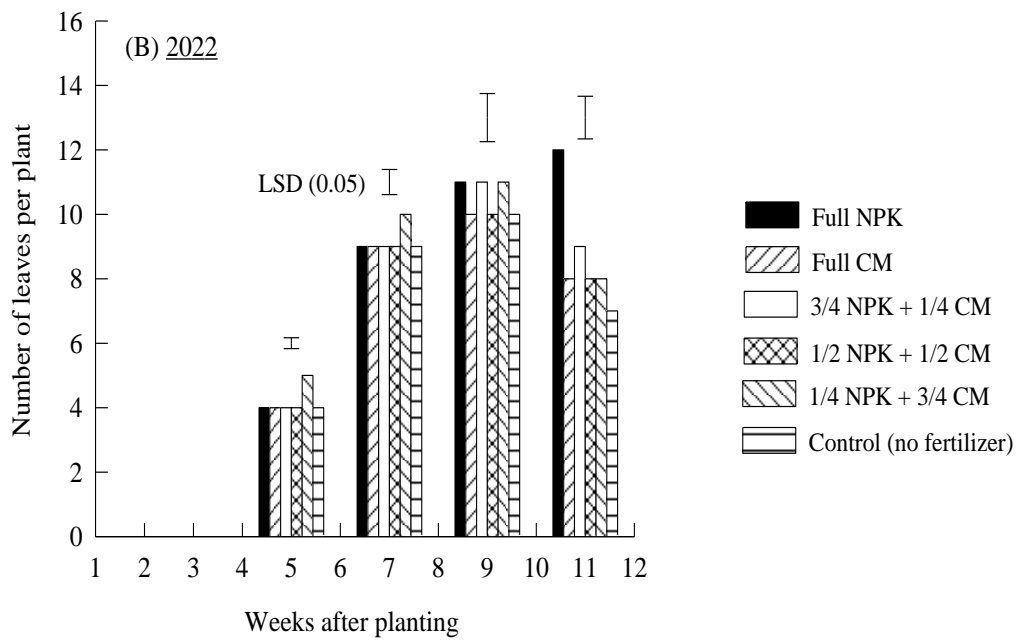
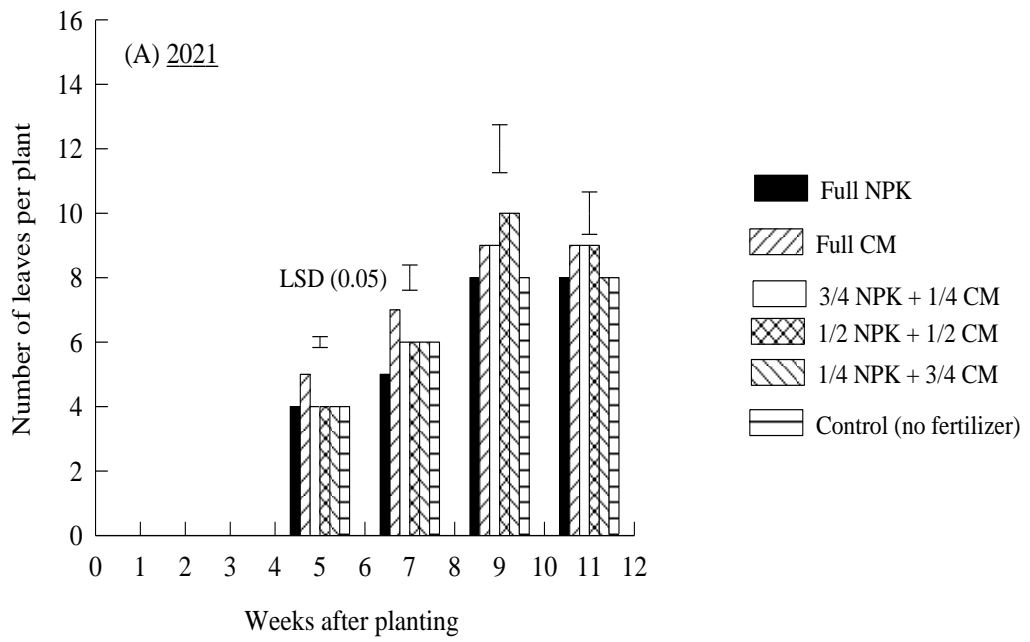


Figure 4.6. Effect of integrated nutrient management on the number of leaves per plant

4.9 Root diameter

In 2021, the Full CM treatment recorded the largest root diameter, while $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM recorded the smallest (Table 4.4). The remaining treatments recorded intermediate root diameters. There were significant differences between Full CM and Full NPK, as well as between Full CM and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM. However, no significant differences were observed among Full CM, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, and the Control.

In 2022, the $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatment recorded the largest root diameter, while the Control recorded the smallest. Other treatments, including Full NPK, Full CM, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, showed intermediate root diameters (Table 4.4). A significant difference was observed between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and Full CM. There was also a significant difference between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and other treatments, although no significant difference was found among Full NPK, Full CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and the Control.

A significant interaction between year and fertilizer treatments was observed. In 2021, Full CM produced the largest root diameter, followed by $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and then both the Control and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. In contrast, in 2022, the largest root diameter was recorded under $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, followed by $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and then Full NPK.

4.10 Root Length

In 2021, the Full CM treatment recorded the longest root length, while $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM recorded the shortest (Table 4.4). The remaining treatments recorded intermediate root lengths. Statistically, Full CM differed significantly from $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, Full NPK, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, as well as from both the Control and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM. However, there were no significant differences among Full NPK, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, and the Control during the 2021 season.

In 2022, the $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM treatment recorded the longest root length, whereas $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM had the shortest. However, no significant differences were observed among all treatments, including Full NPK, Full CM, Control, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM (Table 4.4).

There was a significant interaction between year and fertilizer treatment. In 2021, Full CM produced the longest roots, followed by $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM. In contrast, in 2022, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM recorded the longest root length, followed by $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM.

Table 4.4. Effects of integrated nutrient management on root diameter and length for 2021 and 2022

Treatment	Root diameter (cm)			Root length (cm)		
	2021	2022	Mean	2021	2022	Mean
Full NPK	2.99	3.91	3.45	14.88	19.96	17.42
Full CM	3.65	3.81	3.73	17.02	20.12	18.57
$\frac{3}{4}$ NPK + $\frac{1}{4}$ CM	3.35	4.15	3.75	15.61	19.74	17.68
$\frac{1}{2}$ NPK + $\frac{1}{2}$ CM	3.12	3.77	3.45	14.65	22.12	18.39
$\frac{1}{4}$ NPK + $\frac{3}{4}$ CM	3.25	4.89	4.07	14.89	21.14	18.02
No fertilizer (Control)	3.25	3.61	3.43	15.35	20.31	17.83
Mean	3.27	4.02		15.40	20.57	
CV (%)	10.77			11.15		

Fertilizer	LSD(0.05) =0.40, p=0.0147	LSD(0.05)=2.04, p=0.8434
Year	LSD(0.05)=0.23, p<0.0001	LSD(0.05)=1.2, p<0.0001
Fert x Year	LSD(0.05)=0.56, p=0.0123	LSD(0.05)=2.89, p=0.3235

4.11 Number of plants harvested

In 2021, the $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatment recorded the highest number of plants harvested, while Full NPK recorded the lowest (Table 4.5). A significant difference was observed between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and Full NPK, as well as between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and the Control. However, no significant differences were found among $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and Full CM.

In 2022, Full CM recorded the highest number of plants harvested, while Full NPK recorded the lowest. However, no significant differences were found among treatments during the 2022 season (Table 4.5). A significant difference was observed between the two years. An interaction between year and fertilizer treatment was also noted. In 2021, the highest number of plants harvested occurred under the $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatment, followed by Full CM. In contrast, in 2022, Full CM produced the highest number of harvested plants, followed by $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM (Table 4.5).

4.12 Number of marketable roots

In 2021, the $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM treatment produced the highest number of marketable roots, while both the Control (no fertilizer) and Full NPK treatments recorded the lowest (Table 4.5). A significant difference was observed between $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and both the Control and Full NPK. However, there were no significant differences among Full NPK, Control, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. In 2022, Full CM recorded the highest number of marketable roots, while Full NPK recorded the lowest (Table 4.5). However, the differences among treatments in 2022 were not statistically significant.

A significant difference was observed between the two years, along with a notable interaction between year and fertilizer treatments. In 2021, ½ NPK + ½ CM recorded the highest number of marketable roots, followed by Full CM. In contrast, Full CM had the highest number of marketable roots in 2022 (Table 4.5).

Table 4.5. Effects of integrated nutrient management on the number of plants harvested and the number of marketable roots of carrot at harvest in 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
¾ NPK + ¼ CM	26.25	36.75	31.5	13.00	29.75	21.38
½ NPK + ½ CM	25.00	36.50	30.75	16.75	30.00	23.38
¼ NPK + ¾ 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		

4.13 Number of Non-Marketable Roots

In 2021, the ¼ NPK + ¾ CM treatment recorded the highest number of non-marketable roots, while ½ NPK + ½ CM recorded the lowest (Table 4.6). A significant difference was observed between these two treatments. No significant differences were observed among the other treatments. In 2022, Full CM resulted in the highest number of non-marketable roots, whereas the Control and ¼ NPK + ¼ CM recorded the lowest. However, no significant differences were observed among treatments that year (Table 4.6). A significant difference was observed between the two years. Additionally, a significant interaction

occurred between year and fertilizer treatments. In 2021, the highest number of non-marketable roots was recorded under the $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatment, followed by $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM. In contrast, in 2022, Full CM recorded the highest number of non-marketable roots, followed by both Full NPK and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM (Table 4.6).

4.14 Total root yield at harvest

In 2021, the Full CM treatment recorded the highest total root yield at harvest, while the Control (no fertilizer) recorded the lowest (Table 4.6). A significant difference was observed between Full CM and all other treatments except $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM. Full CM produced approximately four times more root yield than the Control, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and Full NPK, and about twice as much as $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM. There were no significant differences among Full NPK, Control, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM.

In 2022, the highest total root yield was obtained from the $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatment, while the Control recorded the lowest yield. A significant difference was observed between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and the other treatments, including Full CM, Full NPK, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and Control (Table 4.6). However, there were no significant differences among $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, Full CM, Full NPK, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM.

A significant difference was observed between the years. Notably, the 2022 yield under $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM was about three times greater than the highest yield in 2021, which was achieved by Full CM. A significant interaction between year and fertilizer treatments was also evident. In 2021, Full CM produced the highest total root yield, followed by $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM. Conversely, in 2022, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM recorded the highest yield, with Full CM coming second (Table 4.6).

Table 4.6. Effects of integrated nutrient management on the number of non-marketable roots and total root yield at harvest (t/ha) of carrot at harvest in 2021 and 2022

Treatment	Number of non-marketable roots			Total root yield at harvest (t/ha)		
	2021	2022	Mean	2021	2022	Mean
Full NPK	11.25	7.00	9.13	1.17	13.90	7.54
Full CM	10.75	7.50	9.13	4.06	14.06	9.06
¾ NPK + ¼ CM	13.25	7.00	10.13	1.09	13.59	7.34
½ NPK + ½ CM	8.25	6.00	7.13	2.34	13.43	7.89
¼ NPK + ¾ CM	14.50	6.25	10.38	2.03	14.37	8.2
No fertilizer (Control)	12.00	6.25	9.13	0.93	11.95	6.44
Mean	11.66	6.67		1.95	13.55	
CV (%)	41.22			23.98		
Fertilizer	LSD(0.05)=3.99, p =0.5858			LSD(0.05)=1.89, p=0.1424		
Year	LSD(0.05)=2.25, p =0.0001			LSD(0.05)=1.09, p <0.0001		
Fert x Year	LSD(0.05)=5.51, p =0.6705			LSD(0.05)=84.5, p =0.6469		

4.15 Combined correlation analysis

Correlation analysis was conducted to assess the strength and direction of the association between total root yield and other measured traits, and to better understand the interrelationships among these variables. The results revealed a weak but positive and significant correlation between total root yield and fresh root weight at the 11th week ($r = 0.38$, $p = 0.0074$), indicating that increases in fresh root weight slightly contributed to higher yields (Table 4.9).

Conversely, a strong, negative, and significant correlation was observed between total root yield and dry root weight at the 11th week ($r = -0.64$, $p < 0.001$), suggesting that increased dry matter accumulation may be associated with reduced overall yield. A strong, positive, and significant correlation was found between total root yield and root diameter ($r = 0.65$, $p < 0.0001$), as well as between total root yield and root length ($r = 0.74$, $p < 0.0001$), indicating that larger and longer roots are closely associated with higher yields. Similarly, the number of plants harvested showed a strong, positive, and significant correlation with total root yield ($r = 0.77$, $p < 0.0001$), comparable to the correlation observed with root length. The number of marketable roots was found to have the strongest positive correlation with total root yield ($r = 0.89$, $p < 0.0001$), highlighting its direct contribution to yield performance. In contrast, the number of non-marketable roots was negatively and significantly correlated with total root yield ($r = -0.56$, $p < 0.0001$), indicating that higher proportions of unmarketable roots are associated with lower yields (Table 4.9).

Table 4.7 Correlation analysis

	1	2	3	4	5	6	7	8
1. Fresh root weight	1	-0.08 p=0.5891	0.39 p=0.0067	0.37 p=0.0096	0.24 p=0.0945	0.38 p=0.0074	0.31 p=0.0376	0.22 p=0.1311
2. Dry root weight		1	-0.8 p=0.2319	-0.55 p<0.0001	-0.40 p=0.0043	-0.64 p<0.001	-0.56 p<0.0001	0.50 p=0.0003
3. Root diameter			1	0.64 p<0.0001	0.50 p=0.003	0.65 p<0.0001	0.61 p<0.0001	-0.42 p=0.0029
4. Root length				1	0.44 p=0.0016	0.74 p<0.0001	0.59 p<0.0001	-0.50 p=0.0003
5. Number of plants harvested					1	0.77 p=<0.0001	0.89 p<0.0001	-0.16 p=0.281
6. Total root yield						1	0.89 p<0.0001	-0.56 p<0.0001
7. Number of marketable roots							1	0.60 p<0.0001
8. Number of non-marketable roots								1

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

4.16 Partial budget analysis for 2021 and 2022

Partial budget analyses were conducted for the 2021 and 2022 cropping seasons and are presented in Tables 4.8 and 4.9, respectively. To calculate the gross farm gate benefits, the total root yield was adjusted downward by 10%. This adjustment was made to account for the likely overestimation of returns from experimental trials, which typically produce higher yields than on-farm conditions due to superior management practices, smaller plot sizes, more precise harvesting methods, and reduced losses (Alimi and Manyong, 2000).

In 2021, the benefit-cost ratio (BCR) revealed that the application of 20 t/ha poultry manure (PM) recorded the highest BCR of 2.57, followed by 150 kg/ha NPK + 10 t/ha PM with a ratio of 1.58. The lowest BCR of 0.38 was recorded under the 225 kg/ha NPK + 5 t/ha PM treatment (Table 4.8). Dominance analysis, which identifies treatments that are not economically viable due to higher costs but lower net benefits, showed that 300 kg/ha NPK and 225 kg/ha NPK + 5 t/ha PM were dominated by the control (no fertilizer). Additionally, the 75 kg/ha NPK + 15 t/ha PM treatment was dominated by 150 kg/ha NPK + 10 t/ha PM (Table 4.8).

The Marginal Rate of Return (MRR) analysis indicated that 150 kg/ha NPK + 10 t/ha PM had an MRR of 54.98% over the control. The 20 t/ha PM treatment had a much higher MRR of 641.72% over the 150 kg/ha NPK + 10 t/ha PM treatment. This implies that for every GHC10.00 invested in switching from 150 kg/ha NPK + 10 t/ha PM to 20 t/ha PM, the farmer would gain an additional GHC631.00.

Table 4.8: Partial budget analysis for 2021

	300 kg/ha NPK	20 t/ha PM	225 kg/ha NPK + 5 t/ha PM	150 kg/ha NPK + 10 t/ha PM	75 kg/ha NPK + 15 t/ha PM	Control (No fertilizer)
GROSS FARM BENEFITS						
Average yield (t/ha)	1.17	4.06	1.09	2.34	2.03	0.94
Adjusted yields (10%)	1.055	3.66	0.98	2.11	1.83	0.84
Farm Gate Price/ton of carrots (GHS)	5656.11	5656.11	5656.11	5656.11	5656.11	5656.11
Total Gross Benefits (TGB) (GHS/ha)	5966.07	20682.70	5569.01	11932.13	10338.80	4774.89
TOTAL VARIABLE COST						
Cost of NPK fertilizer applied (GHS)	2640	0	1980	1320	660	
Cost of PM applied (GHS)	0	5000	1250	2500	3750	0
Total labour cost for fertilizer application	800	800	800	800	800	0
Total Variable Cost (TVC) (GHS/ha)	3440	5800	4030	4620	5210	0
Net Benefits (TGB - TVC) (GHS/ha)	2526.06	14882.70	1539.01	7312.12	5128.80	4774.89
BENEFIT: COST RATIO	0.73	2.57	0.38	1.58	0.98	0
MARGINAL RATE OF RETURNS (MRR)						
	Control (No fertilizer)	300 kg/ha NPK	225 kg/ha NPK + 5 t/ha PM	150 kg/ha NPK + 10 t/ha PM	75 kg/ha NPK + 15 t/ha PM	20 t/ha PM
Total variable cost (TVC) (GHS/ha)	0	3440	4030	4620	5210	5800
Net benefits (GHS/ha)	4774.88	2526.06	1539.01	7312.13	5128.80	14882.69
MRR= (ΔNB/ΔTVC)*100	0	D*	D*	54.92	D*	641.57

Table 4.9: Partial budget analysis for 2022

	300 kg/ha NPK	20 t/ha PM	225 kg/ha NPK + 5 t/ha PM	150 kg/ha NPK + 10 t/ha PM	75 kg/ha NPK + 15 t/ha PM	Control (No fertilizer)
GROSS FARM BENEFITS						
Average yield (t/ha)	13.010	14.06	13.59	13.44	14.38	11.95
Adjusted yields (10%)	11.79	12.66	12.23	12.09	12.94	10.76
Farm Price/ton of carrots (GHS)	5656.11	5656.11	5656.11	5656.11	5656.11	5656.11
Total Gross Benefits (TGB) (GHS/ha)	66665.17	71587.69	69200.24	68406.13	73175.92	60846.73
TOTAL VARIABLE COST						
Cost of NPK fertilizer applied (GHS)	2640	0	1980	1320	660	0
Cost of PM applied (GHS)	0	5000	1250	2500	3750	0
Total labour cost for fertilizer application	800	800	800	800	800	0
Total Variable Cost (TVC) (GHS/ha)	3440	5800	4030	4620	5210	0
Net Benefits (TGB - TVC) (GHS/ha)	63225.17	65787.69	65170.24	68406.13	67965.92	60846.74
BENEFIT: COST RATIO	18.38	11.34	16.17	13.81	13.05	0
MARGINAL RATE OF RETURNS (MRR)						
	Control (No fertilizer)	300 kg/ha NPK	225 kg/ha NPK + 5 t/ha PM	150 kg/ha NPK + 10 t/ha PM	75 kg/ha NPK + 15 t/ha PM	20 t/ha PM
Total variable cost (TVC) (GHS/ha)	0	3440	4030	4620	5210	5800
Net benefits (GHS/ha)	60846.747	63225.17	65170.24	63786.13	67965.92	65787.69
MRR= (ΔNB/ΔTVC)*100	0	69.14	329.673	D*	708.44	D*

4.17 Nutritional analysis

In 2021, the Control treatment recorded the highest moisture content, whereas the Full NPK treatment recorded the lowest. In terms of protein content, Full NPK had the highest value, while both Full CM and Control treatments had the lowest. The highest carbohydrate content was observed in the $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatment, with the lowest recorded in the $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM treatment (Table 4.10). For carotenoid content, the $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM treatment recorded the highest value, while the Control treatment had the lowest. Oxalate content was highest under the Full CM treatment and lowest under the Control. The greatest amount of reducing sugars was found in the $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatment, whereas the $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM treatment recorded the lowest value.

In 2021, the $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM treatment recorded the highest calcium content, while the Control treatment had the lowest. Full CM recorded the highest iron content, whereas the lowest was observed in the $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatment (Table 4.10). Regarding moisture content, significant differences were observed between Full NPK and Full CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, and Control. Additionally, Full CM differed significantly from $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and the Control treatment showed significant differences when compared to Full CM, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. For protein content, Full NPK showed significant differences from Full CM, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, and Control. Also, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM significantly differed from Full CM, Control, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. In terms of carbohydrate content, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM differed significantly from Full NPK, Full CM, Control, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM. Furthermore, the Control showed significant differences with Full NPK, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, while Full CM differed significantly from $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and Full NPK.

For carotenoid content, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM significantly differed from Control, Full NPK, Full CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. Full NPK also differed significantly from $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, and Control. Additionally, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM differed significantly from Control. With respect to oxalate content, Full CM significantly differed from Control, Full NPK, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. Similarly, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM showed significant differences with Full NPK, Control, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. Full NPK also differed significantly from Control and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM (Table 4.10).

In 2021, reducing sugar content showed significant variation among treatments. Full CM differed significantly from Full NPK, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, and Control. Additionally, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM differed significantly from $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM. The $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatment was significantly different from all other treatments. Moreover, Control showed significant differences from all treatments except $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM (Table 4.10). Regarding calcium content, both $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM were significantly different from $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and Control (Table 4.10). In terms of iron content, Full CM significantly differed from all other treatments, recording the highest value. Similarly, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM was significantly different from all treatments except Full CM. Full NPK also differed significantly from the rest, except Full CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, which performed better. Control significantly differed from both $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. Lastly, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM also showed a significant difference from each other (Table 4.10).

In 2022, Control recorded the highest moisture content, while Full NPK recorded the lowest. There was a significant difference between Control and all other treatments. Additionally, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM differed significantly from both Full NPK and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM also differed significantly from Full NPK. However, no significant differences were observed among Full CM, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM (Table 4.11). For protein content, Full NPK recorded the highest value, while the Control had the lowest. Full NPK showed a significant difference compared to all other treatments. Similarly, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM was significantly different from all treatments except Full NPK and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM. A significant difference was also observed between Full CM and the Control. However, no significant difference was found between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM (Table 4.11).

For carbohydrate content in 2022, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM recorded the highest amount, while $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM recorded the lowest. There was a significant difference between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and Full CM, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM. Additionally, Control and Full NPK were significantly different from Full CM, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM. Furthermore, both Full CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM differed significantly from $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM. However, no significant differences were observed between Control, Full NPK, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, nor between Full CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM (Table 4.11).

For total carotenoid content, the highest value was recorded under the $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM treatment, while the Control had the lowest. A significant difference was observed between $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM and all other treatments. Both Full NPK and Full CM also showed significant differences compared to the other treatments, except between each other. Additionally, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM differed significantly from the Control.

However, no significant differences were found between Full NPK and Full CM, or between $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM (Table 4.11).

Regarding oxalate content, Full CM recorded the highest level, while Control had the lowest. Full CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM were significantly different from all other treatments. Similarly, Full NPK and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM differed significantly from the rest, except $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM and Full CM. There was no significant difference between Full CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, nor between Full NPK and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM (Table 4.11).

For reducing sugars, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM recorded the highest amount, while $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM recorded the lowest (Table 4.11). There was a significant difference between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and Full NPK, Full CM, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM in terms of reducing sugar content. Additionally, a significant difference was observed between Full CM and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, as well as between Full NPK and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM. Furthermore, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM differed significantly from $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM. However, there was no significant difference between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and Control.

Likewise, no significant differences were found among Full NPK, Full CM, and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM. Additionally, Control and Full CM were not significantly different (Table 4.11).

For calcium content, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM recorded the highest amount, while Control had the lowest. There was a significant difference between both $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM compared to the other treatments. Significant differences were also observed between Full CM and Full NPK when compared to Control and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM. However, no significant difference was found between $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, or between Full CM and Full NPK. Similarly, Control and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM were not significantly different (Table 4.11). Regarding iron content, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM recorded the highest

amount, whereas Control recorded the lowest. There was a significant difference between $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and all other treatments. $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM also differed significantly from the rest, except $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM. Additionally, Full CM showed a significant difference from the other treatments, except $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM. However, no significant difference was observed among Full NPK, $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM, and Control (Table 4.11).

Table 4.10. Effects of integrated nutrient management on the nutritional qualities of carrots (2021)

Treatment	% moisture	% crude protein	% carbo.	Total carotenoid ug/g	Total oxalate ug/g	% Reducing sugar	Ca content mg/kg	Fe content mg/kg
Full NP K	82.023	6.675	6.372	226.250	11.385	5.78	241.568	3.251
Full CM	84.201	3.550	7.809	225.516	13.915	5.91	235.312	3.982
¾ NPK + ¼ CM	83.392	4.400	7.234	283.815	13.580	5.80	251.214	3.706
½ NPK+ ½ CM	84.846	4.865	6.175	191.379	10.725	5.60	228.438	2.735
¼ NPK + ¾ CM	84.139	4.010	8.765	182.946	8.855	6.2	251.025	1.405
No fertilizer (Control)	86.197	3.605	7.854	154.714	7.200	6.05	224.145	3.151
LSD (5%)	0.75	0.64	0.56	24.73	1.45	0.12	18.44	0.07

Table 4.11. Effects of integrated nutrient management on the nutritional qualities of carrots (2022)

Treatment	% moisture	% crude protein	% carbo.	Total carotenoid ug/g	Total oxalate ug/g	% Reducing sugar	Ca content mg/kg	Fe content mg/kg
Full NP K	80.262	6.275	8.211	231.712	12.265	6.840	239.712	3.868
Full CM	82.260	5.280	7.633	230.997	14.795	6.965	245.811	4.801
¾ NPK + ¼ CM	81.453	5.600	7.619	289.094	14.465	6.850	257.911	5.232
½ NPK+ ½ CM	82.902	5.665	6.784	196.709	11.605	6.615	207.546	3.732
¼ NPK + ¾ CM	82.198	5.910	8.430	188.458	9.735	7.215	250.438	5.689
No fertilizer (Control)	84.249	4.675	8.265	159.653	8.085	7.105	205.06	3.531
LSD (5%)	0.75	0.30	0.36	24.77	1.45	0.14	9.28	0.36

4.18. Organoleptic (sweetness) test

In the 2021 organoleptic (sweetness) test, 66.7% of participants rated $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM as highly palatable, while 0.0% rated Control as highly palatable. Additionally, 53.3% of participants found Full CM to be slightly palatable, with none rating Control as such. When assessing blandness, 60.0% of participants described $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM as bland, whereas the Control received no such rating. Moreover, 80.0% of participants considered Control to be slightly unpalatable, while Full NPK, Full CM, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM all recorded 0.0% in this category. Finally, 40.0% of participants rated $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM as highly unpalatable, whereas Full NPK, Full CM, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM each recorded 0.0% for this rating.

In the 2022 organoleptic (sweetness) test, 86.6% of participants rated Full NPK as highly palatable, while Control, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM each recorded 0.0% for this rating. Additionally, 73.4% of participants described $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM as slightly palatable, and 6.7% rated Full NPK the same. Furthermore, 26.7% of participants found both Control and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM to be bland, whereas Full CM was not considered bland by any participant (0.0%). Regarding slight unpalatability, 46.7% of participants indicated Full CM was slightly unpalatable, while Full NPK again recorded 0.0%. Lastly, 26.7% of participants rated both Control and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM as highly unpalatable, with Full NPK and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM each receiving 0.0% in this category. There was a clear interaction between years and fertilizer treatments. In 2021, the highest number of participants (66.7%) rated $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM as highly palatable, while in 2022, the highest percentage (86.6%) rated Full NPK as highly palatable.

Table 4.12. Effect of integrated nutrient management on the organoleptic (sweetness) of carrot for 2021.

	Full NPK	Full CM	$\frac{3}{4}$ NPK+ $\frac{1}{4}$ CM	$\frac{1}{2}$ NPK + $\frac{1}{2}$ CM	$\frac{1}{4}$ NPK + $\frac{3}{4}$ CM	No Fertilizer
Highly palatable	9(30%)	12(40%)	6(20%)	0(0%)	20(66.7%)	0 (0%)
Slightly palatable	15(50%)	16(53.3%)	6(20%)	0(0%)	6(20%)	0(0%)
Bland	6(20%)	2(6.7%)	18(60%)	3(10%)	4(13.3%)	0(0%)
Slightly unpalatable	0(0%)	0(0%)	0(0%)	15(50%)	0(0%)	24(80%)
Highly unpalatable	0(0%)	0(0%)	0(0%)	12(40%)	0(0%)	6(20%)
Total	30(100%)	30(100%)	30(100%)	30(100%)	30(100%)	30(100%)

NB: Numbers in brackets represents percentage of panelist who participated in the sensory evaluation.

Table 4.13. Effect of integrated nutrient management on the organoleptic (sweetness) of carrot for 2022.

	Full NPK	Full CM	$\frac{3}{4}$ NPK+ $\frac{1}{4}$ CM	$\frac{1}{2}$ NPK + $\frac{1}{2}$ CM	$\frac{1}{4}$ NPK + $\frac{3}{4}$ CM	No Fertilizer
Highly palatable	26(86.6%)	4(13.3%)	0(0%)	0(0%)	2(6.7%)	0 (0%)
Slightly palatable	2(6.7%)	6(20%)	22(73.4%)	16(53.3%)	6(20%)	8(26.7%)
Bland	2(6.7%)	0(0%)	4(13.3%)	4(13.3%)	8(26.7%)	8(26.7%)
Slightly unpalatable	0(0%)	14(46.7%)	4(13.3%)	2(6.7%)	10(33.3%)	6(20%)
Highly unpalatable	0(0%)	6(20%)	0(0%)	8(26.7%)	4(13.3%)	8(26.7%)
Total	30(100%)	30(100%)	30(100%)	30(100%)	30(100%)	30(100%)

NB: Numbers in brackets represents percentage of panelist who participated in the sensory evaluation.

CHAPTER FIVE: DISCUSSION

5.1. Growth parameters

5.1.1. Plant height

In 2021 and 2022, the tallest carrot plants were recorded under full CM and full NPK treatments, respectively. These treatments might have supported greater growth due to their ability to supply essential macronutrients for plant development. Additionally, full CM provided micronutrients released through mineralization, further enhancing plant growth. Conversely, the control (no fertilizer) consistently recorded the shortest plant heights in both years, presumably due to the lack of sufficient nutrients in the soil. Overall, plant height was greater in 2022 than in 2021, which may be attributed to higher total rainfall and average humidity, improving nutrient solubility and root uptake. These findings align with Dapaah *et al.* (2022), who reported that full poultry manure (PM) and integrated nutrient management ($\frac{1}{2}$ CD + $\frac{1}{2}$ PM) produced the tallest carrot plants.

5.1.2 Canopy Width

Canopy width followed a similar trend as plant height, with full CM and full NPK producing the widest canopy widths in 2021 and 2022, respectively. The enhanced vegetative growth is likely due to the availability of both macro and micronutrients from these treatments. In addition, full CM may have improved soil physical properties, such as texture, structure, and water retention, thereby enhancing nutrient availability and uptake. These outcomes support findings by Dapaah *et al.* (2022), who also observed the widest canopy width under full CM treatment.

5.1.3 Number of Leaves per Plant

The highest number of leaves per plant was recorded under full CM in 2021 and full NPK in 2022. The control consistently produced the fewest leaves in both years. These results mirror the trends observed in plant height and canopy width, reinforcing the importance of nutrient-rich treatments for optimal vegetative growth. Full CM may have further improved soil structure, enhancing root activity and nutrient absorption. The lower number of leaves in the control treatment might be due to poor nutrient availability. These findings are in line with Agyei and Bayor (2017), who reported that 40 t/ha of PM led to the highest leaf count, while the control produced the least.

5.1.4 Dry Shoot Weight

In 2021, full CM and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM recorded the highest dry shoot weight, while in 2022, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM produced the highest value. On the other hand, full NPK recorded the lowest dry shoot weight in both years. The improved performance of the organic and integrated treatments could be attributed to the slow and sustained release of nutrients from poultry manure, which ensures consistent nutrient availability during vegetative growth. This also reflects the benefit of combining macro- and micronutrient sources through integrated nutrient management. The control also recorded the least dry shoot weight in 2021 due to lack of nutrient input. These findings align with the study by Kiran et al. (2022), who found that NPK combined with poultry manure resulted in the highest biomass per plant, while NPK alone gave lower values.

5.1.5 Fresh Root Weight

In 2021, full CM produced the highest fresh root weight, while the control had the lowest. In 2022, both $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and full NPK recorded the highest fresh root weight, while full CM had the

lowest. The strong performance of full CM in 2021 is likely due to its rich nutrient content and its ability to improve soil physical properties like water retention, organic matter content, and nutrient-holding capacity. The 2022 results suggest that the faster nutrient release from full NPK and its combination with CM supported better early root development, while full CM may have underperformed due to the delayed nutrient release from mineralization. These observations are consistent with findings from Eze *et al.* (2024) and Ahmad *et al.* (2014).

5.1.6 Dry Root Weight

For both 2021 and 2022, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM recorded the highest dry root weight. In contrast, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM and full NPK recorded the lowest dry root weight in 2021 and 2022, respectively. The superior performance of $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM may be due to the increased nutrient availability and reduced nutrient losses associated with integrated fertilizer use. The low performance of $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM and full NPK could be related to the nutrient losses from chemical fertilizers and the slow decomposition of organic matter in CM. These results support findings by Sunandarani and Mallareddy (2007).

5.2 Yield parameters

5.2.1 Root diameter and length

In 2021, full CM produced the widest root diameter and longest root length, while $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM recorded the smallest in both traits. In 2022, the combination of $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM produced the widest diameter and longest roots, respectively, whereas the control and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM had the lowest values. The superior performance of full CM and the integrated treatments could be attributed to higher nutrient concentrations and the improved soil physical

properties resulting from organic matter application. These improvements likely enhanced nutrient retention, root development, and overall plant vigor, contributing to better vegetative growth and assimilate translocation to roots. Conversely, the poor performance of the control may be due to nutrient deficiency, resulting from the absence of soil amendments. These findings are in line with Toor *et al.* (2020) and Ahmad *et al.* (2014).

5.2.2 Number of Plants Harvested

In 2021, the highest number of plants harvested was recorded under $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, while full NPK recorded the lowest. In 2022, full CM resulted in the highest number of harvested plants, with full NPK again producing the lowest. The high plant survival and harvest under full CM and integrated treatments may be due to enhanced nutrient availability and uptake, which supported better photosynthesis and plant development throughout the growing period. On the other hand, the consistently low performance of full NPK could be attributed to the quick release and early depletion of nutrients, which may have led to nutrient stress at later growth stages, reducing plant survival till harvest.

5.2.3 Number of Marketable and Non-Marketable Roots

In both 2021 and 2022, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and full CM recorded the highest number of marketable and non-marketable roots, respectively. Full NPK consistently produced the lowest number of marketable roots, while $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM in 2021 and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM in 2022 recorded the fewest non-marketable roots. The improved performance in marketable roots under $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and full CM may be due to enhanced nutrient availability and absorption, leading to increased photosynthetic activity and efficient assimilate translocation from leaves to roots, resulting in well-

formed, healthy roots. Conversely, the low microbial activity and possible nutrient imbalances associated with full NPK might have contributed to fewer marketable roots. The control (no fertilizer) produced the lowest number of harvestable roots, likely due to nutrient deficiency during the reproductive phase, which impaired root development. The higher number of non-marketable roots observed under full CM could be linked to increased nematode infestation, potentially triggered by heightened microbial activity and excessive moisture from high rainfall in 2022. These results align with Adeleye (2024), who found that integrating poultry manure with NPK significantly enhanced marketable root yield.

5.2.4 Total Root Yield

Across both seasons, the highest total root yield was recorded under full CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, while the control produced the lowest yield. The superior performance of full CM and the integrated treatment may be attributed to the rich supply of both macro and micronutrients, which supported vigorous vegetative growth, enhanced photosynthetic efficiency, and effective translocation of assimilates to the roots. These factors likely contributed to improved root development and increased total root weight. In contrast, the poor performance of the control may be due to limited nutrient availability, which restricted photosynthesis and assimilate movement, resulting in reduced root biomass. These findings are consistent with the work of Singh *et al.* (2017) and Kirad *et al.* (2010), who reported similar trends in radish.

5.2.5 Correlation analysis

A combined correlation analysis was conducted to assess the relationships between total root yield and various agronomic traits, including fresh root weight at 11 weeks after planting (WAP), dry

root weight at 11 WAP, root diameter, root length, number of plants harvested, number of marketable roots, and number of non-marketable roots. The results revealed strong, positive, and significant correlations between total root yield and the following variables: root diameter ($r = 0.65$, $p < 0.0001$), root length ($r = 0.74$, $p < 0.0001$), number of plants harvested ($r = 0.77$, $p < 0.0001$), and number of marketable roots ($r = 0.89$, $p < 0.0001$). Additionally, a weak but significant positive correlation was observed between total root yield and fresh root weight at 11 WAP ($r = 0.38$, $p = 0.0074$).

In terms of influence, the number of marketable roots showed the strongest correlation with total root yield, followed by number of plants harvested, root length, root diameter, and finally fresh root weight at 11 WAP. Conversely, dry root weight at 11 WAP ($r = -0.64$, $p < 0.001$) and number of non-marketable roots ($r = -0.56$, $p < 0.0001$) showed strong, negative, and significant correlations with total root yield. In conclusion, the traits that most strongly influenced total root yield at harvest were number of marketable roots, number of plants harvested, root length, root diameter, and fresh root weight at 11 WAP. These can be considered key yield components of carrot production.

5.3 Economic analyses for 2021 and 2022

In 2022, the economic analysis revealed that 75 kg/ha NPK + 15 t/ha PM recorded the highest net benefit, while 300 kg/ha NPK recorded the lowest net benefit. In terms of benefit – cost ratio, 300 kg/ha NPK showed the highest BCR, while 20 t/ha PM had the lowest. Dominance analysis revealed that 150 kg/ha NPK + 10 t/ha PM was dominated by 225 kg/ha NPK + 5 t/ha PM (MRR = 329.673%), and 20 t/ha PM was dominated by 75 kg/ha NPK + 15 t/ha PM (MRR = 708.44%).

The dominance of the integrated treatment in 2022 suggests that combined organic–inorganic fertilization provided a more economically efficient outcome under the conditions of that year.

The superior performance of 20 t/ha PM in 2021 in terms of net benefit and benefit: cost ratio (BCR) may be attributed to improved soil physical properties (particularly water retention) from the sole application of chicken manure, in addition to the provision of macro- and micronutrients that became available gradually. According to the marginal rate of return (MRR) analysis, 75 kg/ha NPK + 15 t/ha PM was dominated by 150 kg/ha NPK + 10 t/ha PM with an MRR of 54.98%. More strikingly, 20 t/ha PM dominated 75 kg/ha NPK + 15 t/ha PM by an MRR of 641.72%, and also dominated 150 kg/ha NPK + 10 t/ha PM by the same margin. These large MRRs underscore the strong economic return of applying poultry manure alone under the conditions of the 2021 experiment.

These results may be as a result of improvements in soil physical and chemical conditions such as texture, structure, water-holding capacity, nutrient retention, and nutrient release dynamics under the different fertilizer regimes. The high benefit: cost ratio of 300 kg/ha NPK in 2022 likely reflects enhanced nutrient solubilization and root uptake under the climatic and soil conditions of that year. Overall, the dominance analysis indicates that in 2022, 75 kg/ha NPK + 15 t/ha PM outperformed the other treatments in economic terms, reinforcing the value of combining organic and inorganic fertilizers for sustained productivity and profitability.

5.4 Nutritional qualities and Organoleptic test

Moisture Content:

In both 2021 and 2022, the control treatment recorded the highest moisture content, while full NPK recorded the lowest. This outcome could be due to a higher concentration gradient between the soil solution and the vacuole of root hair cells in unfertilized plots, which facilitated greater water uptake through osmosis. Conversely, the lower moisture content under full NPK might be explained by a reduced concentration gradient, limiting water movement into the plant roots.

Crude Protein: Full NPK consistently produced the highest crude protein content in both years, while the control had the lowest. This is likely due to the abundant nitrogen in NPK fertilizers, which supports protein synthesis, as nitrogen is a key element in amino acids the building blocks of proteins. The low protein content in the control can be attributed to insufficient nitrogen availability. These findings align with Faisal *et al.* (2013), who also observed higher protein content with inorganic fertilizer use.

Carbohydrate Content: The $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatment recorded the highest carbohydrate content in both years, whereas $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM had the lowest. This could be due to the balanced supply and uptake of nitrogen and potassium, both of which play crucial roles in sugar formation and storage. As supported by Singh *et al.* (2012), fertilization significantly affects carbohydrate accumulation, and previous studies by El-Sarag & Moselhy (2013) and Gocan *et al.* (2013) highlight the importance of adequate N and K for enhanced sugar content in carrots.

Total Carotenoid: The $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM treatment resulted in the highest carotenoid levels in both 2021 and 2022, while the control recorded the lowest. Carotenoid accumulation is influenced by several factors, including fertilization, light, and temperature (Tatjana *et al.*, 2012). The differences

observed may be attributed to varying nutrient inputs, with combined NPK and CM treatments enhancing carotenoid synthesis more effectively than the control.

Total Oxalate Content: In both years, full CM recorded the highest oxalate content, while the control had the lowest. Oxalates, naturally occurring compounds in plants, can contribute to kidney stone formation in humans when consumed in large amounts. The findings suggest that fertilizer application, particularly organic amendments like CM, can increase oxalate accumulation in crops compared to untreated soils.

Reducing Sugars: The $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatment recorded the highest reducing sugar content in both 2021 and 2022, while the $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM treatment recorded the lowest. This aligns with findings by Cacek and Lagner (1986) and Raupp (1996), who reported increased reducing sugar levels in carrot roots when organic fertilizers were used. The enhanced sugar content may be due to the gradual and sustained nutrient release from organic matter, supporting consistent carbohydrate metabolism.

Calcium Content: The $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM treatment recorded the highest calcium content in both years, whereas the control had the lowest. This could be attributed to the combined contribution of calcium from both organic and inorganic sources, leading to better nutrient availability and uptake by plant roots. These findings are consistent with Djoufack *et al.* (2020), who observed improved calcium accumulation in carrots with integrated nutrient applications.

Iron Content: Full CM produced the highest iron content in both 2021 and 2022, while the $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatment recorded the lowest. The high iron levels under full CM may be due to the abundant supply and increased availability of micronutrients, including iron, in organically enriched soils, enhancing uptake by the plants.

Sweetness (Organoleptic Test): In 2021, full CM and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM were perceived as the sweetest by participants, while in 2022, full NPK and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM were most preferred. This variation may be linked to the high levels of carbohydrates and reducing sugars present in those treatments, which enhance sweetness. The results are consistent with previous observations by Djoufack et al. (2020), highlighting the role of nutrient composition in influencing taste.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

- Vegetative growth parameters such as plant height, canopy width, and number of leaves per plant were significantly enhanced with the application of full CM and full NPK, compared to the control. Thus, the application of full CM during the minor season and full NPK during the major season is recommended for optimal vegetative growth of carrots.
- Dry shoot weight, fresh root weight, and dry root weight were notably higher under full CM, full NPK, $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM, and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM treatments compared to the control. Therefore, both sole application of CM and integrated use of NPK and CM are recommended for improved carrot growth.
- For yield-related traits such as root diameter, root length, number of plants harvested, number of marketable roots, and total root yield, the treatments full CM, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM performed better than the control. Hence, the application of full CM and integrated nutrient management is recommended to enhance carrot yield.
- Nutritional qualities of carrots—including crude protein, iron, calcium, reducing sugars, total oxalate, total carotenoids, carbohydrate, and moisture content—were generally higher with full CM, full NPK, $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM, and $\frac{3}{4}$ NPK + $\frac{1}{4}$ CM than with the control. These treatments are therefore recommended to improve the nutritional value of carrots.
- Economic analysis revealed that full CM and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM were more profitable in 2021, while $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and full NPK yielded higher profits in 2022. Thus, full CM and $\frac{1}{2}$ NPK + $\frac{1}{2}$ CM are suitable for minor season production, while $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM and full NPK are ideal for major season profitability.

6.2 Recommendations

- Farmers are encouraged to adopt full CM during the minor season and $\frac{1}{4}$ NPK + $\frac{3}{4}$ CM during the major season to achieve maximum root yield and profitability in carrot production.
- It is recommended that future studies be conducted across other agro-ecological zones in Ghana where carrot cultivation is practiced.
- I further recommend that future studies should cover other organoleptic parameters such as texture and other postharvest quality characteristics.

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APPENDIX

Appendix 1: Guide to interpretation of soil analytical data in Ghana

Nutrient	Rank/Grade			
Phosphorus, P (ppm), (Bray 1)				
< 10	Low			
10 – 20	Moderate			
> 20	High			
Potassium, K (pmm)				
< 50	Low			
50 – 100	Moderate			
> 100	High			
Calcium, Ca (ppm)/Meg = 0.25 Ca				
< 5.0	Low			
5.0 – 10.0	Moderate			
> 10.0	High			
ECEC (cmol (+)/kg)				
< 10	Low			
10 - 20	Moderate			
> 20	High			
Soil pH (Distilled Water Method)				
< 5.0	Very Acidic			
5.1 – 5.5	Acidic			
5.6 – 6.0	Moderately Acidic			
6.0 – 6.5	Slightly Acidic			
6.5 – 7.0	Neutral			
7.0 – 7.5	Slightly Alkaline			
7.6 – 8.5	Alkaline			
> 8.5	Very Alkaline			
% Organic Carbon	% Organic Carbon	Interpretation		
< 1.0	< 1.5	Low		
1.0– 2.0	1.6 – 3.0	Moderate		
2.0-4.0	3.0	Adequate		
> 4.0	>3.0	High		
Nitrogen (%)				
< 0.1	Low			
0.1 – 0.2	Moderate			
> 0.2	High			
Exchangeable cations (cmol (+)/kg)	Units	low	moderate	High
Sodium (Na)	(cmol (+)/kg)	-	0-2	> 2.0
Potassium (K)	(cmol (+)/kg)	<0.2	0.2 – 0.4	> 0.4
Calcium (Ca)	(cmol (+)/kg)	< 2.0	2.0-10	> 10
Magnesium (Mg)	(cmol (+)/kg)	< 1.0	1.0-3.0	> 3.0

- Source: (SRI, 2007)

Appendix 2: Guide to interpretation of poultry manure analytical data as reported by Chastain et al, (2001).

Nutrient	Rank/Interpretation
Nitrogen (%)	
< 1.5%	Low
1.5% - 3%	Moderate
> 3%	High
Phosphorus (%)	
< 1.0%	Low
1.0% - 1.8%	Moderate
> 1.8%	High
Potassium (%)	
< 1.5%	Low
1.5 – 2.5%	Moderate
> 2.5%	High
Magnesium (%)	
< 0.30%	Low
0.30 – 0.50%	Moderate
> 0.50%	High
Calcium (%)	
< 1.5%	Low
1.5% - 3.5%	Moderate
> 3.5%	High
Organic Carbon (%)	
< 20%	Low
20– 35%	Moderate
>35%	High