

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

ASANTE MAMPONG

**INTEGRATION OF BIOCHAR, ORGANIC AND INORGANIC
FERTILIZER AMENDMENTS ON GROWTH AND YIELD
OF CARROT (*Daucus carota*)**

EBENEZER ASANTE ASSEMIAH

**MASTER OF PHILOSOPHY (M. PHIL) CROP SCIENCE
(AGRONOMY)**

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Graduate Studies in partial fulfilment of the requirements for the award of the degree
of Master of Philosophy Crop Science (Agronomy)
in the Akenten Appiah-Menka University of Skills Training and Entrepreneurial
Development**

APRIL, 2024

DECLARATION

Student's Declaration

I, Ebenezer Asante Assemiah that this thesis with the exception of quotations and references contained in published works which have all been identified and acknowledged is entirely my own original work and it has not been submitted either in part or whole for another degree elsewhere.

Name: Ebenezer Asante Assemiah

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.

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DEDICATION

This work is dedicated to my wife and children, Mrs. Charlotte Andoh and Petra Asante Assemiah, Courage Adom Assemiah Junior.

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ABSTRACT

Two field experiments were carried out at the Multipurpose Crop Nursery of AAMUSTED, Mampong campus, in two seasons: the minor rainy season (September to December 2021) and the major rainy season (April to July 2022). The study aimed to assess the impact of integrating biochar, organic, and inorganic fertilizer amendments on the growth and yield of carrots. The experimental design followed a 2 x 6 factorial arrangement, implemented in a Randomized Complete Block Design (RCBD) with four replications. The treatments included two carrot varieties (Technisen and Tokita) and five different soil amendment rates: (i) 10 t/ha chicken manure (CM), (ii) 250 kg/ha NPK fertilizer, (iii) 10 t/ha *Leucaena* biochar (LB), (iv) 5 t/ha CM + 5 t/ha LB, (v) 5 t/ha LB + 125 kg/ha NPK, and (vi) a control with no fertilizer.

The findings indicated that soil amendment with 10 t/ha CM and 5 t/ha CM + 5 t/ha LB improved soil chemical properties (organic carbon, organic matter, nitrogen, phosphorus, potassium, calcium) compared to the other amended treatments and the control. Tokita variety showed significantly greater plant height and wider canopy spread than Technisen in both seasons. Carrot plants treated with 10 t/ha CM and 5 t/ha CM + 5 t/ha LB exhibited significantly better vegetative growth—such as taller plants, more leaves per plant, wider canopy, and higher dry matter accumulation—compared to the unamended control plots. Tokita, along with 10 t/ha CM, and their interactions, produced significantly longer and thicker roots, as well as higher marketable root weight, root weight per plot, and root tuber yield, especially in the 2021 minor season.

Across both seasons, the amended plots showed significantly higher root length, plant biomass at harvest, carrot root yield, marketable root yield, and harvest index compared to the control. Based on the improved soil chemical properties and higher carrot yields, it is recommended

that farmers use 10 t/ha CM and/or 5 t/ha CM + 5 t/ha LB for optimal carrot (Tokita variety) production.

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Carrot (*Daucus carota*), a cool-season crop belonging to the Apiaceae family, is one of the most widely cultivated horticultural crops, prized for its edible roots. Known for its positive impact on eye health and various other human diseases (Appiah *et al.*, 2015), carrots are rich in carotenoids, which help reduce the risk of vitamin A deficiency (Adetuyi *et al.*, 2022). The roots also provide significant amounts of protein, carbohydrates, fiber, thiamin, riboflavin, iron, calcium, phosphorus, and vitamins C, K, B1, B2, and B6, in addition to water and minerals (Datta *et al.*, 2019). Carotene, derived from the roots, is used to color margarine and enhance egg yolk color when added to poultry feed.

Carrots are consumed in various forms, including raw (as a salad), shredded, boiled, or cooked in stews, soups, curries, and other dishes. They are also used to make pickles, jams, and desserts (Salis *et al.*, 2021). Beyond their nutritional value, carrots have documented medicinal properties, offering a range of therapeutic benefits (Singh *et al.*, 2022). Carrot cultivation presents a viable opportunity for smallholder farmers with limited resources, as it is a short-growing crop with high yields per unit area (Taylor *et al.*, 2018). In Ghana, carrots are one of the most sought-after exotic vegetables in urban markets and hold potential as an export crop (Bahadur & Pal, 2020). The leaves and roots of mature plants are also used to produce animal feed (Abebe, 2022). Typically grown as an annual crop, carrots are biannual by nature (Simon, 2021). The crop thrives in deep, well-drained clay soils rich in organic matter, with a pH range of 5.5 to 6.5 (Mwangi, 2021). Despite its potential, carrot yields in many developing countries remain below the global average, mainly due to poor soil fertility and unsustainable agricultural practices (FAO, 2021).

Soil degradation and ineffective management practices, which deplete soil fertility, are major contributors to the low productivity of carrot farming. Many carrot growers rely on inorganic fertilizers (Fouda, 2021), but these fertilizers have been linked to soil acidification, human health risks, and overall soil deterioration (Sharma *et al.*, 2022). Moreover, the high cost of synthetic fertilizers has made them unaffordable for many small-scale farmers, necessitating the exploration of alternative solutions (Margenot *et al.*, 2016).

Organic amendments like biochar may offer a promising alternative to improve soil fertility and crop yields by reducing nutrient leaching and directly supplying nutrients to plants (Hussain *et al.*, 2017). Biochar, produced from organic waste through pyrolysis, has gained attention as a sustainable agricultural input, offering multiple benefits such as enhanced soil structure, higher water retention, and reduced nutrient loss, all of which increase crop yield potential (Liu *et al.*, 2018; Banitalebi *et al.*, 2021). *Leucaena leucocephala*, a fast-growing leguminous tree, is used to produce biochar that can improve soil fertility, especially in alley cropping systems, by fixing atmospheric nitrogen (Hefner *et al.*, 2021). Biochar's ability to improve soil's physical, chemical, and biological properties, and its influence on carbon and nitrogen cycles, further contribute to its effectiveness in enhancing crop productivity (Das & Avasthe, 2020). Although previous studies have focused on biochar's impact on soil alone, combining biochar with other amendments may enhance its effectiveness.

Poultry manure, another organic amendment, is widely recognized for its ability to improve soil quality by reducing bulk density, increasing water retention, and boosting nutrient availability and retention, which is crucial for sustainable soil health (Singh *et al.*, 2022). Poultry manure, when used alongside or in place of mineral fertilizers, can help mitigate soil

degradation and improve long-term soil fertility. Traditional tillage methods, commonly used in large-scale carrot production in Ghana, contribute to soil degradation by depleting organic matter, reducing fertility, and disrupting soil structure, which leads to increased soil erosion, nutrient cycling problems, and higher operational costs (Das *et al.*, 2018; Šarauskis *et al.*, 2018).

1.2 Problem statement and justification

Food insecurity and poverty are major challenges in Ghana. Carrots (*Daucus carota*) are an essential vegetable crop, particularly in the Asante Mampong area of the Ashanti region, where they are grown for local consumption and regional markets. Carrots are highly valued for their nutritional benefits, and demand for them continues to rise. However, carrot production is constrained by several factors, including poor soil fertility and the presence of root-knot nematodes, which have led to stagnation in yields. These challenges are especially prominent in tropical and subtropical regions, such as sub-Saharan Africa, where poor soil conditions pose a significant barrier for smallholder farmers (Kamanga *et al.*, 2021).

To address these issues and improve crop yields, many farmers are turning to soil amendments, both organic and inorganic, to boost plant growth. The need for soil enhancement has been driven by declining food production, shorter fallow periods, and increasing population pressures on limited land resources (Khan *et al.*, 2020). In Asante Mampong, many farmers face financial constraints, making it difficult to regularly use inorganic fertilizers. Consequently, they often rely on organic amendments such as compost, cocoa pod husks, cattle manure, and poultry manure to improve soil fertility (Atakora *et al.*, 2019).

Poultry manure is particularly effective in enhancing soil fertility by providing essential nutrients, increasing organic matter, and improving soil physical properties. It boosts cation exchange capacity, raises soil pH in acidic soils, and improves water retention, which helps reduce soil erosion (Rayne *et al.*, 2020). Additionally, poultry manure improves soil structure, increases nutrient retention, and supports greater biodiversity by enriching soil organic matter (Rayne *et al.*, 2020). Another promising soil amendment gaining attention is biochar, a nutrient-rich material produced from biomass. Biochar has been shown to improve plant growth and crop yields by enhancing nutrient availability in the soil, making it a valuable tool for sustainable agriculture.

Incorporating biochar into soil can improve its physical, chemical, and biological properties and influence carbon and nitrogen cycles (Chauhan *et al.*, 2017). While inorganic fertilizers are commonly used in carrot cultivation and result in increased growth and yield, carrot yields can also be improved when inorganic fertilizers are combined with organic manures (Ayer *et al.*, 2019). Many studies have focused on the effects of inorganic nitrogen fertilizers on carrot growth and output, as carrots require nutrients like nitrogen, phosphorus, magnesium, and sulfur (Shakeel *et al.*, 2021). However, there is growing interest in using organic manure correctly and efficiently to preserve soil fertility. Organic manures, such as chicken manure, have enhanced agricultural productivity in West Africa and provide important nutrients for plants. Organic manure also increases soil microorganisms, which can help protect plants from nematodes and soil-borne pests and supply plant growth hormones like auxins (Gouda & Patra, 2018).

Organic manure not only improves the soil's physical health but also enhances cation exchange capacity and acts as a buffer against pH fluctuations in the soil (Hossain *et al.*, 2020). Research has shown that applying organic manure offers better economic benefits compared to using inorganic fertilizers (Hoover & Soupir, 2019). Combining organic and inorganic fertilizers has been found to produce higher and more sustainable yields than using either type alone (Baghdadi *et al.*, 2018). However, in Ghana, limited research has been conducted on the integration of biochar and fertilizer regimes for optimizing carrot growth, yield, and development. Therefore, more intensive research is needed to explore nutrient supply strategies that can maximize the crop's yield potential for commercial and industrial use. Identifying and selecting the right combinations and rates of biochar, inorganic fertilizers, and organic amendments will help boost carrot yields in the country.

1.3 Objectives of the study

1.3.1 Main objective

The primary aim of the study is to assess the growth and yield of two carrot varieties in response to the integration of biochar, organic, and inorganic fertilizer amendments.

1.3.2 Specific objectives

The specific objectives were to:

1. Determine the effect of biochar, organic and inorganic fertilizers on soil physical and chemical properties.

2. Assess the effectiveness of organic manure (chicken manure), inorganic fertilizer (N P K 15:15:15) and Biochar amendments (*Leucaena leucocephala*) and their interaction on the crop growth analysis of two varieties of carrot.
3. Determine the effect of biochar, organic manure and inorganic fertilizer and their interaction on yield and yield component of two carrot varieties.

CHAPTER TWO: LITERATURE REVIEW

2.1 Origin and distribution

Carrots are one of the most widely cultivated root vegetables globally, with around 1.2 million hectares dedicated to their production (Machaj *et al.*, 2018). The carrot's wild ancestor, *Daucus carota L.*, is a weed found across all temperate regions. Asia Minor and parts of Asia have been identified as potential centers for carrot cultivation (İkiz *et al.*, 2020). This vegetable is believed to have originated in Afghanistan over 5,000 years ago (Nagraj *et al.*, 2020). Carrots are thought to have been introduced to Europe during the sixth and seventh centuries (Peña *et al.*, 2019). In 1930, Europeans brought carrots to Ghana, and in certain parts of West Africa, they can bloom and produce seeds in just one growing season, even under cold conditions (Pardee *et al.*, 2019). Carrot production is significant in several countries, with China leading the world in production in 2005, followed by the United States and Russia (Encalada *et al.*, 2019).

A member of the Apiaceae family, the carrot is native to the temperate regions of Europe and Asia (Clarkson *et al.*, 2021). Afghanistan is considered the original center of carrot diversity, with Turkey being the second (Iqbal *et al.*, 2021). Carrots are grown worldwide in temperate and subtropical climates, including regions such as North America, North and West Africa, India, China, Europe, Syria, Afghanistan, Pakistan, and parts of Southern Africa (Molotievskiy *et al.*, 2019). To meet market demands, carrots are cultivated in both urban and rural areas, with production now extending to various parts of West Africa, including Ghana.

2.2 Botany

Carrot (*Daucus carota*), a member of the Apiaceae family, is typically a biennial plant, though it is commonly grown as an annual. In its natural biennial cycle, the carrot stores sugar in its taproot during the first year, preparing for flowering and seed production in the second year. During this period, the plant forms a rosette of leaves while accumulating nutrients in the root (Christian, 2015). After germination, carrot seedlings develop a clear distinction between the taproot and stem, with the stem appearing thicker and lacking a true root (Barth, 2019). When cultivated as an annual, carrots focus on vegetative growth in the first year, storing energy for future reproduction, while the taproot is harvested for consumption or sale. If left in the soil after vernalization, the root will eventually flower or bolt, requiring at least six weeks of cold exposure. However, some wild carrot varieties can flower or bolt even without significant vernalization (Que *et al.*, 2019).

Around 10 to 15 days after germination, the seed leaf emerges at the top of the stem, followed by the first true leaf. Carrot leaves are complex and alternately arranged in a spiral, with each leaf attached to a node along the stem (Bel, 2021). The internodes are not clearly defined, and the stem remains somewhat compressed near the ground (Erndwein *et al.*, 2020). As the plant matures, the stem elongates and produces flowers, while the tip of the stem becomes a highly branched, sturdy structure. The taproot consists mainly of a pulpy outer cortex (phloem) and an inner core (xylem), with high-quality carrots typically having a larger proportion of cortex compared to the core (Sarron *et al.*, 2021). While carrots can have either cylindrical or spherical shapes, they typically possess a long, conical taproot (Hernandez, 2020). Carrots are a diploid species with nine relatively short, uniform chromosomes ($2N = 18$), and their genome is estimated to be 473 megabase pairs in length (Hong *et al.*, 2020). Carrot plants

typically range in height from 20 to 100 cm, with a taproot that swells and thickens into various shapes and sizes. The root is typically orange or red, with solid, compact stems at its proximal end.

2.3 Varieties

There is no universally accepted list of carrot cultivars, as different researchers from various regions classify them differently. In Ghana, especially in the Asante Mampong area, the most commonly grown varieties are ‘Nantes’ and ‘Tokita’ (Ahiale & Abunyuwah, 2021). Carrots are available in various root shapes, with notable varieties including Amsterdam, Chantenay, Danvers, Nairobi, and Nantes. These varieties are often used by growers to produce popular hybrid carrots sold in the market (Simon, 2021). According to Brainard (2021), carrots can be grouped into four main types based on root shape and storage characteristics: Chantenay, Nantes, Danvers, and Emperor. Abuzar *et al.* (2016) also included the Kuroda variety in this classification. Each carrot variety is distinguished by unique characteristics such as root color, maturation time, tapering degree, root length, shelf life, smoothness, fiber content, and juiciness (Bitters, 2021).

2.4 Nutritional value and uses

Carrot (*Daucus carota* L.) is a widely grown root vegetable that was initially used for medicinal purposes before becoming a common food source. Historical records from Europe indicate that carrots were cultivated as early as the 10th century. The earliest cultivated varieties were orange, yellow, and purple-fleshed, with the orange variety now the most prevalent being developed in Central Europe during the 15th and 16th centuries. The popularity of orange carrots grew significantly after their high provitamin A content was

recognized (Singh *et al.*, 2021). Orange carrots are particularly rich in α - and β -carotene, which serve as important sources of provitamin A. Yellow carrots, which derive their color from lutein, help prevent macular degeneration (Langi *et al.*, 2018). Compared to other vegetables, carrots are an excellent source of vitamin A due to the high bioavailability of their carotenoids (Van *et al.*, 2000). Carrots also provide essential nutrients like vitamin A, beta-carotene, vitamin C, lutein, vitamin K, and dietary fiber. A medium-sized carrot contains 38 kcal, 6.7g of carbohydrates, 1g of protein, 0.5g of fat, 5g of fiber, 7mg of vitamin C, 451mcg of vitamin A, and 2706mcg of beta-carotene (Nagraj *et al.*, 2020).

The vitamin C in carrots supports immune function and healing, while vitamin A plays a key role in maintaining mucous membranes that protect the body from infections (Nagraj *et al.*, 2020). Carrots have a low natural sugar content, and their high fibre content helps keep their glycemic index low, making them beneficial for diabetics by preventing blood sugar spikes. Eating foods low in sugar and high in fibre, like carrots, may help prevent type II diabetes and assist in managing blood sugar levels for those already diagnosed. Additionally, carrots contain a unique combination of flavonoids kaempferol, quercetin, and luteolin (Tech, 2022). Carrots are also a good source of dietary fiber and the trace mineral molybdenum, which is crucial for fat and carbohydrate metabolism, as well as iron absorption. They also provide magnesium and manganese, essential for bone health, energy production, and muscle relaxation (Ramya *et al.*, 2019). Rich in antioxidants, carrots contain carotenoids, polyphenols, and vitamins that function as antioxidants, anticarcinogens, and immune system boosters (Varshney *et al.*, 2022). Singh *et al.* (2021) highlighted that the flavonoids and phenolic compounds in carrots contribute to their antioxidant, anti-carcinogenic, anti-inflammatory, and immune-modulating effects.

2.5 Climatic and Soil Requirements

Climate variability significantly influences crop yields from year to year, even in regions with high agricultural productivity and advanced technologies (Lemi and Haclu, 2019). Climate is a critical factor in agricultural production, including the cultivation of vegetable crops (Parajuli *et al.*, 2019). Carrots (*Daucus carota* var. *sativus*) are a cool-season vegetable that thrives under specific environmental conditions. High temperatures can damage the tops of carrots, negatively affecting their flavour (Kennedy, 2021). Carrots grow best when temperatures range from 15.6°C to 21.1°C, and their performance declines when temperatures exceed 26.7°C (Nair *et al.*, 2021).

Although carrots are somewhat resistant to frost, prolonged exposure to cold temperatures can slow leaf development and impact their flavour. Temperatures below 5°C can further reduce growth rates (Pramanik *et al.*, 2020). Carrots can tolerate varying rainfall amounts, but excessive water can alter the colour of their roots (Abdelrazek *et al.*, 2020). The water needs of carrots depend on the soil's moisture and climate conditions (Zedan *et al.*, 2022). Nijabat *et al.* (2021) emphasized that regular watering after seeding is crucial to prevent soil compaction, which can hinder germination. Additionally, avoiding water stress after germination is important to support healthy and rapid growth. In Norway, irrigation practices such as watering when soil tension reached 30 or 60 mm did not significantly affect germination. Under optimal climatic conditions, carrots can be grown year-round, with sowing every two weeks to ensure a continuous harvest. Similar to radishes, carrots require consistent irrigation for optimal root development.

The best soils for vegetable production are typically deep, fertile, well-drained, and consist of light to medium loams (Okiror *et al.*, 2022). Organic, well-drained soils are also ideal, though most vegetable crops can thrive in various soil types (Welbaum, 2015). Root crops like carrots perform best in light, nutrient-rich soils, and silt loam soils are especially suited for high vegetable yields (Alordzinu and Qiao, 2021). Carrots prefer soils with a pH range of 5.8 to 6.5, as they do best in soils that are neither too acidic nor too alkaline (Mwangi, 2021). Additionally, carrots require soil that remains adequately moist to avoid the development of small, hairy roots, which negatively affect root texture (Festus *et al.*, 2018).

Soil temperature plays a critical role in seed germination and root development. Carrots, being a cool-season crop, have an optimal temperature range for seed germination between 7°C and 23°C. For optimal root growth, temperatures between 18°C and 23°C are ideal. Extreme soil temperatures—whether too high or too low—can hinder root growth and affect root colour. Greenhouse-grown carrots typically produce the largest roots at temperatures between 10°C and 15.6°C, but the best root colour is achieved between 15.6°C and 21.1°C. Bolaños-Martínez *et al.* (2022) found that growth was poorer at 15°C compared to 20°C-30°C, with maximum root weight recorded at temperatures between 20°C and 25°C. The study also noted that at soil temperatures of 35°C or higher, carrot seeds failed to germinate. The ideal soil moisture content for seed germination is 40% of the field capacity.

2.6 Production estimate

The carrot (*Daucus carota*) is one of the most widely grown root vegetables globally. According to the United Nations Food and Agriculture Organization (FAO), global production of carrots and turnips reached nearly 45 million tonnes in 2019. China was the top producer,

accounting for 47.9% of the total, followed by Uzbekistan (6.2%), the United States (5.0%), Russia (3.5%), Ukraine (1.9%), the United Kingdom (1.8%), and Germany (1.8%). In Italy, over 11,000 hectares are dedicated to carrot cultivation each year (FAOSTAT, 2021). Worldwide carrot consumption has seen significant growth in recent years, with North America emerging as the leading market for carrots and turnips in 2020 (Górska-Warsewicz *et al.*, 2021).

The United States is a key producer of carrots, with California responsible for more than 85% of the country's total production. Texas and Michigan also play important roles in carrot farming, where carrots are among the most commonly consumed fresh vegetables (Nagraj *et al.*, 2020). Domestic carrot production in the U.S. satisfies a large portion of national demand, with imports filling the remainder. In 2019, carrot imports to the United States rose to 229,136 metric tonnes, up from 224,937 metric tonnes in 2018, indicating an increase in demand and a growing market (Intelligence from Mordor, 2020).

In Sub-Saharan Africa, Nigeria is the leading producer of carrots, ranking 32nd globally with an annual output of about 225,000 tonnes, or 37.5% of its full production capacity of 600,000 tonnes (Okwuonu *et al.*, 2021). In Ghana, carrots are considered an exotic vegetable, with higher demand and value in urban areas, where the country produces approximately 1,000 metric tonnes (Abu *et al.*, 2021).

2.7 Crop propagation

Carrots are typically sown directly into the field, requiring a smooth, well-prepared seedbed. Raised beds are recommended for carrot production, with row planting preferred over

broadcast sowing. Seed propagation is the most common method used by many gardeners (Singh, 2018). Carrots thrive in loose, well-aerated soil (Chopra and Koul, 2020). The recommended seeding depth is between 10 and 25 mm, or up to 40 mm in light, sandy soils. Rows should be spaced 25 cm apart. In heavier soils, planting should be shallow, while slightly deeper planting is advised during the summer months when the soil tends to dry out more quickly. Successful crop establishment is more likely if seeds are sown in moist soil and the soil is kept consistently moist. Row planting ensures proper plant density and simplifies weeding and pesticide application. Garden lines can assist in maintaining straight rows. For optimal quality and yield, seedlings should be free from diseases and insect damage. Thinning seedlings is important to prevent insect infestations, and row planting helps streamline farm operations (Megersa, 2022).

2.8 Agronomic practices

Crop production is guided by a set of well-established cultural practices, developed through a series of experiments by agricultural scientists (Mühl and de Oliveira, 2022). To fully harness a crop's potential, these management strategies must be properly implemented and adopted. The primary goal of every farmer is to maximize yield per unit area, and achieving this requires effective crop management. These practices, often referred to as cultural practices, encompass all the activities performed on the farm throughout the growing season (Palti, 2012). For carrots, for example, raised beds are ideal for growing, and they can also thrive in containers (Guinita, 2019).

Water requirements for carrots depend on soil moisture levels and climate conditions (Zedan *et al.*, 2022). When seedlings germinate too densely, thinning is necessary to remove excess

or weaker plants. This process is best carried out after rainfall, when the soil is moist, to minimize damage to the roots of surrounding plants. Insects and diseases pose a significant threat to crops, often leading to reduced yields or even total crop loss. Therefore, pest and disease management is crucial. This can be achieved through the use of resistant varieties, effective farm management practices, crop rotation, biological pest control (such as introducing natural predators), and, when necessary, insecticide applications.

2.9 Organic manure sources

Marine by-products, including oysters, crabs, lobsters, and sea urchins, are valuable nutrient sources in agricultural practices (Bello *et al.*, 2021). Alongside these marine sources, animal manure from cattle, horses, sheep, pigs, chickens, and goats, as well as plant residues such as hay, legumes, straw, alfalfa pellets, and seaweed, contribute to the production of organic fertilizers (Martínez-Alcántara & Quinones, 2016). Both plant-based and animal-based organic fertilizers supply essential macro- and micronutrients that enhance soil health and support plant growth (Martínez-Alcántara & Quinones, 2016). For instance, poultry manure is particularly rich in nitrogen, making it a key organic fertilizer (Awasth *et al.*, 2019). Additionally, cattle dung collected during the rainy season, when livestock graze on lush green grass, has a higher nutrient content compared to dung collected in the dry season (Asher & Brosh, 2022).

Organic manure consists of plant and animal waste at various stages of decomposition (Prasad *et al.*, 2020). Common sources include crop residues, decaying plant roots, green manure, decomposed soil microorganisms, and farmyard manure (Jakhar & Kumar, 2020). Farmers commonly use compost, plant materials like straw and dried leaves, garden waste, and green

manure to improve soil fertility (Kostenko *et al.*, 2021). Green manure refers to leguminous plants grown as cover crops, which are later incorporated into the soil to enrich its nutrient content (Kostenko *et al.*, 2021). In Florida, the three most widely used organic manure sources among organic farmers are poultry manure, bagged organic fertilizers, and fish emulsion products (Burnett *et al.*, 2016). While poultry manure serves as the primary nutrient source, 71% of citrus and vegetable growers use fish emulsion as a supplementary fertilizer.

Vanlauwe and Zingore (2015) highlighted the advantages of Integrated Soil Fertility Management (ISFM) practices, particularly the role of biological nitrogen fixation in enhancing soil fertility in tropical regions. Leguminous crops like cowpeas are particularly effective at improving soil fertility. Cowpeas grow quickly, produce abundant biomass, and decompose rapidly, enriching the soil (Ravi & Moore, 2021). As a living mulch, cowpeas shield the soil from direct sunlight and rainfall, reduce surface runoff and erosion, and improve soil structure and water infiltration (Osman, 2018). Cowpeas can fix up to 240 kg of nitrogen per hectare and contribute 60-70 kg of nitrogen per hectare to the soil for future crops (Katiana, 2020). Other leguminous species, such as *Gliricidia sepium*, are also used as mulch to boost crop yields by supplying essential nutrients to the soil (Awopegba *et al.*, 2017).

2.10 *Leucaena leucocephala*

Leucaena, named after the Greek words *leucus* meaning "white" and *caena* meaning "new," refers to the plant's characteristic whitish flowers. The species name *leucocephala* further emphasizes this feature, with *leu* meaning "white" and *cephala* meaning "head," describing the plant's white, globular flower clusters. Known as the "miracle tree," *Leucaena leucocephala* is recognized worldwide for its remarkable adaptability, longevity, and high

nutritional value as a forage tree. It serves various purposes, including firewood, timber, food for humans, green manure, shade, and erosion control. As a shrub or small tree, it can grow up to 10 meters tall and spread across cleared areas, forming dense thickets. *Leucaena* species are evergreen, drought-resistant, and produce abundant flowers (Mwendwa, 2021). The plant's leaves resemble those of the tamarind, with white flowers tinged with yellow and long, flattened pods (Mead, 2017). The seeds are dark brown, with a hard, shiny seed coat, and the wood is dense and heavy, featuring pale yellow sapwood and reddish-brown heartwood.

The leaves of *L. leucocephala* are compound and pinnate, with a rachis measuring between 5–10.2 cm in length. The leaves are bipinnate, consisting of 6–8 pairs of pinnae and 9–20 pairs of linear-lanceolate leaflets, 8–15 mm long and 2–4.5 mm wide. These leaflets are slightly asymmetric, with acute tips and smooth margins, except at the base, where they are rounded to obtuse. The plant's leaves fold in response to heat, cold, or water scarcity (Ishihara et al., 2018). The flowers grow in axillary, globular heads measuring 12–20 mm in diameter, with peduncles 2–3 cm long. The fruit pods mature to a dark brown, hard texture, measuring 10–15 cm long and 1.6–2.5 cm wide. Each pod contains 15–20 hard, shiny, brown seeds, which are flat and tear-shaped. This species is polyploid, with $2n = 104$ chromosomes.

The characteristics of *L. leucocephala* may vary depending on the variety and growing conditions (Al-Bugg, 2021), but it can flower year-round. Flower colors range from white to pale cream, and the pods are typically 11–19 cm long and 15–21 mm wide, linear-oblong in shape, with 8–18 seeds per pod. The seeds are hard, dark brown, and shiny, measuring 6.7–9.6 mm long and 4–6.3 mm wide. For centuries, *L. leucocephala* has been recognized as an excellent fodder source, with its nutritional value comparable to that of alfalfa (*Medicago sativa*), particularly due to its high β -carotene content (Prakash et al., 2020). The leaves are

commonly fed to chickens and pigs, and they are also processed into pellets for freshwater fish feed (Oosting *et al.*, 2021).

The dry matter digestibility (DMD) of *L. leucocephala* is 57.7%, and its crude protein content based on dry matter is 29.5%. In terms of forage quality, *L. leucocephala* surpasses other species like *L. pallida* and *L. diversifolia* (Radrizzani & Alejandro, 2019). The leaves contain 6.7% moisture, 22.76% crude protein, 22.29% crude fibre, 4.6% fat, and 9.73% ash. A study by Srinivasan *et al.* (2016) found that the leaves are the richest in minerals (12.5–14.0%) and crude protein (30.9–33.0%), while the twigs are high in crude fibre (31.5–37%) and calcium (1.9–2.1%). Dry seeds have the highest crude fat content (7.2–10.1%) and nitrogen-free extract (55.9–58.8%). Additionally, *L. leucocephala* leaves possess antimicrobial, nematicidal, and pesticidal properties (Awwad *et al.*, 2020).

Due to its positive effects on soil physical and chemical properties, *L. leucocephala* (in the form of biochar) is widely used as a soil conditioner (Jha *et al.*, 2016). This leguminous shrub can fix atmospheric nitrogen, improving soil fertility. It can fix between 150 to 300 kg of nitrogen per hectare, benefiting plant growth (Ishihara *et al.*, 2018). Along with its nitrogen-fixing capabilities, *L. leucocephala* produces high biomass and has excellent re-sprouting potential, making it a promising bioenergy source. It can be used as an alternative to traditional biomass feedstocks (Huang *et al.*, 2017). However, while biochar enhances soil productivity, it does not significantly increase nutrient levels in the soil (El-Naggar *et al.*, 2019).

2.11 Effect of organic manure on soil physical and chemical properties

Organic manure is primarily sourced from plants and animals, with examples including farmyard manure, green manure, and compost. These organic materials tend to be bulky and

have relatively low nutrient content, so they must be applied in large amounts to be effective (Biramo, 2018). Organic matter plays an essential role in improving soil health by acting as a reservoir for nutrients. It enhances cation exchange capacity, supports microbial activity, increases water retention, reduces soil compaction, and helps buffer rapid changes in acidity, alkalinity, and salinity. Additionally, it contributes to soil structure stabilization and improves tilth (Rawat *et al.*, 2020). According to Ahmad Bhat *et al.* (2022), higher levels of soil organic matter lead to greater structural stability, reduced bulk density, and improved soil pore balance, both fine and coarse. These changes enhance root penetration, boost erosion resistance, and improve soil moisture properties, including better water retention, permeability, and aeration. When organic matter levels decrease, these soil properties deteriorate, resulting in poor root growth and reduced water retention capacity (Zhang *et al.*, 2021).

Geng *et al.* (2019) found that organic manure improves both the physical and chemical properties of soil. Their study revealed that soils amended with organic manure had higher organic matter content, as well as increased levels of available potassium, phosphorus, and exchangeable calcium and magnesium, compared to untreated soils. The pH and water retention capacity of the soil also showed improvement (Haque *et al.*, 2021). Numerous experiments on manure application have consistently demonstrated its positive effects on soil organic carbon levels (Aula *et al.*, 2019). Furthermore, organic manure not only reduces bulk density but also enhances soil porosity and water retention (Şeker *et al.*, 2020).

Usharani *et al.* (2019) observed that animal waste enhances soil water retention by improving its structure. This leads to increased permeability and a greater proportion of soil porosity being utilized for water storage. Organic manure is known to supply essential macro- and

micronutrients that support plant growth, development, and yield (Jardin, 2015). Animal manures are particularly rich in nitrogen, phosphorus, and potassium (NPK), as well as exchangeable cations like calcium and magnesium, all of which are crucial for crop growth. The specific composition of manure provides a nutrient boost to the soil (Adugna, 2016).

Organic fertilizers are an important source of plant nutrients and play a vital role in maintaining soil fertility. They contribute to cation exchange capacity and act as buffering agents to reduce pH fluctuations, which helps sustain long-term soil health and crop development (Okon *et al.*, 2016). Organic matter's ability to retain nutrients in a plant-available form ensures sustained nutrient availability. The microbial decomposition of organic manure also releases calcium ions, further aiding in pH buffering (Shi and Xu, 2019). According to Manyi-Loh *et al.* (2019), animal manure improves soil pH, provides key macronutrients and micronutrients, and helps decrease exchange acidity, thereby reducing toxic elements such as aluminum (Al^{3+}) and iron (Fe^{2+}) in the soil.

2.12 Effect of chicken manure on soil physical and chemical properties

Poultry manure is a nutrient-rich organic fertilizer that significantly improves soil fertility and boosts organic matter content. When used in the right amounts, it enhances soil structure and promotes biological activity (Biramo, 2018). As the cost of synthetic fertilizers continues to rise, many farmers, especially those growing vegetables, are increasingly turning to poultry manure as an affordable and effective alternative. Poultry manure is particularly prized for its high nitrogen content (Alauddin, 2021), which typically ranges from 2.0 to 3.0 percent (Akuamoah-Boateng, 2016), making it more valuable than other types of farmyard manure, such as those from cows, goats, or horses. In southern Ghana, poultry manure has become an

important source of soil nutrients, with strong demand, especially among urban market gardeners (Okorosobo, 2017).

Like other organic fertilizers, poultry manure contains chelating agents that help maintain the solubility of micronutrients in the soil (Joshi *et al.*, 2020). When applied properly, it improves the soil's water retention, microbial activity, and overall physical and chemical properties (Laghari *et al.*, 2016). It benefits both light and heavy soils by enhancing aeration, aiding in seedbed preparation, supporting seed germination, promoting water infiltration, and stabilizing soil structure (Chhabra, 2021). Research by Sistani *et al.* (2019) found that poultry manure contains higher levels of organic matter compared to other manures. Ntsoane (2022) also reported that plots treated with poultry manure had higher levels of available phosphorus, potassium, exchangeable calcium, magnesium, and organic matter compared to those amended with cow dung or left untreated. The incorporation of organic manure can increase cation exchange capacity (CEC) from 14.3 C mol kg⁻¹ to 17.1 C mol kg⁻¹, improving soil fertility (Edgar & Ileana, 2021). Masud *et al.* (2020) observed that poultry manure can increase soil pH, helping to reduce soil acidity through ammonia release.

The application of poultry manure has a notable impact on the chemical properties of soil (Inal *et al.*, 2015). It increases levels of exchangeable calcium and magnesium, improves phosphorus uptake, and lowers concentrations of potentially harmful elements like iron, aluminum, and manganese. Bansal and Jagadamma (2021) found that incorporating chicken litter at depths of 15 to 30 cm increases soil organic carbon and nitrogen levels. The depth of manure application depends on the soil type and climate conditions: lighter, more permeable soils benefit from deeper incorporation, while heavier, moister soils require less. Proper tillage is necessary to reduce nitrogen and phosphorus losses due to volatilization and surface runoff

(Hlatshwayo, 2022). However, applying raw poultry manure just before planting can harm crops due to its caustic nature and the heat generated during decomposition (Bhatnagar *et al.*, 2022). To avoid ammonia toxicity, it is recommended to allow some time between manure application and planting. The rate of ammonification and nitrification processes in this context varies based on local climate and soil conditions.

As poultry farming increases, especially with the deep litter method, poultry manure is becoming more widely available. The nutrient composition of poultry manure typically includes nitrogen (1.0–1.5%), phosphorus (0.5–0.8%), and potassium (0.4–0.5%). The nitrogen content in pure poultry manure is generally higher than that from deep litter systems. These nutrient levels can also vary depending on the type of feed given to the poultry (Peng *et al.*, 2022). Overall, poultry manure is richer in nitrogen than in phosphorus and has a nitrogen efficiency that is about two-thirds that of synthetic fertilizers (Vimal *et al.*, 2022).

2.13 Effect of organic and inorganic fertilizers combination on soil physical and chemical properties

To overcome the high costs of chemical fertilizers and the limited availability of sufficient manure, it is crucial to combine organic and inorganic fertilizers. Qaim (2020) emphasizes that the integration of these two types of fertilizers is vital for achieving sustainable agricultural productivity. This combined approach has proven to be an effective fertility management strategy in many countries. Using both organic and inorganic fertilizers not only accelerates crop growth but also delivers long-term benefits, offering more lasting improvements than relying on either organic manure or chemical fertilizers alone.

Research by Anas *et al.* (2019) demonstrates that applying both organic and inorganic fertilizers enhances the physical properties of soil, reducing bulk density and increasing porosity and water retention. This approach improves soil structure by decreasing bulk density and enhancing its water-holding capacity, ensuring a steady supply of nutrients throughout the growing cycle while minimizing nutrient leaching (Fan *et al.*, 2021). While synthetic fertilizers rapidly release primary nutrients, organic manure provides a slower, more sustained release of these nutrients (NPK) and micronutrients, along with other compounds that promote plant growth. Additionally, organic manure helps bind soil particles, which improves moisture retention, water infiltration, and overall soil structure, thereby boosting productivity.

However, Bhatt *et al.* (2019) warn against relying exclusively on chemical fertilizers, as they can lead to increased soil acidity, nutrient leaching, imbalances, and deterioration of soil physical properties and organic matter. Conversely, Atakora *et al.* (2019) report that combining organic manure with inorganic fertilizers optimizes soil characteristics, improving acidity levels, nutrient content, and concentrations of essential elements such as NPK, iron, manganese, zinc, copper, nickel, and lead. A study by Adekiya *et al.* (2022) in southwestern Nigeria found that the combined use of organic manure and NPK fertilizer significantly increased soil organic carbon, nitrogen, phosphorus, potassium, calcium, and magnesium, compared to the use of either manure or chemical fertilizers alone, as well as the control group.

2.14 Effect of chicken manure on growth and yield of carrot

Poultry manure is highly regarded for its effectiveness in promoting the growth of various crops, whether used alone or in combination with commercial fertilizers (Sosinski *et al.*, 2022). Awad *et al.* (2021) emphasize the advantages of broiler litter, noting that it replenishes

essential plant nutrients, including nitrogen (N), phosphorus (P), potassium (K), and molybdenum (Mo), in the soil. Unagwu *et al.* (2022) observed that poultry manure application led to an increase in the number of leaves on okra plants. Likewise, Frempong *et al.* (2016) reported a significant rise in okra leaf count in plots treated with chicken manure compared to the control. In the same study, chicken manure also resulted in a greater number of branches in okra plants after nine weeks, outperforming other manure treatments. Furthermore, the application of chicken manure tripled the fresh weight of okra's roots, stems, and leaves compared to plots treated with cow dung, compost, or left untreated. Reddy *et al.* (2022) confirmed that manure use boosts okra growth by promoting the development of leaves and branches, a result consistent with Frempong *et al.* (2016), who found a two-fold increase in the number of okra pods in manure-treated plots compared to controls.

In maize production, Bhatt *et al.* (2020) discovered that poultry manure applied at rates of 6-8 tons per hectare outperformed NPK fertilizers, resulting in higher grain yields and biomass. They attributed these gains to improved soil physical properties and enhanced nutrient release facilitated by the manure. Similarly, Arif *et al.* (2021) found that applying 10 tons of poultry manure per hectare yielded better maize results than using the recommended inorganic nitrogen and phosphorus fertilizers.

For carrots, Etim *et al.* (2022) reported that those grown with chicken manure and neem showed significantly higher root and shoot weight per plant compared to those grown in control soil. Poku *et al.* (2014) also observed that carrots in poultry manure-amended soils had considerably larger root length and diameter. Additionally, experiments by Ewulo *et al.* (2018) showed that key growth parameters such as plant height, fruit length, fruit weight, fruit

diameter, and fresh fruit yield were all significantly higher in plots treated with chicken manure compared to the control.

2.15 Combined effects of organic and inorganic fertilizers on crop growth and yield

As the cost of chemical fertilizers continues to rise and the bulky nature of organic manure presents logistical challenges, the need to combine various nutrient sources to support crop growth has become increasingly important. The integrated use of organic manure and mineral fertilizers has proven to be an effective method for maintaining soil fertility worldwide (Upadhyay *et al.*, 2022). Jiang *et al.* (2017) suggest that a balanced approach, which combines NPK fertilization with organic manure, can significantly increase crop yields. Likewise, Kiponda *et al.* (2022) emphasize that integrating multiple fertility practices, such as mineral fertilizers, organic manure, and intercropping, can foster rapid crop growth, enhance ground cover, and optimize resource use by roots at various soil depths. In particular, poultry manure has been shown to complement inorganic fertilizers, resulting in improved crop yields when used together.

Combining poultry manure with mineral fertilizers generally provides a more balanced nutrient profile than using either manure or inorganic fertilizers alone (Verma *et al.*, 2021). Research on alternative nutrient delivery systems for okra growth found that plots treated with either poultry manure or inorganic fertilizers showed significantly better growth and yields compared to untreated control plots (Frempong *et al.*, 2016). Similarly, the combination of organic and inorganic fertilizers has been shown to boost crop yields and improve soil physical properties. For example, a mix of poultry manure and inorganic fertilizers improved seedling numbers, plant height, and yields of shallot bulbs (Handajaningsih *et al.*, 2021). In sorghum,

the combination of chicken manure with inorganic fertilizers led to better plant height, dry matter accumulation, and green yield (Allam & Mancinelli, 2022).

Field studies comparing the use of poultry manure and inorganic fertilizers, both separately and in combination, consistently show that the mixed approach yields superior results. Gezahegn (2021) explains that while inorganic fertilizers promote early crop establishment during the vegetative stage, organic manure provides a sustained release of nutrients throughout the crop cycle, supporting continuous growth. The combined use of mineral fertilizers and organic manure has been found to outperform the use of either input alone, across all application rates (Ehmann *et al.*, 2018). In an experiment with sweet pepper plants grown in newly reclaimed sandy soil, Ghabour and El-Yazai (2019) observed that combining organic manure with both bio-N-fertilizer and mineral N-fertilizers resulted in vigorous plant growth, reflected in increased plant height, leaf numbers, and shoot fresh weight.

The advantages of combining organic manure with fertilizers extend beyond vegetative growth to fruit production. This combined approach has been shown to increase the number of fruits per plant, improve fruit size, and enhance fruit quality, including better fruit length and flesh thickness. When used alongside NPK fertilizers, organic manure promotes crop growth and increases yields more effectively than either NPK or organic manure alone (Dev-Nath *et al.*, 2022). A recent study in southwestern Nigeria comparing poultry manure and NPK fertilizer on yam growth and yield found that the best results were achieved when both fertilizers were used together. This was attributed to improved nutrient use efficiency, including both macro- and micronutrients, as well as the additional growth-promoting substances in poultry manure (Agbede *et al.*, 2022).

In conclusion, a balanced approach that incorporates both NPK fertilizers and organic manure is essential for ensuring high and sustainable crop production (Adane *et al.*, 2020). For crops like cocoyam and sweet potatoes, combining organic manure with the appropriate amount of NPK fertilizer has been shown to result in higher production and more vigorous growth, including increased leaf numbers, compared to using NPK alone (Obalum *et al.*, 2020).

2.16 Impact of inorganic fertilizers (NPK) on carrot growth and yield

Ganeshamurthy *et al.* (2016) demonstrated that applying the full recommended NPK ratio of 100:60:80 can significantly enhance carrot root production, including root length and diameter. Both nitrogen and potassium are crucial for improving carrot root quality. Mahmoud and Ibrahim (2019) noted that nitrogen and potassium fertilization has a notable effect on the carotene content in carrot roots. Potassium, in particular, plays a vital role in plant growth by regulating mineral and carbohydrate movement through plant tissues, promoting early growth, supporting protein synthesis, reducing water stress, and boosting resistance to pests and diseases. Sufficient potassium also contributes to better shoot growth, weight, and dry matter content.

Khaliq *et al.* (2022) investigated the impact of potassium fertilization on carrot shelf life and periderm damage, finding that increased potassium levels resulted in linear growth in shoot length and both fresh and dry shoot weights. While potassium did not significantly affect root dry matter, it positively influenced root length, fresh root weight, and root diameter. Phosphorus is another essential nutrient for plant processes like growth, respiration, photosynthesis, energy storage, and early crop maturation (Khan *et al.*, 2022). Phosphorus availability is particularly important for carrot establishment and yield (Mwangi, 2021). In a study on carrot development with different nutrient applications, applying 20 kg/ha of phosphorus increased the production of medium and large carrots (25–50 mm and >50 mm in diameter, respectively) while reducing the number of small carrots.

Nitrogen also plays a critical role in carrot yield and quality, as it is a key component of proteins and amino acids. Luyima *et al.* (2021) found that nitrogen fertilization significantly enhanced carrot yield and quality, especially in sandy soils. Their study showed that carotenoid levels peaked at 55 mg, with the highest root yields observed at higher nitrogen application rates, although the best root quality was achieved at lower nitrogen levels. Similarly, Ahmad *et al.* (2021) observed that varying nitrogen and potassium application rates significantly affected both carrot yield and quality. Their study found that nitrogen fertilization increased root yield in direct proportion to the amount applied, with N100 increasing yield by 15.95%, N150 by 121.8%, and N200 by 136.7%, compared to the control. Additionally, nitrogen fertilizers sometimes had a greater impact on shoot weight than root yield, as noted by Habimana *et al.* (2014). In their research on nitrogen nutrition and flavour components in carrots, they observed that higher nitrogen levels generally increased overall biomass, but nitrogen fertilization had a stronger effect on shoot weight than on root yield. They also noted that lower nitrogen applications led to reduced nitrogen and nitrate content in both the plant and leachate, highlighting the need to optimize nitrogen levels for both yield and quality.

2.17 Biochar systems

Biochar is a type of biomass created through pyrolysis, a process in which organic materials such as agricultural residues, sewage sludge, or wood chips are heated in low-oxygen (anaerobic) conditions. It is then added to soils to increase the stock of stable organic matter, enhancing soil fertility (Das & Avasthe, 2020). The primary aim of using biochar is to introduce long-lasting organic carbon compounds into the soil (Jien *et al.*, 2021). In recent

years, biochar has gained popularity for its role in carbon sequestration, improving soil quality to boost agricultural productivity, and supporting bioremediation efforts (Gupta *et al.*, 2020).

The highly porous structure of biochar provides several benefits. Its surface can offer a protective habitat for beneficial bacteria, shielding them from predators, while its ability to retain water helps prevent microbial dehydration. Additionally, biochar can serve as an energy source through carbon reduction and contribute essential minerals to the soil. This combination of benefits makes biochar a valuable long-term supporter of soil health and beneficial microorganisms (Egamberdieva *et al.*, 2018).

Another advantage of biochar is its relatively low production cost. It can be produced locally, is easily accessible, and is environmentally sustainable (Gupta *et al.*, 2022). The pyrolysis of woody waste and crop biomass to create biochar offers substantial potential for increasing the natural rate of carbon sequestration in soils, reducing agricultural waste, and replacing fossil fuels with renewable energy sources. Biochar systems also show promise for improving crop yields and providing farmers with opportunities to access carbon markets, offering additional benefits beyond the conventional method of directly adding carbon to the soil (Singh *et al.*, 2019).

2.18 Biochar's nutrient contribution

From an agronomic perspective, harvesting crops can lead to a reduction in soil organic carbon and overall soil quality. This makes biomass extraction for bioenergy production unsustainable unless alternative sources of organic carbon are introduced to replace the carbon lost with the removed biomass (Björnsson & Prade, 2021). Biochar presents a promising solution to this challenge, as its large surface area and porous structure allow it to retain both

nutrients and water, while also providing a conducive environment for beneficial microbes (Anyanwu *et al.*, 2021).

A practical approach to addressing these issues is the use of small-scale pyrolysis plants to process biomass, with biochar produced as a byproduct. This biochar can then be applied as a soil amendment, offering an efficient method to improve soil quality. The properties of biochar, both physical and chemical, are influenced by various factors, such as the quality of the feedstock (including its ash, lignin, cellulose, and hemicellulose content) and the specific conditions of the pyrolysis process, especially the method and temperature used. The caloric content and ash composition of biochar, which contain various chemical elements, are key indicators of its quality (Jafri *et al.*, 2018).

2.19 Effect of biochar on physical and chemical properties of soils

Improved soil aggregation, along with reduced bulk density and tensile strength, leads to better soil pH, porosity, and water retention, while also promoting the stabilization of soil organic matter (Karamina & Fikrinda, 2020). Biochar, with its low density and high porosity compared to conventional soil particles, helps retain more air and water in the soil, thereby lowering bulk density (Werdin *et al.*, 2020). Soils treated with biochar demonstrate increased water-holding capacity due to the reduction in bulk density, which supports better root development and enhances microbial activity (Soliman *et al.*, 2022). For example, Feng *et al.* (2020) showed that biochar application reduced soil bulk density and encouraged rice growth. Similarly, biochar application decreased bulk density in Clarion loam soil, and Oladele (2019) found that, in the first year after biochar application, plant water availability improved in the top 20 cm of soil, with this effect continuing into the second year as bulk density remained

reduced. Kang *et al.* (2021) also noted that biochar can decrease soil tensile strength, which helps lower tillage costs.

Biochar further enhances the structure and function of soil organic matter. In a study of highly productive Clarion loam soil, biochar was found to have long-term benefits, even though it decomposes more slowly than typical organic matter. After 500 days, biochar improved nutrient aggregation and water retention (Purakayastha *et al.*, 2019).

Numerous studies support the idea that biochar increases the water-holding capacity of soil. For example, in southern Finland, applying 9 t/ha of biochar boosted water retention by 11% (Winning, 2015). A similar study on Clarion loam soil found that adding 40 t/ha of biochar increased water retention by up to 15% (Winning, 2015). However, Seyedsadr *et al.* (2022) observed that biochar's impact on water retention was more pronounced in soils with lower organic matter content (1–15 g/kg) and less notable in soils with higher organic matter. Furthermore, biochar has been shown to improve saturated hydraulic conductivity and infiltration rates (Hussain *et al.*, 2021).

In addition to improving water retention, biochar enhances soil aggregation and stability (Fan *et al.*, 2020). In clay soils, biochar improves aggregate stability and reduces colloidal material separation, helping to control soil erosion. In a wheat cultivation study over two growing seasons, biochar application (3 or 6 kg/m²) increased soil pH from 5.2 to 6.7 (Fetjah *et al.*, 2022). Another wheat trial found that applying 60 t/ha of biochar raised soil pH from 5.1 to 6.39.

4.20 Effect of Biochar and Inorganic Fertilizer on Soil Characteristics, Plant Growth, and Yield

Biochar is increasingly recognized as a beneficial soil amendment due to its ability to improve nutrient availability and support sustainable agricultural practices. When used alongside synthetic fertilizers, biochar can enhance the effectiveness of organic fertilization (Burezq *et al.*, 2021). Fendel *et al.* (2022) suggested that combining biochar with fertilizers can optimize nutrient use efficiency, compared to applying them separately. However, Butphu *et al.* (2020) found that biochar alone, without nitrogen fertilizers, did not increase radish yields, which supports the idea that biochar is more effective when paired with nitrogen fertilizers. Gandahi *et al.* (2015) demonstrated that applying biochar with a reduced rate of NPK fertilizers significantly boosted maize plant height, with the best results achieved by using 25% less than the recommended NPK rate and 10 t/ha of biochar.

Chhabra (2021) observed that combining biochar with fertilizers greatly enhanced corn growth in sterile Oxisols. In both the first and third crop cycles, the biochar-fertilizer combination resulted in a doubling of corn growth in the first cycle and a tripling in the third cycle compared to using only inorganic fertilizers. Biochar-treated soil also showed improvements in organic matter, pH, available phosphorus, and cation exchange capacity (CEC), indicating its role in enhancing soil fertility by boosting nutrient retention and organic matter content (Fachini *et al.*, 2021).

Biochar also influences nitrogen dynamics in the soil. Mulatu (2022) found that biochar significantly reduced nitrate-N concentrations in biochar-amended soils, likely because biochar adsorbs nitrogen fertilizers and inhibits nitrification, leading to lower nitrate levels

after application. Mahmoud *et al.* (2019) concluded that biochar application could enhance both soil fertility and crop yields.

Several studies have reported positive effects of biochar on crop yields, particularly in nutrient-poor soils. For example, Lynch and Thomason (2016) observed a 91% increase in maize grain yield and a 44% increase in biomass when biochar was applied to soils in Ghana. In Kenya, eucalyptus-derived biochar improved maize yields in degraded soils (Dhir, 2021), and in Laos, biochar enhanced rice yields in phosphorus-deficient areas (Oladele, 2019). However, Hussain *et al.* (2017) noted that biochar reduced leaf chlorophyll levels in nitrogen-deficient soils, suggesting that without additional nitrogen, biochar could limit grain production in such soils.

The impact of biochar on yields in nutrient-rich soils remains unclear, with some studies reporting slight yield increases and others showing minimal or even negative effects. Cuthbertson *et al.* (2019) found that higher biochar application rates led to a linear decrease in grain production, highlighting the context-dependent nature of biochar's effects on crop yield. Factors such as biochar type, application rate, soil properties, and climate all play a role in its effectiveness (Aller *et al.*, 2018).

A meta-analysis by Kalu *et al.* (2021) found a modest but significant increase in grain yield from biochar application, attributed to its liming effect and improved water retention. However, most studies have focused on short-term effects (1–2 years), and more long-term research is needed to fully understand biochar's impact on agricultural productivity. Hussain *et al.* (2017) reviewed 44 studies on biochar and found that approximately half reported increased crop yields following biochar application.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Experimental site and location

Two field experiments were conducted at different locations within the Multipurpose Crop Nursery on the Mampong campus of the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development (AAMUSTED) in 2021 and 2022. The first experiment was carried out from September to December 2021, coinciding with the minor rainy season, while the second experiment took place from April to July 2022, during the major rainy season. Mampong-Ashanti is situated in the Forest-Savanna Transitional Zone, at an altitude of 457.5 meters above sea level. It is located between latitudes 7° and 8° North of the Equator and longitudes 1° and 24° West of Greenwich (MSD, 2018). The region, which spans much of the Ashanti Region and extends into parts of the Bono Region, experiences an average annual rainfall of about 1300 mm, with a bimodal rainfall pattern. The major rainy season lasts from April to July, while the minor rainy season occurs from September to November, with a short dry period typically in August separating the two (Nkrumah *et al.*, 2019). The relative humidity is generally high, ranging from 75% to 97% in the mornings, and decreases to between 73% and 32% in the afternoons, depending on the season. The daily temperature varies between 24.4°C and 28.6°C (Nkrumah *et al.*, 2019).

3.2 Soil type and Vegetation

The soil at the experimental site is derived from Voltarian sandstone in the Afram Plains and is classified as a Savanna Ochrosol. It is a deep, sandy loam with no pebbles, well-drained, and contains moderate levels of organic matter. The soil exhibits good water retention capabilities. According to the FAO/UNESCO (2008) classification system, it is identified as

Chromic Luvisol and is locally known as the Bediesi series. The soil pH ranges from 6.0 to 6.5. The area has previously been used to cultivate a variety of crops, including carrots, tomatoes, maize, cowpeas, okra, sweet potatoes, tubers, cereals, and legumes. Common grass species in the region include nut grass (*Cyperus rotundus*), giant grass (*Cynodon plectostachyum*), and guinea grass (*Panicum maximum*).

3.3 Experimental design and treatments

3.3.1 Experimental design

The experimental design used was a 2 x 6 factorial arrangement within a Randomized Complete Block Design (RCBD), comprising twelve treatments, each repeated four times. The study involved two factors: (A) carrot varieties, which included (i) Technisen and (ii) Tokita, and (B) fertilizer application rates, which consisted of: (i) 10 t/ha of chicken manure (CM), (ii) 250 kg/ha of NPK fertilizer (15:15:15), (iii) 10 t/ha of Leuceana biochar (LB), (iv) 5 t/ha of CM + 5 t/ha of LB, (v) 5 t/ha of LB + 125 kg/ha of NPK (15:15:15), and (vi) a control with no fertilizer.

3.3.1 The total number of Treatment combinations is provided in table 3.1

Table 3.1 Treatment combinations

Treatment	Variety	Fertilizer
T1	Technisen	10 t/ha chicken manure (CM)
T2	Technisen	250 kg/ha N.P.K (15:15:15)
T3	Technisen	10 t/ha Leuceana Biochar (LB)
T4	Technisen	5 t/ha Chicken Manure + 5 t/ha Leuceana Biochar (LB)
T5	Technisen	5 t/ha Leuceana Biochar +125 kg/ha N: P: K (15: 15:15)
T6	Technisen	No fertilizer (Control)
T7	Tokita	10 t/ha chicken manure (cm)
T8	Tokita	250 kg/ha N.P.K (15:15:15)
T9	Tokita	10 t/ha Leuceana Biochar (LB)
T10	Tokita	5 t/ha Chicken Manure + 5 t/ha Leuceana Biochar (LB)
T11	Tokita	5 t/ha Leuceana Biochar +125 kg/ha N: P: K (15: 15:15)
T12	Tokita	No fertilizer (Control)

Table 3.2 Treatment combinations

Treatments code	Component of treatments	Fertilizer Rates		
		CM (kg/m ²)	NPK (kg/m ²)	LB (kg/m ²)
T1	Technisen + CM	3.6		
T2	Technisen + NPK		0.4	
T3	Technisen + LB			3.6
T4	Technisen + CM + LB	1.8		1.8
T5	Technisen + LB + NPK		0.2	1.8
T6	No fertilizer (Control)			
T7	Tokita + CM	3.6		
T8	Tokita + NPK		0.4	
T9	Tokita + LB			3.6
T10	Tokita + CM + LB	1.8		1.8
T11	Tokita + LB + NPK		0.2	1.8
T12	No fertilizer (Control)			

CM = Chicken manure; LB = *Leuceana leucocephala* Biochar

3.4 Organic Manure preparation

Poultry manure was sourced from the poultry farm at the AAMUSTED Mampong Campus. It was piled under shade and covered with a black polythene sheet for two weeks to undergo further decomposition. During this period, the temperature stabilized before the manure was incorporated into the soil.

Leucaena leucocephala Biochar Preparation

The biomass of *Leucaena leucocephala* was collected from the AAMUSTED crop farm in Asante Mampong. To produce biochar, the *L. leucocephala* cuttings were covered with sand to limit oxygen exposure and subjected to slow pyrolysis at approximately 500°C in an anoxic heap reactor. After pyrolysis, the biochar was crushed and ground into a fine powder with a particle size of less than 2 mm. The powdered biochar was applied one week after preparing the planting beds, incorporated into the soil to a depth of 10 cm according to the designated treatment rates, and left to rest for two weeks before planting.

3.6 Planting Materials

New improved Kuroda (Techisen and Tokita) varieties of carrot seeds was obtained from Kyeiwaa Agrochemical Shop in Ashante Mampong. Tokita matures within 65-70 days after planting whereas Technisen takes about 60-65 days to mature.

3.7 Land Preparation

The land was marked out, ploughed, harrowed, and then lined and pegged in mid-September 2021 for the minor cropping season, and again in March 2022 major cropping season.

3.8 Bed preparation, Manure and Biochar application and planting

Raised beds measuring 2 m x 2 m were constructed to a height of 25 cm and leveled accordingly. A 1.0 m walkway was left between each bed, and a 2.0 m gap was maintained between replications. Chicken manure and *Leucaena leucocephala* biochar were applied to the beds according to the treatment specifications to allow for further decomposition. Carrot seeds were sown at a depth of 1-2 cm and later thinned to a spacing of 25 cm between rows and 10 cm between individual plants. To retain moisture, the beds were covered with grass straw. Two improved carrot varieties, Kuroda (Tokita) and Techisen, were used in the study. Each plot contained eight rows, with 20 plants per row, amounting to 160 plants per plot.

3.9 Soil and Biochar Sampling and Analysis

Before ploughing, soil samples were randomly gathered from five distinct spots within each plot and block at a depth of 0-15 cm. These samples were combined, air-dried, and then divided into sub-samples for analysis before planting. Additionally, samples of biochar and chicken manure were collected and tested. Routine laboratory tests on the soil, biochar, and chicken manure were carried out at the Soil Science Laboratory, Department of Crop and Soil Sciences, KNUST, Kumasi, Ghana. The analyses included evaluations of soil texture, pH, organic matter content, total nitrogen, exchangeable cations (calcium, magnesium, potassium, sodium), exchangeable acidity (aluminium and hydrogen), and organic carbon content.

3.10 Cultural Practices

Weed control was carried out manually using a cutlass and hoe throughout both cropping seasons, with four weeding sessions in total. Every two weeks, the area between the carrot

plant rows was gently stirred with a hand fork to prevent the roots from greening. Irrigation was conducted twice a day, in the morning and evening, except during rainfall periods up to 21 days after sowing (DAS). Initially, a 15-liter watering can was used per plot, which was increased to two cans per plot as the plants grew, ensuring the soil remained moist throughout the growing period.

Seedlings were thinned 21 days after germination to achieve an intra-row spacing of 10 cm and an inter-row spacing of 25 cm. NPK fertilizer (15:15:15) was applied at rates of 250 kg/ha and 125 kg/ha, as per the treatment schedule, two weeks after planting. For each 4 m² bed, 120 g of NPK was applied via side dressing, placed 3 cm from the base of the seedlings. Earthing-up was done bi-weekly after thinning to cover any exposed roots, followed by watering to ensure proper soil coverage.

3.11 Data collected

3.11.1 Soil chemical and physical analysis

Soil chemical and physical analyses, which included assessments of pH, total nitrogen, organic carbon, organic matter, available phosphorus, particle size distribution (clay, sand, silt), and exchangeable cations (calcium and magnesium), were performed at the Soil Science Laboratory within the Department of Crop and Soil Sciences at KNUST.

3.11.2 Plant Height

Plant height was measured from the soil surface to the tip of the longest shoot on five randomly selected plants from the four central rows. Measurements were taken starting at 21

days after planting (DAP) and repeated every two weeks thereafter. The average plant height for each treatment was then calculated and recorded.

3.11.3 Number of leaves per plant

The number of leaves per plant was counted on the five randomly selected plants from each plot. The average number of leaves per plant was then recorded. This process was carried out starting at 21 days after planting (DAP) and repeated every two weeks thereafter.

3.11.4 Canopy width

Canopy width was measured starting at 21 days after planting (DAP) and every two weeks thereafter. The width was determined by measuring the distance between the tips of two diagonal leaves with the widest spread, using a meter rule. The average measurements were then recorded.

3.11.5 Dry shoot and root weight

At 5 weeks after planting (WAP) and every two weeks until 11 WAP, four plants were randomly selected from the border rows of each plot. The plants were carefully uprooted, ensuring the roots were not damaged, and the soil was washed off before drying them under shade. The roots and shoots were separated, with both being destructively sampled for fresh weight. Fresh weights of the roots and shoots were measured using an electronic scale, and average values were recorded. To determine dry weight, 200g samples of both roots and shoots were oven-dried for 72 hours at 70-75°C in the Crop Science Laboratory at

AAMUSTED, Mampong campus. After drying, the samples were weighed, and the mean dry weights for both the roots and shoots were calculated.

3.11.6 Crop growth rate

This was calculated in g/m²/day using the formula outlined by Pandey et al. (2017):

$$\text{CGR} = (1/\text{GA}) \times ((\text{W2} - \text{W1}) / (\text{T2} - \text{T1}))$$

Where:

CGR = crop growth rate

W1 = total dry matter at the first harvest

W2 = total dry matter at the second harvest

T1 = days of observation at the first harvest

T2 = days of observation at the second harvest

3.11.7 Relative Growth Rate

This was calculated in g/m²/day using the formula provided by Pandey et al. (2017):

$$\text{RGR} = ((\text{LnW2} - \text{LnW1}) / (\text{T2} - \text{T1}))$$

Where:

RGR = relative growth rate

W1 = total dry matter at the first harvest

W2 = total dry matter at the second harvest

T1 = days of observation at the first harvest

T2 = days of observation at the second harvest

Ln = natural logarithm

3.11.8 Root length

At harvest, five plants were randomly chosen from each treatment plot. The roots were measured from the crown to the tip using a 30 cm ruler, and the average length was recorded.

3.11.9 Root diameter

At harvest, five roots were randomly chosen from the four harvestable rows of each plot. The root diameter was measured 2 cm from the top to the tip using a vernier caliper, and the average diameter was then calculated.

3.11.10 Root yield

The root yield from the harvestable area of each plot, consisting of twenty plants, was determined by weighing the roots on an electronic balance after removing the leaves and cleaning off any soil or debris. The yield for each plot's harvestable area was then calculated and expressed in t/ha using the formula provided by Amanullah *et al.* (2019).

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

3.11.11 Marketable yield

Roots weighing more than 35 grams and free from deformities such as cracks, nematode damage, forked shapes, disease, malformations, or discoloration were selected from each plot. These roots were then weighed, and the average weight was recorded.

3.11.12 Non-marketable yield

Roots exhibiting abnormalities such as cracks, nematode damage, forked or deformed shapes, spots, or those weighing less than 35 grams were collected from each plot, weighed, and the average weight was recorded.

3.11.13 Number of Cracked roots per plot

Cracked roots were collected from each plot, and the total count was recorded.

3.11.14 Number of Forked roots per plot

All branched roots from each plot were collected and counted, and their totals recorded.

3.11.15 Number of Deformed roots per plot

All roots with abnormal shapes were grouped and counted, and the total number was recorded.

3.11.16 Harvest Index

At harvest, twenty-four plants from the two central rows of each plot were harvested, and the roots were separated from the above-ground parts. The weight of each part was recorded, and the harvest index was calculated as the ratio of root yield to the total plant biomass yield.

3.12 Statistical Analysis

The collected data were analyzed using Analysis of Variance (ANOVA) with the GenStat Release 18.1 Statistical Package. Significant differences between means were determined and compared using Tukey's Honestly Significant Difference (HSD) test at the 5% significance level. Furthermore, correlation analysis was conducted to evaluate the relationships between vegetative growth, yield, and yield components of carrots.

CHAPTER FOUR: RESULTS

4.1 Biochar, Chicken Manure and Soil Analysis

4.1.1 Chemical properties of biochar and chicken manure used in the field studies

Table 4.1 presents the nutrient composition of the biochar and chicken manure used in the study. Based on the 2007 soil nutrient guidelines from the CSIR-Soil Research Institute (SRI, 2007), both chicken manure and biochar exhibited high levels of total nitrogen (N) and potassium (K). Chicken manure contained the highest concentrations of total nitrogen, phosphorus, potassium, calcium, and magnesium. In contrast, biochar was particularly rich in organic carbon and had a higher carbon-to-nitrogen ratio. The pH of chicken manure was slightly alkaline, while biochar had a neutral pH (SRI, 2007) (Appendix 1).

Table 4.1: Chemical properties of the chicken manure and biochar used in the studies

Property	Total N (%)	Total P (%)	K (%)	Ca (%)	Mg (%)	(%) Org. C	pH	C: N ratio
Biochar	1.27	0.18	1.34	0.82	0.40	66.14	6.87	37.52
Chicken manure	2.55	1.34	1.98	1.29	0.41	44.23	7.14	17.35

4.1.2 Soil Characteristics

Table 4.2 presents the initial chemical and physical properties of the background soil at the experimental site. The soil pH at the site for both the 2021 and 2022 cropping seasons was highly acidic (Table 4.2). The levels of available phosphorus (P) and total nitrogen (N) were moderate (Table 4.2). Organic matter content was low in both seasons, and the levels of calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) were also low in both years (Table 4.2). The soil's textural class at both experimental sites was sandy loam (Table 4.2).

Table 4.2: Initial physical and chemical properties of the soil

	2021	2022
pH	4.81	4.39
Avail. P (mg/kg)	15.55	10.65
Total nitrogen 9%)	0.14	0.12
Org. Carbon (%)	0.32	0.31
Org. matter (%)	0.42	0.60
Exch. Bases (cmol/kg)		
K	0.16	0.13
Ca	1.50	1.11
Mg	1.04	0.04
Na	0.01	0.02
Exch. Acidity (cmol/kg)		
Al	0.33	0.43
H	0.23	0.25
Particle size analysis		
(%)		
Sand	87.40	85.47
Clay	6.96	8.80
Silt	5.64	5.64
Textural class	Sandy Loam	Sandy Loam

4.1.3 Final chemical properties of the soil during 2021 minor and 2022 major cropping seasons

In the 2021 minor cropping season, the treatments of 5 t/ha chicken manure (CM) + 5 t/ha Leucaena biochar (LB) and 10 t/ha CM resulted in higher soil pH levels compared to other amended plots and the control (Table 4.3). The manure-treated plots had higher concentrations of available phosphorus (P), calcium (Ca), nitrogen (N), magnesium (Mg), and organic matter than the plots treated with only NPK, biochar, or the control. The combination of 5 t/ha CM + 5 t/ha LB achieved the highest levels of potassium (K), hydrogen (H), organic matter, and organic carbon compared to the control plots. In contrast, the 250 kg/ha NPK treatment produced the highest aluminum (Al) levels among all treatments and the control.

In the 2022 major cropping season, the application of 10 t/ha LB resulted in higher levels of total nitrogen, exchangeable bases (K and Ca), compared to the sole NPK, chicken manure, 5 t/ha CM + 5 t/ha LB, 5 t/ha LB + 125 kg/ha NPK, and control plots (Table 4.3). The 5 t/ha CM + 5 t/ha LB treatment had the highest levels of magnesium (Mg), aluminum (Al), and available phosphorus (P) compared to other amended and unamended treatments. Additionally, the 10 t/ha CM treatment increased soil pH, sodium (Na), and hydrogen (H) levels. The combination of 5 t/ha LB + 125 kg/ha NPK recorded the highest organic carbon (OC%) and organic matter content in the soil (Table 4.3). When compared to the initial soil sample, all amended plots showed higher levels of available P, total nitrogen, total exchangeable bases (TEB), exchangeable acidity (EA), organic carbon, and organic matter than the control.

Table 4.3: Final chemical properties of the soil and soil plus amendments after harvesting of carrot

SAMPLE NAME (SOIL)	pH	Avail. P mg/kg	N (%)	Exch. Bases (cmol/kg)				Exch. Acidity		% Org. C.	% Org. M.
				K	Ca	Mg	Na	Al	H		
2021 minor cropping season											
10 t/ha CM (full)	6.45	47.62	0.210	0.195	2.40	1.20	0.041	0.342	0.242	0.439	0.757
250 kg/ha NPK (full)	6.44	23.25	0.140	0.228	1.84	0.96	0.041	0.352	0.249	0.479	0.825
10 t/ha LB (full)	6.63	15.66	0.147	0.202	1.80	1.00	0.042	0.351	0.242	0.469	0.808
5 t/ha CM + 5 t/ha LB	6.73	23.86	0.116	0.268	2.00	1.20	0.041	0.342	0.276	0.559	0.963
5 t/ha LB + 125 kg/ha NPK	6.40	17.96	0.147	0.205	1.70	1.14	0.042	0.344	0.257	0.419	0.722
No amendment (Control)	4.88	12.03	0.121	0.163	1.52	1.14	0.012	0.316	0.239	0.305	0.319
2022 major cropping season											
10 t/ha CM (full)	6.82	27.09	0.121	0.197	1.68	1.28	0.043	0.341	0.289	0.379	0.653
250 kg/ha NPK (full)	6.55	19.94	0.143	0.328	2.10	1.10	0.043	0.339	0.271	0.200	0.344
10 t/ha LB (full)	6.62	24.11	0.176	2.333	2.22	1.04	0.042	0.344	0.256	0.351	0.605
5 t/ha CM + 5 t/ha LB	6.38	33.89	0.143	0.262	1.81	1.29	0.042	0.346	0.252	0.279	0.482
5 t/ha LB + 125 kg/ha NPK	6.16	21.68	0.151	0.229	1.60	0.88	0.042	0.347	0.269	0.439	0.757
No amendment (Control)	4.05	12.51	0.128	0.168	1.44	0.12	0.013	0.322	0.249	0.249	0.316

4.2 Climatic conditions at the experimental sites

Table 4.4 summarizes the climatic conditions at the experimental sites during the study period. From August to December 2021, the total monthly rainfall for the minor cropping season was 676.7 mm, with the heaviest rainfall occurring in September and October, at 225.1 mm and 208.7 mm, respectively. The average monthly temperature during this period ranged from 23.1°C to 31.9°C, while the mean relative humidity was 70.4%, with the highest daily temperature of 34.3°C recorded in December 2021.

For the 2022 major cropping season, a total of 694.6 mm of rainfall was recorded between March and July, with the highest rainfall occurring in July and the least in April (Table 4.4). The average monthly temperature ranged from 23.4°C to 32.2°C, and the average relative humidity remained at 70.4%.

Table 4.4: Climatic conditions for experimental sites during 2021 minor cropping season and 2022 major season

Month	Total Rainfall (mm)	Relative Humidity (%)	Mean Temperature (°C)	
			Max	Min
2021 Minor Season				
August	169.5	77	29.7	22.7
September	225.1	77	30.3	23.2
October	208.7	72	32.1	22.3
November	73.4	68	33.1	23.4
December	0.0	58	34.3	23.7
Total	676.7			
2022 Major Season				
March	109.2	67	34	23.9
April	79.6	66	33.1	23.5
May	147.8	71	32.7	23.8
June	149.0	74	31	23.3
July	203.6	74	30	22.7
Total	694.6			

4.3 Growth Performance

4.3.1 Plant height

Figure 4.1 shows that Tokita consistently grew slightly taller than Technisen throughout the sampling period, from 21 to 77 days after planting (DAP), with a significant difference ($P \geq 0.05$) observed between the two carrot varieties during both the 2021 minor and 2022 major cropping seasons. Significant differences ($P \leq 0.05$) in plant height were also observed among the different fertilizer treatments applied during both seasons (Figures 4.3 and 4.4). Carrot plants treated with 10 t/ha of chicken manure (CM), followed by the combination of 5 t/ha CM + 5 t/ha Leucaena biochar (LB), produced the tallest plants from 21 to 77 DAP in both seasons, with these treatments showing a significant ($P \leq 0.05$) increase in plant height compared to the control (no amendment). The control plots consistently resulted in the shortest plants across both cropping seasons (Figure 4.2).

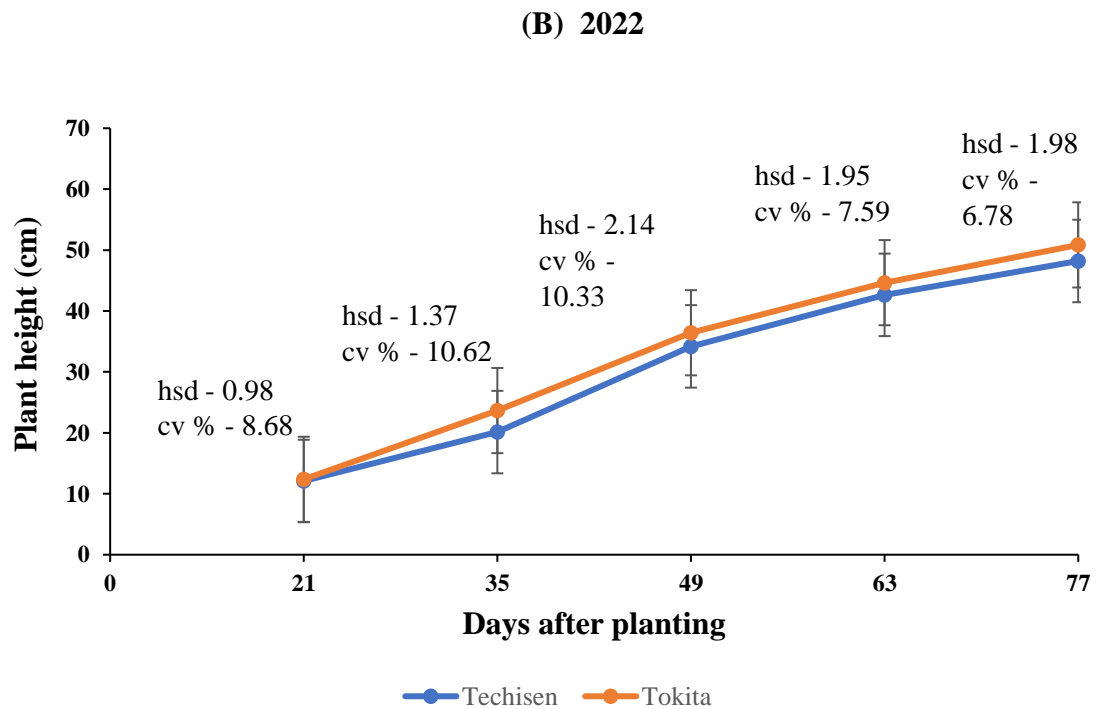
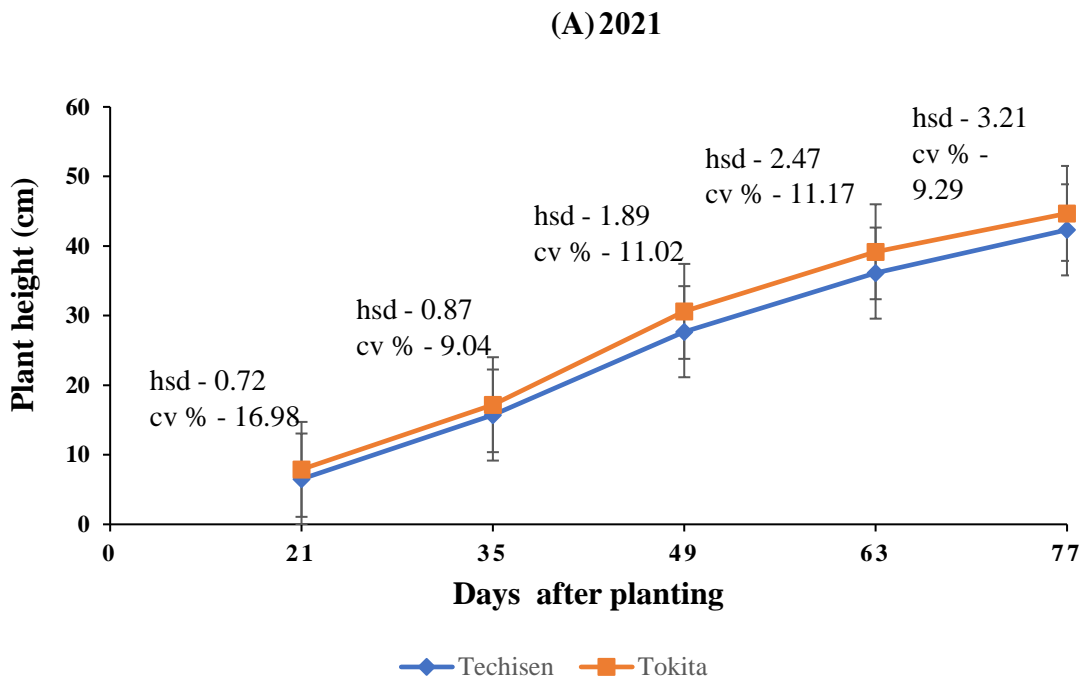


Figure 4.1: Plant height of carrots as affected by varieties during the 2021 minor and 2022 major cropping seasons.

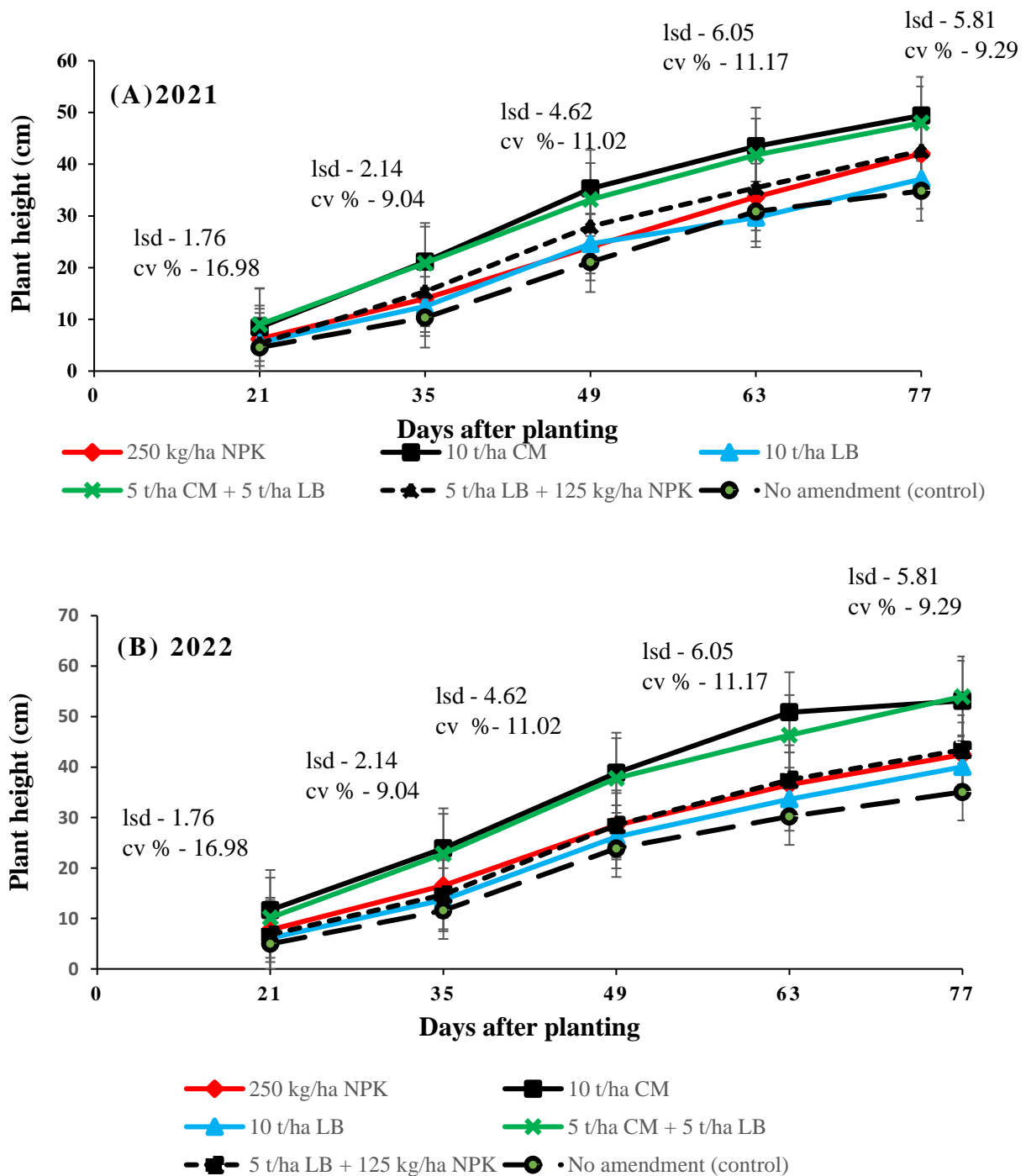


Figure 4.2: Plant height of carrots as affected by fertilizer rates during the 2021 minor and 2022 major cropping seasons.

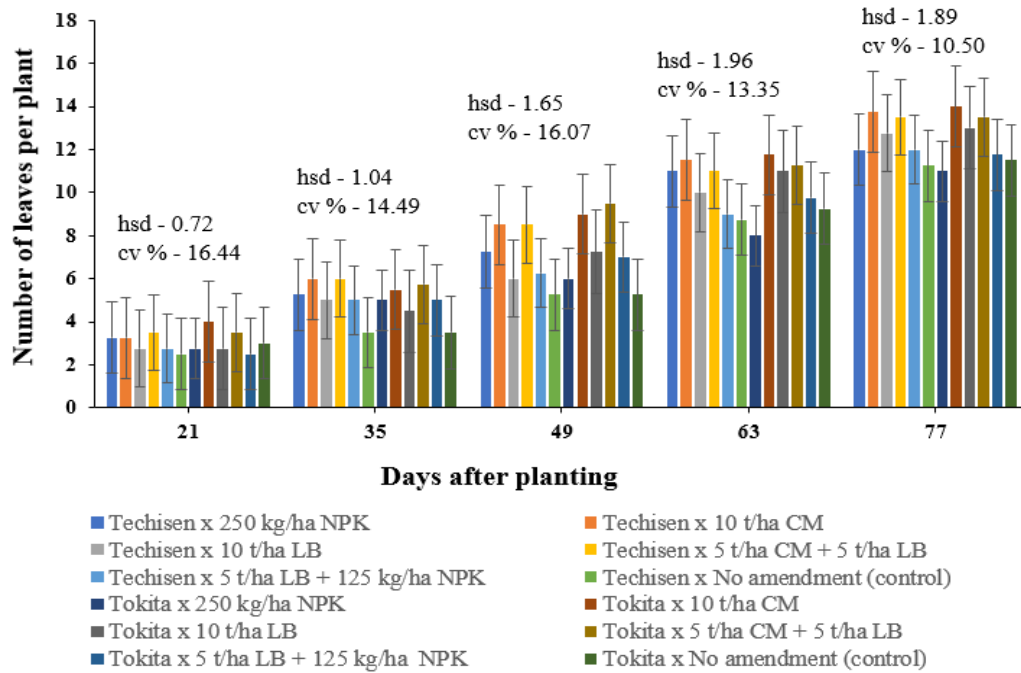
4.3.2 Number of leaves per plant

There was no significant ($P \geq 0.05$) difference in the number of leaves per plant between Technisen and Tokita from 21 to 77 days after planting (DAP) in both cropping seasons. However, the number of leaves per plant increased across all fertilizer treatments from 21 to 77 DAP in both the 2021 minor and 2022 major cropping seasons. Figure 4.3 illustrates how the number of leaves per plant was influenced by the interaction between varieties and fertilizer treatments during both cropping seasons.

Overall, there was a consistent increase in the number of leaves per plant from 21 to 77 DAP in both seasons. During the 2021 minor cropping season, Tokita treated with 10 t/ha chicken manure (CM) had significantly more leaves per plant than both varieties grown with other treatments or in the control plot. From 35 to 77 DAP, there were no significant differences ($P \geq 0.05$) between the interactions of Technisen and 10 t/ha CM, Technisen and 5 t/ha CM + 5 t/ha Leucaena biochar (LB), Tokita and 10 t/ha CM, and Tokita and 5 t/ha CM + 5 t/ha LB. However, these treatments differed significantly ($P \leq 0.05$) from the control, which had the fewest leaves per plant during the same period (Fig. 4.3).

In the 2022 major cropping season, both varieties grown with amended treatments showed significant ($P \leq 0.05$) increases in the number of leaves per plant compared to the unamended control plot from 21 to 77 DAP (Fig. 4.3). Technisen and Tokita treated with 10 t/ha CM and 5 t/ha CM + 5 t/ha LB had the highest number of leaves per plant, with these treatments significantly differing from both varieties grown with other amendments and the control plot throughout the growing period (Fig. 4.3).

(A) 2021



(B) 2022

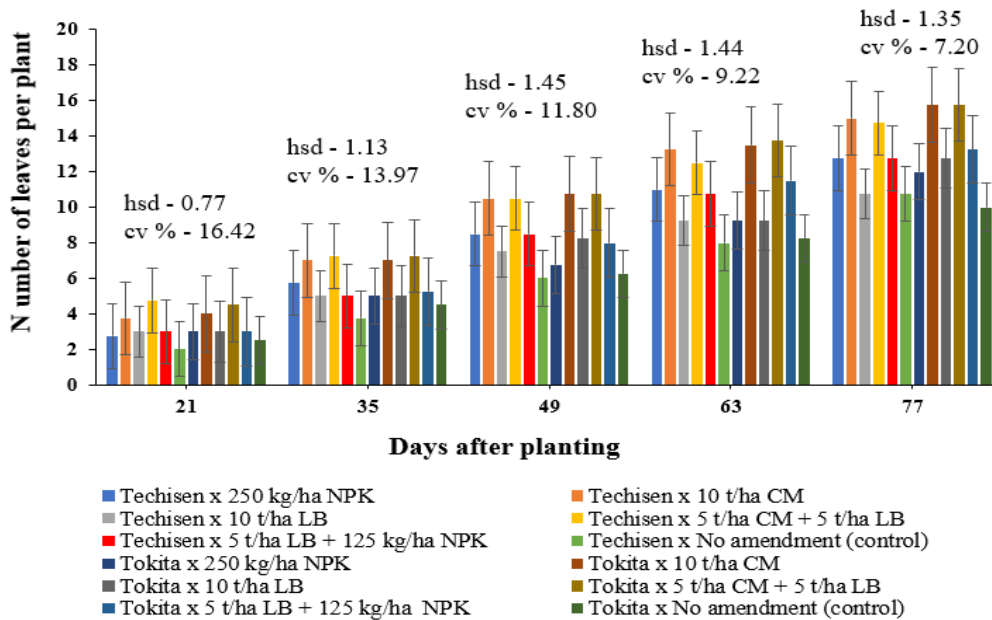


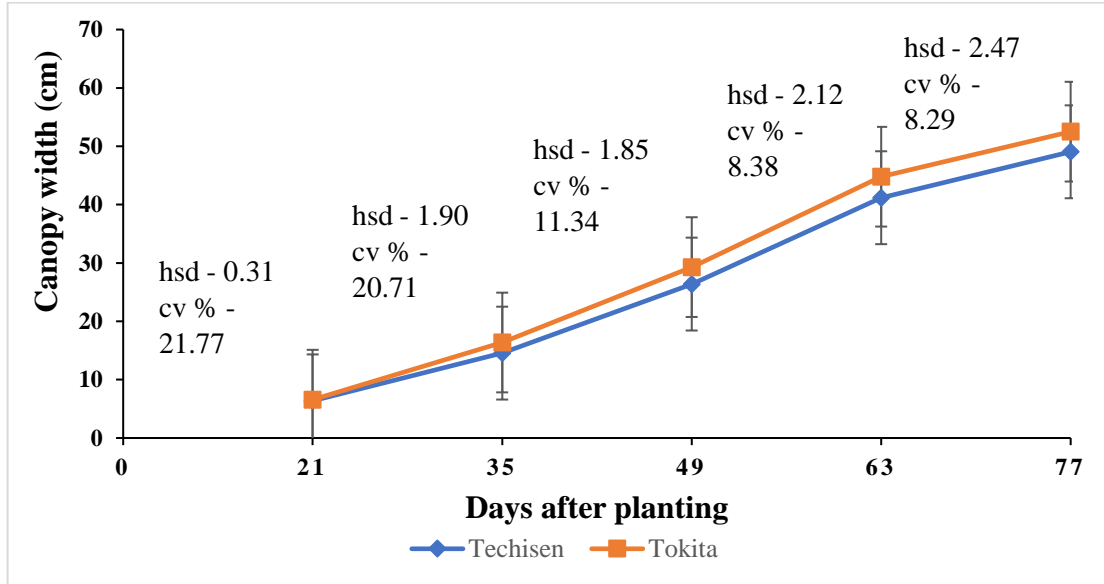
Figure 4.3: Number of leaves per plant as affected by the interaction of varieties x fertilizer rates during the 2021 minor and 2022 major cropping seasons

4.3.3 Canopy width

Figure 4.4 illustrates the impact of carrot varieties on canopy width during the 2021 minor and 2022 major cropping seasons. There was no significant ($P \geq 0.05$) difference in canopy width between Technisen and Tokita at 21 days after planting (DAP) in either season. However, Tokita had a significantly wider canopy than Technisen from 35 to 77 DAP across both seasons (Fig. 4.4).

Overall, canopy width steadily increased for plants treated with 10 t/ha chicken manure (CM) and 5 t/ha CM + 5 t/ha Leucaena biochar (LB) from 21 to 77 DAP in both seasons (Fig. 4.4). These treatments consistently showed significantly wider canopies than the other amended treatments and the control, from 21 to 77 DAP in both seasons. The control plots, which received no amendments, consistently had the narrowest canopy width throughout both cropping seasons.

(A) 2021



(B) 2022

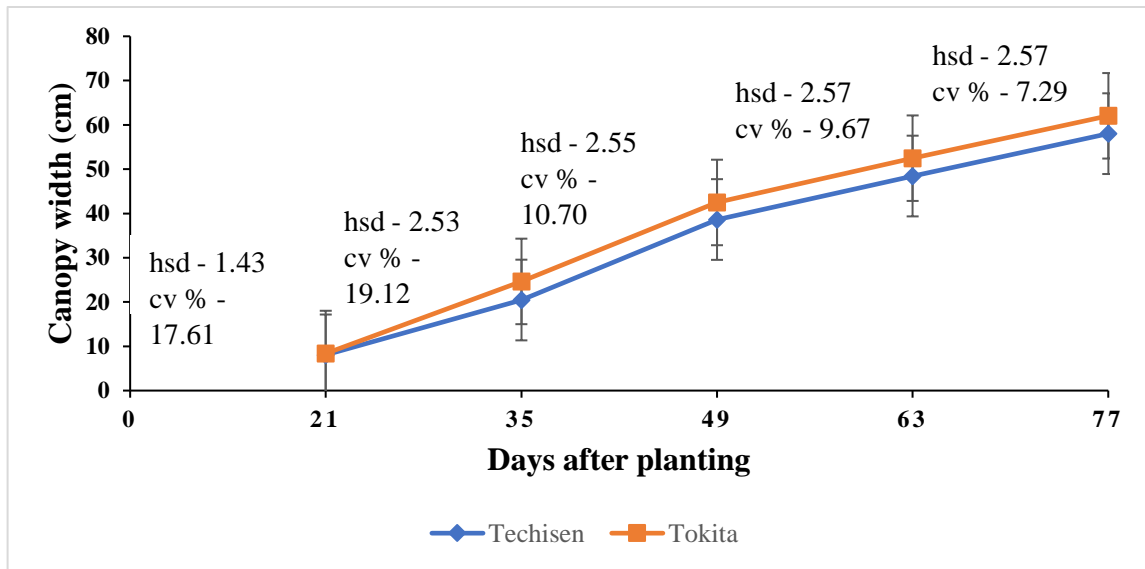
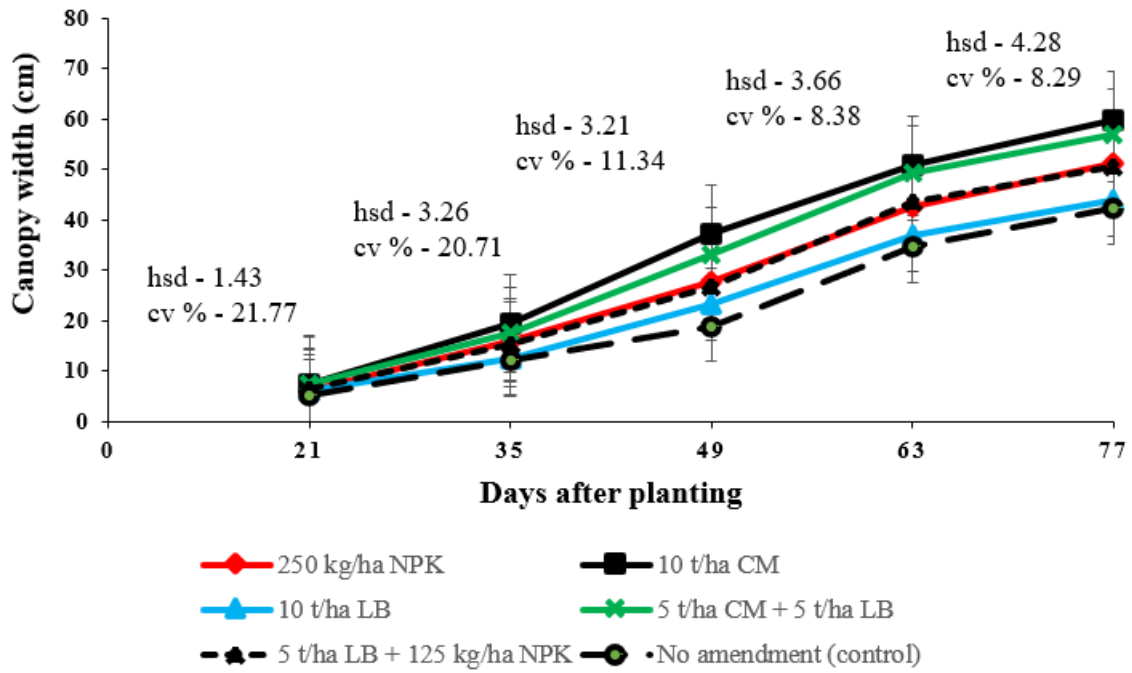


Figure 4.4: Canopy width as affected by varieties during the 2021 minor and 2022 major cropping seasons

(A) 2021



(B) 2022

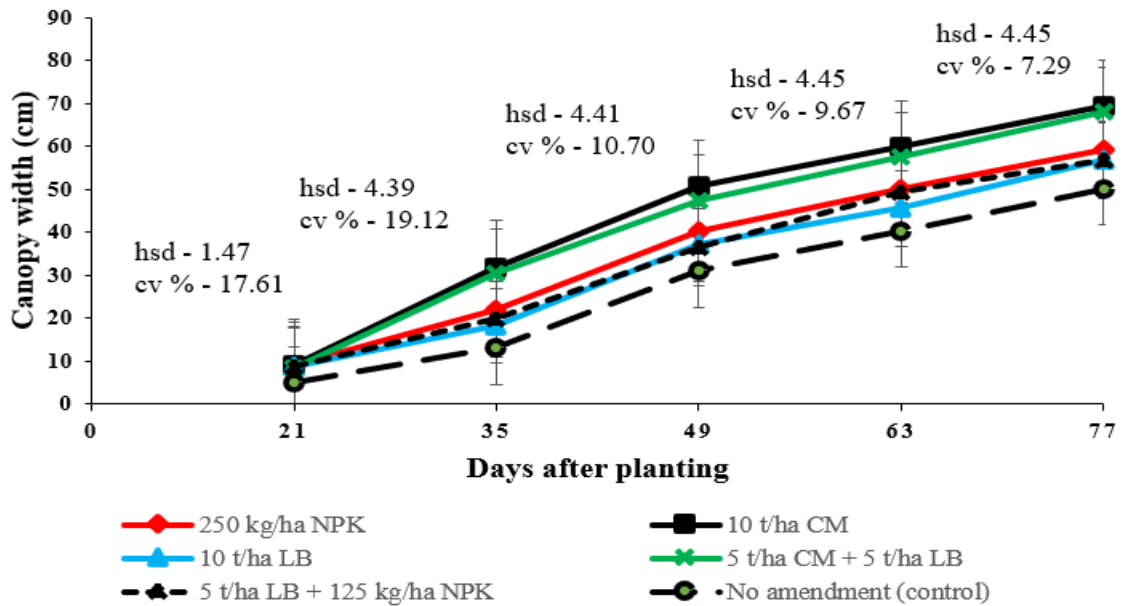


Figure 4.5: Canaopy width as affected by fertilizer rates during the 2021 minor and 2022 major cropping seasons

4.3.4 Shoot dry weight per plant

Shoot dry weight gradually increased across all treatments from 35 to 77 days after planting (DAP) in both cropping seasons (Fig. 4.6). During the 2021 minor cropping season, the combination of Tokita and 5 t/ha chicken manure (CM) + 5 t/ha Leucaena biochar (LB) resulted in significantly higher shoot dry weight from 35 to 77 DAP compared to the interactions involving Technisen with other amendments, Tokita with different amendments, and the control plot.

In the 2023 major cropping season, the combinations of Tokita with 5 t/ha CM + 5 t/ha LB and Technisen with 10 t/ha CM showed significantly higher shoot dry weight at 35 and 49 DAP, respectively, compared to other amended treatments. From 63 to 77 DAP, the Tokita x 5 t/ha CM + 5 t/ha LB combination recorded significantly higher shoot dry weight than Technisen with 5 t/ha LB + 125 kg/ha NPK, as well as other amended treatments with Tokita and the control plot (Fig. 4.6).

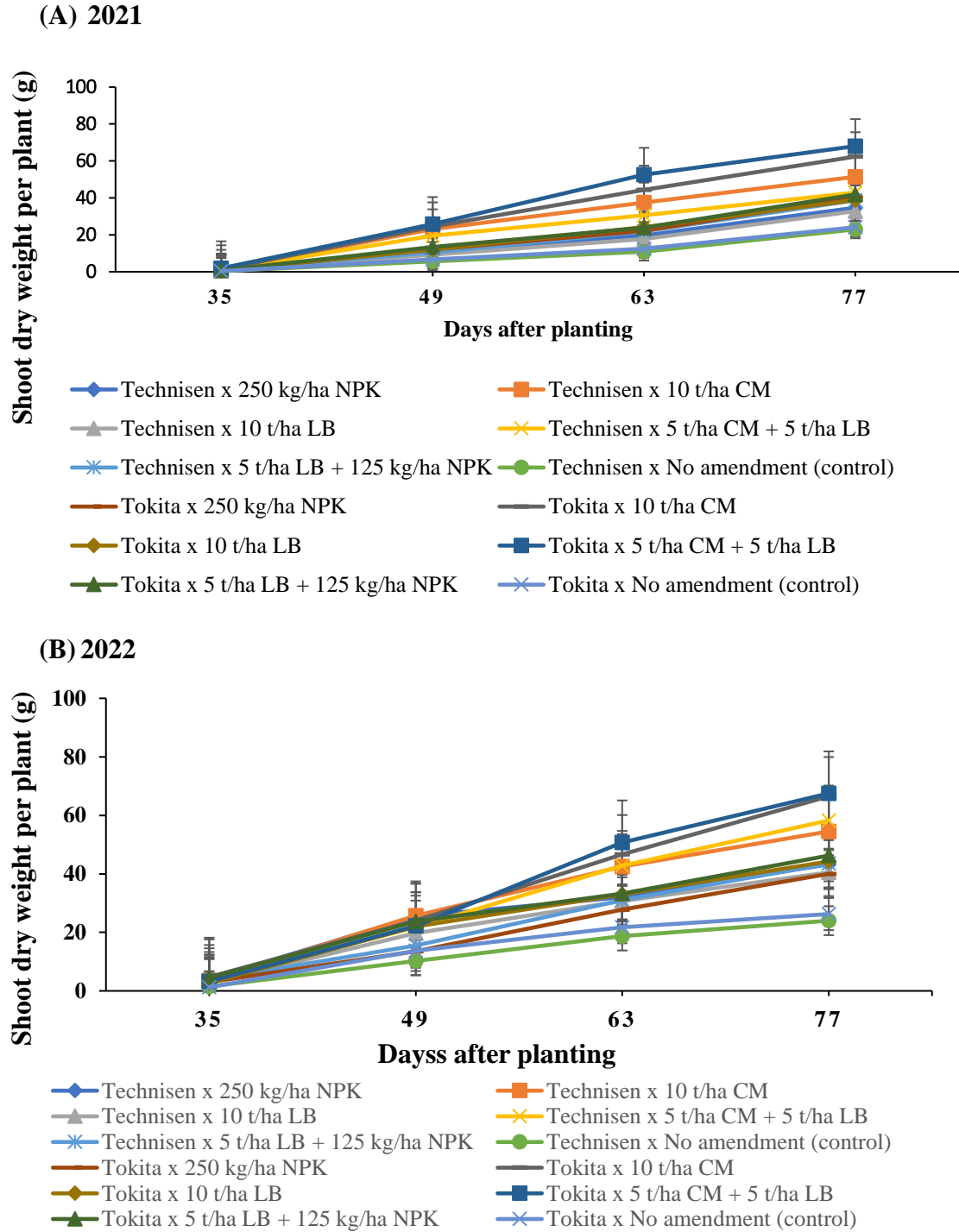


Figure 4.6: Shoot weight per plant as affected by the interaction of varieties x fertilizer rates during the 2021 minor and 2022 major cropping seasons

4.3.5 Root dry weight per plant

In the 2021 minor cropping season, the combination of Technisen and 10 t/ha chicken manure (CM) produced the highest root dry weight, which was significantly ($P \leq 0.05$) greater than that of the control plot at 35 days after planting (DAP). However, from 49 to 77 DAP, the combination of Tokita and 5 t/ha CM + 5 t/ha Leucaena biochar (LB) resulted in the highest root dry weight. The lowest root dry weight from 35 to 77 DAP was recorded in the Technisen x unamended plot (Fig. 4.7).

In the 2022 major cropping season, the interaction between Technisen and 10 t/ha CM again produced the highest root dry weight, significantly ($P \leq 0.05$) surpassing that of both varieties treated with other amendments and the control plot from 35 to 77 DAP (Fig. 4.7).

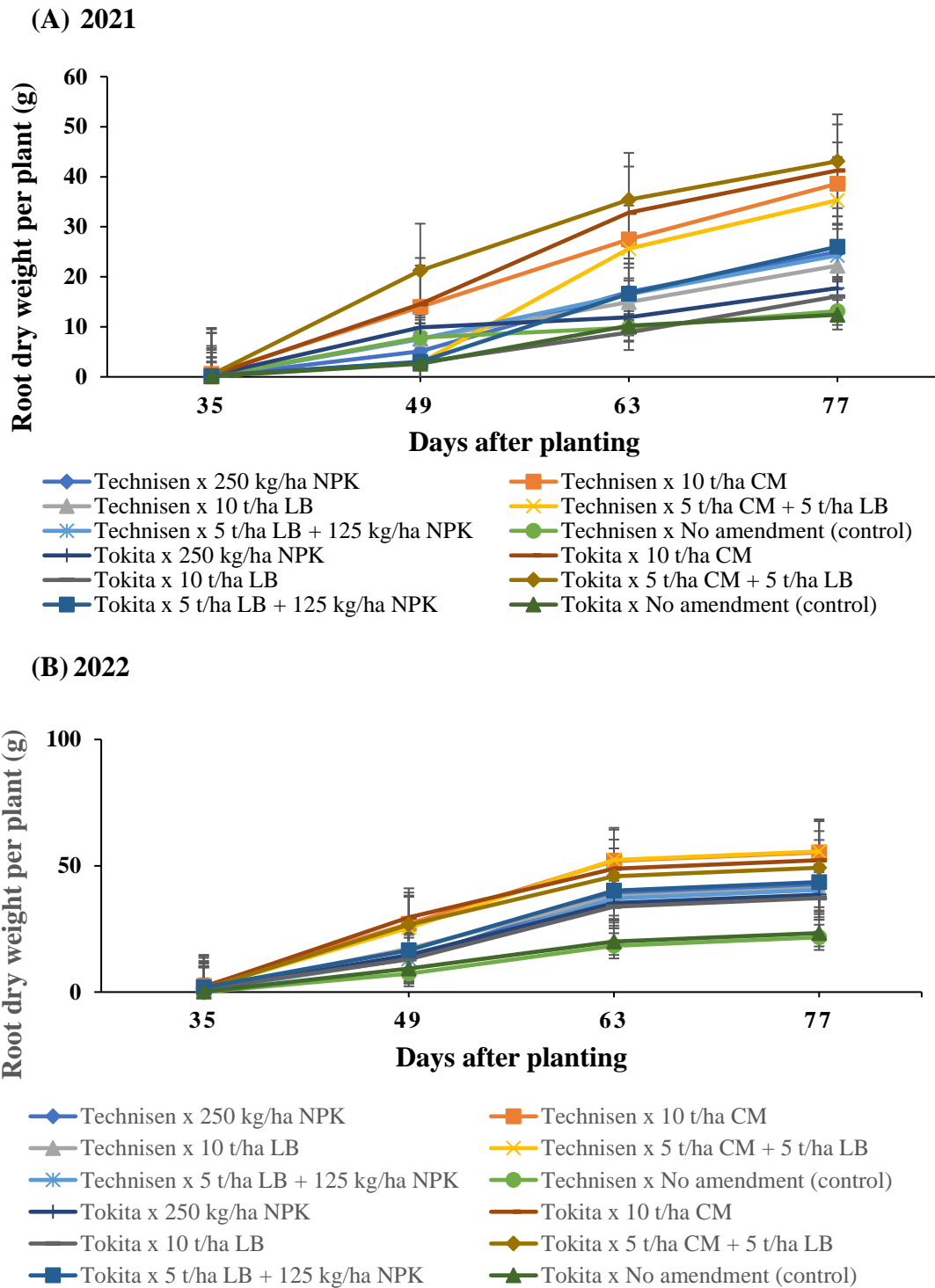


Figure 4.7: Root dry weight per plant as affected by the interaction of varieties x fertilizer rates during the 2021 minor and 2022 major cropping seasons

4.4 Physiological Growth Parameters of Two Carrot Varieties as Influenced by Biochar, Organic and Inorganic Fertilizers

4.4.1 Crop growth rate

The interaction between Tokita and 5 t/ha chicken manure (CM) + 5 t/ha Leucaena biochar (LB) resulted in the highest crop growth rate (CGR) of 1.73 g/m²/day, which was significantly ($P \leq 0.05$) higher than the interactions of both varieties with unamended plots and 250 kg/ha NPK during the 0-35 DAP and 77 DAP to harvest periods in the 2021 minor cropping season. However, no significant ($P \geq 0.05$) differences in CGR were observed among the various variety-fertilizer interactions during the 35-49 DAP and 63-77 DAP periods (Table 4.5a).

In the 2022 major cropping season, the Tokita x 10 t/ha CM interaction also recorded the highest CGR, significantly ($P \leq 0.05$) higher than the interactions involving both varieties with unamended plots. CGR values were highest during the 0-35 DAP period but showed a decline by harvest (77 DAP) in both cropping seasons (Table 4.5b).

Table 4.5a: Crop growth rate as influenced by different fertilizer rates and biochar during 2021 minor cropping season

Treatment	Crop growth rate (g m ⁻² day ⁻¹)				
	0-35 DAP	35-49 DAP	49-63 DAP	63-77 DAP	77 DAP to harvest
Interaction (Variety x Fertilizer)					
Technisen x 250 kg/ha NPK	0.83bc	15.75	32.99	46.99	20.02cdef
Technisen x 10 t/ha CM	1.31ab	24.55	33.20	47.08	26.71abc
Technisen x 10 t/ha LB	0.69bc	9.81	33.91	46.75	17.04def
Technisen x 5 t/ha CM + 5 t/ha LB	1.09abc	21.57	32.60	41.16	22.27cde
Technisen x 5 t/ha LB + 125 kg/ha NPK	1.29ab	21.67	32.92	42.80	20.09cdef
Technisen x No amendment (control)	0.43c	11.61	22.11	34.87	13.02f
Tokita x 250 kg/ha NPK	0.79bc	23.49	29.20	42.62	21.89cdef
Tokita x 10 t/ha CM	1.35ab	18.49	33.43	49.66	32.41ab
Tokita x 10 t/ha LB	0.86bc	22.85	31.72	43.39	24.27bcd
Tokita x 5 t/ha CM + 5 t/ha LB	1.73a	23.53	33.02	42.28	35.34a
Tokita x 5 t/ha LB + 125 kg/ha NPK	0.83bc	23.49	34.56	49.66	22.46cde
Tokita x No amendment (control)	0.41c	9.99	21.12	36.70	13.88ef
HSD (P ≤ 0.05)	0.78	NS	NS	NS	9.16
CV (%)	32.39	33.00	22.60	15.85	16.43

Means bearing the same letters within a column are not significantly different at 5% level of significance; CV = coefficient of variation; HSD = Highest significant difference at 5%; DAP = Days after planting; x = interaction; CM = chicken manure; LB = Leuceana Biochar

Table 4.5b: Crop growth rate as influenced by different fertilizer rates and biochar during 2022 major cropping season

Treatment	Crop growth rate (g m ⁻² /day ⁻¹)				
	0-35 DAP	35-49 DAP	49-63 DAP	63-77 DAP	77 DAP to harvest
Interaction (Variety x Fertilizer)					
Technisen x 250 kg/ha NPK	4.57ab	20.71bc	27.56b	39.64bcd	16.79c
Technisen x 10 t/ha CM	4.00abbc	27.76ab	33.83b	48.36abc	22.43abc
Technisen x 10 t/ha LB	3.15abc	20.59bc	28.57b	40.09bcd	18.22bc
Technisen x 5 t/ha CM + 5 t/ha LB	4.29abc	23.78abc	36.58ab	49.54abc	22.08abc
Technisen x 5 t/ha LB + 125 kg/ha NPK	4.29abc	24.81abc	31.43b	40.71abcd	17.61bc
Technisen x No amendment (control)	1.72bc	12.80c	18.65b	30.72d	13.33c
Tokita x 250 kg/ha NPK	3.43abc	17.44bbc	37.08b	38.11bcd	20.78abc
Tokita x 10 t/ha CM	5.43a	33.66a	57.72a	57.23a	28.78a
Tokita x 10 t/ha LB	3.15abc	19.46bc	36.39ab	48.52abc	21.53abc
Tokita x 5 t/ha CM + 5 t/ha LB	3.72abc	26.01ab	37.68ab	50.78ab	26.89ab
Tokita x 5 t/ha LB + 125 kg/ha NPK	5.14a	24.78abc	34.02b	44.98abcd	20.12abc
Tokita x No amendment (control)	1.43c	16.43bc	31.34b	33.29cd	14.73c
HSD (P ≤ 0.05)	2.94	12.14	21.63	16.64	9.34
CV (%)	32.10	21.87	26.09	15.41	18.66

Means bearing the same letters within a column are not significantly different at 5% level of significance; CV = coefficient of variation; HSD = Highest significant difference at 5%; DAP = Days after planting; x = interaction; CM = chicken manure; LB = Leuceana Biochar

4.4.2 Relative Growth Rate

In the 2021 minor cropping season, the interaction of Tokita with 5 t/ha chicken manure (CM) + 5 t/ha Leucaena biochar (LB) produced significantly higher relative growth rates (RGR) compared to both varieties grown on unamended plots for most of the growing period, except

during the 49-63 DAP period. The combination of Technisen with unamended plots recorded the lowest RGR throughout the entire growing period (Table 4.6a).

During the 2022 major cropping season, the Tokita x 10 t/ha CM interaction resulted in significantly higher RGR than both varieties grown on unamended plots for most of the growing period, excluding the 35-49 DAP and 49-63 DAP intervals. No significant differences ($P \geq 0.05$) in RGR were found between the variety-fertilizer interactions during the 63-77 DAP and 77 DAP to harvest periods (Table 4.6b).

Table 4.6a: Relative growth rate as influenced by different fertilizer rates and biochar during 2021 minor cropping season

Treatment	Relative growth rate ($\text{g m}^{-2}\text{day}^{-1}$)				
	0-35 DAP	35-49 DAP	49-63 DAP	63-77 DAP	77 DAP to harvest
Interaction (Variety x Fertilizer)					
Technisen x 250 kg/ha NPK	0.65abc	0.32abc	0.19ab	0.10bcd	0.12ab
Technisen x 10 t/ha CM	0.68ab	0.37a	0.20ab	0.15abc	0.14ab
Technisen x 10 t/ha LB	0.65abc	0.31abc	0.16b	0.09cd	0.09ab
Technisen x 5 t/ha CM + 5 t/ha LB	0.67abc	0.35ab	0.19ab	0.13abcd	0.13ab
Technisen x 5 t/ha LB + 125 kg/ha NPK	0.66abc	0.35abc	0.24ab	0.13abcd	0.11ab
Technisen x No amendment (control)	0.57c	0.28c	0.15b	0.07d	0.06b
<hr/>					
Tokita x 250 kg/ha NPK	0.66abc	0.32abc	0.20ab	0.12abcd	0.11ab
Tokita x 10 t/ha CM	0.70a	0.38a	0.22ab	0.16ab	0.13ab
Tokita x 10 t/ha LB	0.69ab	0.33abc	0.20ab	0.11abcd	0.11abb
Tokita x 5 t/ha CM + 5 t/ha LB	0.70a	0.37a	0.25a	0.17a	0.16a
Tokita x 5 t/ha LB + 125 kg/ha NPK	0.67abc	0.33abc	0.21ab	0.12abcd	0.13ab
Tokita x No amendment (control)	0.59bc	0.28c	0.19ab	0.08d	0.08b
<hr/>					
HSD ($P \leq 0.05$)	0.10	0.07	0.09	0.06	0.08
CV (%)	6.33	8.23	17.84	21.84	27.50

Means bearing the same letters within a column are not significantly different at 5% level of significance; CV = coefficient of variation; HSD = Highest significant difference at 5%; DAP = Days after planting; x = interaction; CM = chicken manure; LB = Leuceana Biochar

Table 4.6b: Relative growth rate as influenced by different fertilizer rates and biochar during 2022 major cropping season

Treatment Variety	Relative growth rate (g m ⁻² day ⁻¹)				
	0-35 DAP	35-49 DAP	49-63 DAP	63-77 DAP	77 DAP to harvest
Interaction (Variety x Fertilizer)					
Technisen x 250 kg/ha NPK	0.47bc	0.39abb	0.27ab	0.06	0.02
Technisen x 10 t/ha CM	0.48abc	0.33abc	0.25ab	0.04	0.10
Technisen x 10 t/ha LB	0.46bc	0.37ab	0.18ab	0.03	0.02
Technisen x 5 t/ha CM + 5 t/ha LB	0.49ab	0.35abc	0.25ab	0.05	0.02
Technisen x 5 t/ha LB + 125 kg/ha NPK	0.47bc	0.33abc	0.26ab	0.05	0.03
Technisen x No amendment (control)	0.43e	0.25c	0.11b	0.04	0.02
Tokita x 250 kg/ha NPK	0.46cd	0.33abc	0.21ab	0.05	0.03
Tokita x 10 t/ha CM	0.50a	0.42a	0.31a	0.06	0.03
Tokita x 10 t/ha LB	0.47bc	0.30bc	0.20ab	0.03	0.02
Tokita x 5 t/ha CM + 5 t/ha LB	0.50a	0.39ab	0.23ab	0.06	0.02
Tokita x 5 t/ha LB + 125 kg/ha NPK	0.47bc	0.39ab	0.29a	0.08	0.03
Tokita x No amendment (control)	0.44de	0.33abc	0.16ab	0.03	0.02
HSD (P ≤ 0.05)	0.02	0.12	0.18	NS	NS
CV (%)	2.11	13.77	31.27	74.86	54.11

Means bearing the same letters within a column are not significantly different at 5% level of significance; CV = coefficient of variation; HSD = Highest significant difference at 5%; DAP = Days after planting; x = interaction; CM = chicken manure; LB = Leuceana Biochar

4.5 Yield and Yield Components

4.5.1 Number of plants harvested

There was no significant difference ($P \geq 0.05$) in the number of plants harvested between the two carrot varieties across both cropping seasons (Table 4.7). However, in both the 2021 and 2022 seasons, plots treated with 10 t/ha chicken manure (CM) and 5 t/ha CM + 5 t/ha Leucaena biochar (LB) produced significantly higher ($P \leq 0.05$) numbers of plants compared to other amended plots and the control. The interaction between variety and fertilizer rate also led to significantly more plants being harvested than from the unamended plots. Specifically, the Tokita x 10 t/ha CM interaction resulted in significantly more plants than the Tokita x control

and Technisen x control interactions (Table 4.7). Additionally, the number of plants harvested was greater in the 2021 minor cropping season compared to the 2022 major season.

Table 4.7: Number of plants harvested as influenced by different fertilizer rates and biochar

Fertilizer	Number of plants harvested					
	<u>2021</u>			<u>2022</u>		
	Technisen	Tokita	Mean	Technisen	Tokita	Mean
250 kg/ha NPK	36.00	34.00	35.00	43.00	41.75	42.38
10 t/ha CM	51.25	57.50	54.38	52.00	59.00	55.50
10 t/ha LB	30.00	30.75	30.38	36.75	41.25	39.00
5 t/ha CM + 5 t/ha LB	52.25	53.50	52.88	57.50	54.25	55.88
5 t/ha LB + 125 kg/ha NPK	36.00	41.50	38.75	47.00	39.50	43.25
No amendment (control)	20.00	21.00	20.50	28.50	29.00	28.75
Mean	37.58	39.71		44.13	44.13	
CV (%)	13.05			11.26		
Variety (V)	HSD (0.05) = NS			HSD (0.05) = NS		
Fert (F)	HSD (0.05) = 5.13			HSD (0.05) = 5.05		
V x F	HSD (0.05) = 7.26			HSD (0.05) = 7.15		

Means bearing the same letters within a column are not significantly different at 5% level of significance; CV = coefficient of variation; HSD = Highest significant difference at 5%; DAP = Days after planting; x = interaction; CM = chicken manure; LB = Leuceana Biochar

4.5.2 Root tuber weight per plot

In the 2021 minor cropping season, the Tokita carrot variety produced significantly ($P \leq 0.05$) higher root weight per plot compared to the Technisen variety (Table 4.8). However, no significant ($P \geq 0.05$) differences were observed between the two varieties during the 2022 major cropping season. Carrot plants treated with 10 t/ha chicken manure (CM) and 5 t/ha CM + 5 t/ha Leucaena biochar (LB) had significantly ($P \leq 0.05$) higher root weight per plot compared to those grown with other amendments and the control plots in both cropping seasons. The combination of Tokita x 10 t/ha CM resulted in significantly heavier root weight

per plot than Technisen with other amendments and the control plot during the 2021 season. In the 2022 cropping season, the Tokita x 5 t/ha CM + 5 t/ha LB interaction differed significantly from the other treatments, including Technisen and Tokita with 250 kg/ha NPK or no amendments. Significant ($P \leq 0.05$) differences in root tuber weight per plot were observed between the two seasons.

Table 4.8: Carrot root weight as influenced by different fertilizer rates and biochar

	Root weight per plot (kg)					
	<u>2021</u>			<u>2022</u>		
Fertilizer	Technisen	Tokita	Mean	Technisen	Tokita	Mean
250 kg/ha NPK	0.53	0.65	0.59	2.77	2.67	2.72
10 t/ha CM	1.05	1.30	1.18	4.02	4.04	4.03
10 t/ha LB	0.38	0.70	0.54	3.15	3.05	3.10
5 t/ha CM + 5 t/ha LB	0.85	1.03	0.94	3.95	4.07	4.01
5 t/ha LB + 125 kg/ha NPK	0.65	0.88	0.76	3.85	2.65	3.25
No amendment (control)	0.38	0.43	0.40	1.57	1.58	1.57
Mean	0.64	0.83		3.22	3.01	
CV (%)	32.96			23.71		
Variety (V)	HSD (0.05) = 0.14			HSD (0.05) = NS		
Fert (F)	HSD (0.05) = 0.25			HSD (0.05) = 0.75		
V x F	HSD (0.05) = 0.35			HSD (0.05) = 1.06		

Means bearing the same letters within a column are not significantly different at 5% level of significance; CV = coefficient of variation; HSD = Highest significant difference at 5%; DAP = Days after planting; x = interaction; CM = chicken manure; LB = Leuceana Biochar

4.5.3 Marketable root weight per plot

The Tokita carrot variety produced significantly ($P \leq 0.05$) higher marketable root weight per plot compared to Technisen during the 2021 cropping season. However, no significant ($P \geq 0.05$) difference in marketable root weight per plot was observed between Tokita and Technisen during the 2022 cropping season (Table 4.9). Carrot plants treated with 10 t/ha CM

and 5 t/ha CM + 5 t/ha Leucaena biochar (LB) had significantly heavier marketable root weight per plot than those treated with 10 t/ha LB and the control plots in both seasons. The interaction of Tokita x 250 kg/ha NPK resulted in significantly heavier marketable root weight per plot than Technisen with other amendments and the control plot during the 2021 cropping season. In contrast, in the 2022 cropping season, the interaction of Technisen x 5 t/ha CM + 5 t/ha LB differed significantly from both Technisen and Tokita with 250 kg/ha NPK, 10 t/ha CM, and the control. Significant ($P \leq 0.05$) differences in marketable root weight per plot were observed between the two seasons.

Table 4.9: Marketable root tuber weight per plot as influenced by different fertilizer rates and biochar

Fertilizer	Marketable roots tuber weight per plot (g)					
	<u>2021</u>			<u>2022</u>		
	Technisen	Tokita	Mean	Technisen	Tokita	Mean
250 kg/ha NPK	325.00	650.00	487.50	2275.00	1916.70	2095.80
10 t/ha CM	450.00	550.00	500.00	3580.00	3381.70	3480.80
10 t/ha LB	150.00	250.00	200.00	2462.50	2270.00	2366.30
5 t/ha CM + 5 t/ha LB	275.00	500.00	387.50	3567.50	3440.80	3504.20
5 t/ha LB + 125 kg/ha NPK	300.00	350.00	325.00	3021.70	1837.50	2429.60
No amendment (control)	150.00	225.00	187.50	785.00	756.70	770.80
Mean	280.00	420.00		325.00	379.17	
CV (%)	50.70			29.54		
Variety (V)	HSD (0.05) = 103.60			HSD (0.05) = NS		
Fert (F)	HSD (0.05) = 179.45			HSD (0.05) = 733.50		
V x F	HSD (0.05) = 253.77			HSD (0.05) = 1037.30		

Means bearing the same letters within a column are not significantly different at 5% level of significance; CV = coefficient of variation; HSD = Highest significant difference at 5%; DAP = Days after planting; x = interaction; CM = chicken manure; LB = Leucaena Biochar

4.5.4 Non-marketable root weight per plot

No significant ($P \geq 0.05$) difference in non-marketable root weight per plot was observed between the varieties across both cropping seasons (Table 4.10). In the 2021 minor cropping season, the control plot, as well as the interaction between Technisen and Tokita with the control, produced significantly ($P \leq 0.05$) higher non-marketable root weight than the amended plots. However, in the 2022 major cropping season, there were no significant ($P \geq 0.05$) differences in non-marketable root weight per plot between the fertilizer treatments or the variety x fertilizer interactions. A significant ($P \leq 0.05$) difference in non-marketable root weight per plot was observed between the two seasons.

Table 4.10: Non-marketable root tuber weight per plot as influenced by different fertilizer rates and biochar

	Non-marketable roots tuber weight per plot (g)					
	<u>2021</u>			<u>2022</u>		
Fertilizer	Technisen	Tokita	Mean	Technisen	Tokita	Mean
250 kg/ha NPK	200.00	375.00	287.50	492.50	755.84	624.17
10 t/ha CM	300.00	225.00	262.50	440.00	653.33	546.67
10 t/ha LB	225.00	425.00	325.00	987.50	780.00	733.75
5 t/ha CM + 5 t/ha LB	200.00	200.00	200.00	385.00	624.17	504.58
5 t/ha LB + 125 kg/ha NPK	300.00	250.00	275.00	830.83	807.50	819.17
No amendment (control)	725.00	800.00	762.50	780.00	820.83	800.00
Mean	325.00	379.17		602.64	740.28	
CV (%)	34.32			50.81		
Variety (V)	HSD (0.05) = NS			HSD (0.05) = NS		
Fert (F)	HSD (0.05) = 122.93			HSD (0.05) = NS		
V x F	HSD (0.05) = 173.84			HSD (0.05) = NS		

Means bearing the same letters within a column are not significantly different at 5% level of significance; CV = coefficient of variation; HSD = Highest significant difference at 5%; DAP = Days after planting; x = interaction; CM = chicken manure; LB = Leuceana Biochar

4.5.5 Root length

The root length of the Tokita carrot variety was significantly ($P \leq 0.05$) longer than that of Technisen during the 2021 minor cropping season. However, no significant ($P \geq 0.05$) difference in root length was observed between the two varieties during the 2022 major cropping season (Table 4.11). Across both seasons, carrot plants treated with 5 t/ha CM + 5 t/ha LB had significantly ($P \leq 0.05$) longer root lengths, followed by those treated with 10 t/ha CM, which differed significantly ($P \leq 0.05$) from both the amended and unamended control plots. The interaction of Tokita x 5 t/ha CM + 5 t/ha LB produced the longest roots, while the shortest roots were recorded in both carrot varieties grown without amendments across both seasons. Additionally, carrots grown in the 2022 major cropping season produced longer roots than those in the 2021 minor cropping season, regardless of whether amendments were applied.

Table 4.11: Root length as influenced by different fertilizer rates and biochar

	Root length (cm)					
	<u>2021</u>			<u>2022</u>		
Fertilizer	Technisen	Tokita	Mean	Technisen	Tokita	Mean
250 kg/ha NPK	13.65	15.66	14.32	14.99	15.32	15.49
10 t/ha CM	14.85	16.28	15.56	16.29	18.01	17.14
10 t/ha LB	12.59	13.98	12.97	13.36	13.89	13.94
5 t/ha CM + 5 t/ha LB	15.43	17.17	15.96	16.50	18.66	17.92
5 t/ha LB + 125 kg/ha NPK	13.46	14.78	13.66	13.87	15.27	15.02
No amendment (control)	9.54	12.35	10.85	12.15	12.35	12.35
Mean	13.25	14.52		15.03	15.58	
CV (%)	11.05			8.40		
Variety (V)	HSD (0.05) = 0.90			HSD (0.05) = NS		
Fert (F)	HSD (0.05) = 1.56			HSD (0.05) = 1.31		
V x F	HSD (0.05) = 2.21			HSD (0.05) = 1.85		

Means bearing the same letters within a column are not significantly different at 5% level of significance; CV = coefficient of variation; HSD = Highest significant difference at 5%; DAP = Days after planting; x = interaction; CM = chicken manure; LB = Leuceana Biochar

4.5.6 Root diameter

The Tokita carrot variety exhibited a significantly ($P \leq 0.05$) wider root diameter compared to Technisen during the 2021 minor cropping season. However, no significant ($P \geq 0.05$) difference in root diameter was found between the two varieties during the 2022 major cropping season (Table 4.12).

Carrot plants treated with 5 t/ha CM + 5 t/ha LB had the widest root diameters, followed by those receiving 10 t/ha CM, in both cropping seasons. These treatments showed significant differences ($P \leq 0.05$) compared to other amended and unamended plots, particularly in the 2022 major cropping season. The interaction of Tokita and Technisen with 5 t/ha CM + 5 t/ha LB produced the widest roots in both seasons, while the narrowest roots were observed in the interaction between Technisen and the unamended plots. These differences were statistically significant ($P \leq 0.05$).

Overall, the 2022 major cropping season resulted in wider root diameters compared to the 2021 minor season. Significant differences were also found in root diameter between fertilizer x season and variety x season interactions.

Table 4.12: Root diameter as influenced by different fertilizer rates and biochar

Fertilizer	Root diameter (cm)					
	<u>2021</u>			<u>2022</u>		
	Technisen	Tokita	Mean	Technisen	Tokita	Mean
250 kg/ha NPK	2.45	2.75	2.60	3.65	3.17	3.41
10 t/ha CM	2.65	2.83	2.74	4.51	4.43	4.47
10 t/ha LB	2.08	2.46	2.27	3.65	3.10	3.38
5 t/ha CM + 5 t/ha LB	2.78	3.10	2.94	4.56	4.35	4.46
5 t/ha LB + 125 kg/ha NPK	2.35	2.72	2.54	3.32	3.48	3.40
No amendment (control)	2.06	2.32	2.19	2.27	2.39	2.33
Mean	2.40	2.70		3.66	3.49	
CV (%)	15.61			12.02		
Variety (V)	HSD (0.05) = 0.23			HSD (0.05) = NS		
Fert (F)	HSD (0.05) = 0.40			HSD (0.05) = 0.44		
V x F	HSD (0.05) = 0.57			HSD (0.05) = 0.62		

Means bearing the same letters within a column are not significantly different at 5% level of significance; CV = coefficient of variation; HSD = Highest significant difference at 5%; DAP = Days after planting; x = interaction; CM = chicken manure; LB = Leuceana Biochar

4.5.7 Number of forked roots per plot

As shown in Table 4.13, there were no significant ($P \geq 0.05$) differences in the number of forked roots per plot between the Technisen and Tokita carrot varieties across both cropping seasons. Overall, carrot plants grown without amendments exhibited a significantly higher number of forked roots per plot compared to those treated with amendments. The fewest forked roots per plot were observed in plants that received 10 t/ha CM in both seasons. The interaction of both varieties with 10 t/ha CM resulted in the lowest number of forked roots per plot in the 2021 season, while the highest number was observed in the interaction between Technisen and the control treatment across both seasons. There were no significant ($P \geq 0.05$) differences in the number of forked roots per plot between the two cropping seasons.

Table 4.13: Number of forked roots per plot as influenced by different fertilizer rates and biochar

Fertilizer	Number of forked roots per plot					
	<u>2021</u>			<u>2022</u>		
	Technisen	Tokita	Mean	Technisen	Tokita	Mean
250 kg/ha NPK	1.75	1.75	1.75	3.00	2.00	2.50
10 t/ha CM	1.25	1.25	1.25	1.00	1.50	1.25
10 t/ha LB	2.50	2.00	2.25	2.50	2.00	2.25
5 t/ha CM + 5 t/ha LB	1.75	1.50	1.63	2.00	3.00	2.50
5 t/ha LB + 125 kg/ha NPK	2.00	2.00	2.00	2.25	1.50	1.88
No amendment (control)	4.50	3.25	3.88	4.00	3.50	3.75
Mean	2.29	1.96		2.46	2.25	
CV (%)	40.75			36.24		
Variety (V)	HSD (0.05) = NS			HSD (0.05) = NS		
Fert (F)	HSD (0.05) = 0.88			HSD (0.05) = 0.87		
V x F	HSD (0.05) = 1.25			HSD (0.05) = 1.23		

Means bearing the same letters within a column are not significantly different at 5% level of significance; CV = coefficient of variation; HSD = Highest significant difference at 5%; DAP = Days after planting; x = interaction; CM = chicken manure; LB = Leuceana Biochar

4.5.8 Number of cracked roots per plot

The Tokita carrot variety had a significantly ($P \leq 0.05$) higher number of cracked roots per plot compared to Technisen during the 2021 minor cropping season. However, no significant ($P \geq 0.05$) differences were found between the varieties during the 2022 cropping season (Table 4.14). Across both seasons, plants grown without amendments exhibited a significantly higher number of cracked roots per plot than those that received amendments. The lowest number of cracked roots per plot was observed in plants treated with 10 t/ha CM in both seasons. The interaction between both varieties and 10 t/ha CM resulted in the fewest cracked roots per plot across both seasons, while the highest numbers were recorded in the interactions between Tokita and the control during the minor season and Technisen and the control during

the major season. No significant ($P \geq 0.05$) differences in the number of cracked roots per plot were observed between the two cropping seasons (Table 4.14).

Table 4.14: Number of cracked roots per plot as influenced by different fertilizer rates and biochar

	Number of cracked roots per plot					
	<u>2021</u>			<u>2022</u>		
Fertilizer	Technisen	Tokita	Mean	Technisen	Tokita	Mean
250 kg/ha NPK	2.00	3.25	2.63	2.00	2.25	2.13
10 t/ha CM	1.00	1.25	1.13	1.25	1.25	1.25
10 t/ha LB	1.75	2.50	2.13	2.75	3.00	2.88
5 t/ha CM + 5 t/ha LB	1.50	1.50	1.50	1.75	1.25	1.50
5 t/ha LB + 125 kg/ha NPK	2.75	1.75	2.25	2.75	2.75	2.75
No amendment (control)	2.75	4.75	3.75	4.00	3.75	3.88
Mean	1.96	2.50		2.42	2.38	
CV (%)						
Variety (V)	HSD (0.05) = 0.50			HSD (0.05) = NS		
Fert (F)	HSD (0.05) = 0.87			HSD (0.05) = 0.96		
V x F	HSD (0.05) = 1.23			HSD (0.05) = 1.36		

Means bearing the same letters within a column are not significantly different at 5% level of significance; CV = coefficient of variation; HSD = Highest significant difference at 5%; DAP = Days after planting; x = interaction; CM = chicken manure; LB = Leuceana Biochar

4.5.9 Number of deformed roots per plot

There were no significant ($P \geq 0.05$) differences in the number of deformed roots per plot between the Technisen and Tokita carrot varieties across both cropping seasons. Carrot plants grown without amendments exhibited a significantly higher number of deformed roots per plot compared to those treated with amendments in both seasons (Table 4.15). The interaction between both varieties and 10 t/ha CM resulted in the fewest deformed roots per plot during the 2021 season, while the highest number of deformed roots was observed in the interactions between both Technisen and Tokita with the control treatment across both seasons. No

significant differences in the number of deformed roots per plot were observed between the two cropping seasons (Table 4.15).

Table 4.15: Number of deformed roots per plot as influenced by different fertilizer rates and biochar

Fertilizer	Number of deformed roots per plot					
	<u>2021</u>			<u>2022</u>		
	Technisen	Tokita	Mean	Technisen	Tokita	Mean
250 kg/ha NPK	2.25	2.25	2.25	2.00	2.75	2.38
10 t/ha CM	1.25	1.25	1.25	1.50	1.25	1.38
10 t/ha LB	2.50	2.25	2.38	1.25	2.00	1.63
5 t/ha CM + 5 t/ha LB	1.50	2.00	1.75	1.75	1.25	1.50
5 t/ha LB + 125 kg/ha NPK	1.50	2.00	1.75	1.75	1.50	1.63
No amendment (control)	4.00	4.25	4.13	3.50	3.25	3.38
Mean	2.17	2.33		1.96	2.00	
CV (%)						
Variety (V)	HSD (0.05) = NS			HSD (0.05) = NS		
Fert (F)	HSD (0.05) = 0.95			HSD (0.05) = 0.88		
V x F	HSD (0.05) = 1.34			HSD (0.05) = 1.24		

Means bearing the same letters within a column are not significantly different at 5% level of significance; CV = coefficient of variation; HSD = Highest significant difference at 5%; DAP = Days after planting; x = interaction; CM = chicken manure; LB = Leuceana Biochar

4.5.10 Plant biomass weight per plot at harvest

There were no significant ($P \geq 0.05$) differences in plant biomass weight per plot at harvest between the Tokita and Technisen carrot varieties across both cropping seasons (Table 4.16). Carrot plants treated with 10 t/ha CM showed the highest plant biomass weight per plot, significantly ($P \leq 0.05$) surpassing those treated with 250 kg/ha NPK or the control plots in both seasons. The combination of Tokita and 10 t/ha CM, along with Technisen and 5 t/ha LB + 125 kg/ha NPK, resulted in the highest biomass weight per plot in the 2021 and 2022

seasons, respectively. The lowest biomass weight was recorded in the interactions between both varieties and unamended plots, with a significant difference observed (Table 4.16). The effect of the season on plant biomass weight at harvest was significant.

Table 4.16: Plant biomass weight per plot at harvest as influenced by different fertilizer rates and biochar

	Plant biomass weight per plot at harvest (kg)					
	<u>2021</u>			<u>2022</u>		
Fertilizer	Technisen	Tokita	Mean	Technisen	Tokita	Mean
250 kg/ha NPK	1.50	1.35	1.43	4.10	4.35	4.23
10 t/ha CM	3.45	4.20	3.83	5.23	5.43	5.33
10 t/ha LB	1.60	1.85	1.73	4.35	4.60	4.48
5 t/ha CM + 5 t/ha LB	2.93	2.93	2.93	5.38	5.07	5.22
5 t/ha LB + 125 kg/ha NPK	2.30	1.73	2.01	5.45	3.93	4.69
No amendment (control)	1.15	0.87	1.01	2.38	2.55	2.47
Mean	2.15	2.15		4.48	4.32	
CV (%)	24.91			21.70		
Variety (V)	HSD (0.05) = NS			HSD (0.05) = NS		
Fert (F)	HSD (0.05) = 0.55			HSD (0.05) = 0.97		
V x F	HSD (0.05) = 0.77			HSD (0.05) = 1.37		

Means bearing the same letters within a column are not significantly different at 5% level of significance; CV = coefficient of variation; HSD = Highest significant difference at 5%; DAP = Days after planting; x = interaction; CM = chicken manure; LB = Leuceana Biochar

4.5.11 Root tuber yield (t/ha)

During the 2021 minor cropping season, the Tokita carrot variety produced a significantly ($P \leq 0.05$) higher root tuber yield of 5.18 t/ha, which was 30% greater than the yield of Technisen at 3.98 t/ha (Table 4.17). However, no significant ($P \geq 0.05$) difference in root yield was observed between the two varieties during the 2022 major cropping season.

The highest root yields were recorded in carrot plants treated with 10 t/ha CM, followed by those receiving 5 t/ha CM + 5 t/ha LB across both seasons. The lowest yields were observed in the control plots, with yields of 2.50 t/ha in the minor season and 9.82 t/ha in the major season.

The interaction of both Tokita and Technisen with 10 t/ha CM and 5 t/ha CM + 5 t/ha LB showed significant ($P \leq 0.05$) differences in root yield compared to the unamended plots during both cropping seasons. Overall, carrot plants receiving amendments, whether with or without additional treatments, yielded significantly higher roots in the major cropping season compared to the minor season.

Table 4.17: Root tuber yield (t/ha) plot at harvest as influenced by different fertilizer rates and biochar

Fertilizer	Root tuber yield per plot (t/ha)					
	<u>2021</u>			<u>2022</u>		
	Technisen	Tokita	Mean	Technisen	Tokita	Mean
250 kg/ha NPK	3.28	4.05f	3.66	17.30	16.70	17.00
10 t/ha CM	6.56	8.13	7.34	25.13	25.22	25.17
10 t/ha LB	2.34	4.38	3.36	19.69	19.06	19.38
5 t/ha CM + 5 t/ha LB	5.31	6.41	5.86	24.70	25.41	25.06
5 t/ha LB + 125 kg/ha NPK	4.06	5.47	4.77	24.08	16.53	20.31
No amendment (control)	2.34	2.66	2.50	9.78	9.56	9.82
Mean	3.98	5.18		20.11	18.80	
CV (%)	32.96			23.71		
Variety (V)	HSD (0.05) = 0.89			HSD (0.05) = NS		
Fert (F)	HSD (0.05) = 1.54			HSD (0.05) = 4.69		
V x F	HSD (0.05) = 2.17			HSD (0.05) = 6.64		

Means bearing the same letters within a column are not significantly different at 5% level of significance; CV = coefficient of variation; HSD = Highest significant difference at 5%; DAP = Days after planting; x = interaction; CM = chicken manure; LB = Leuceana Biochar

4.5.12 Harvest index

There were no significant ($P \geq 0.05$) differences in harvest index between the Technisen and Tokita carrot varieties across both cropping seasons (Table 4.18). However, in the 2021 minor cropping season, carrot plants that did not receive any amendments exhibited the highest harvest index. In contrast, during the 2022 major cropping season, carrot plants treated with 5 t/ha CM + 5 t/ha LB, followed by those treated with 10 t/ha CM, showed a significant increase in harvest index compared to plants grown without amendments.

The interaction between Technisen and Tokita with 250 kg/ha NPK and 5 t/ha CM + 5 t/ha LB resulted in the highest harvest index in the 2021 and 2022 seasons, respectively. Conversely, the lowest harvest index in 2021 was observed in the interaction between Technisen and 10 t/ha CM, while the lowest in 2022 occurred with the interaction between Tokita and the control treatment. No significant ($P \geq 0.05$) differences in harvest index were found between the two cropping seasons (Table 4.18).

Table 4.18: Harvest index as influenced by different fertilizer rates and biochar

Fertilizer	Harvest index					
	<u>2021</u>			<u>2022</u>		
	Technisen	Tokita	Mean	Technisen	Tokita	Mean
250 kg/ha NPK	0.70	0.55	0.62	0.67	0.63	0.65
10 t/ha CM	0.29	0.33	0.31	0.78	0.74	0.76
10 t/ha LB	0.35	0.59	0.47	0.73	0.67	0.70
5 t/ha CM + 5 t/ha LB	0.39	0.34	0.37	0.73	0.80	0.77
5 t/ha LB + 125 kg/ha NPK	0.40	0.62	0.51	0.71	0.67	0.69
No amendment (control)	0.81	0.65	0.73	0.66	0.63	0.64
Mean	0.49	0.51		0.71	0.69	
CV (%)	55.36			11.75		
Variety (V)	HSD (0.05) = NS			HSD (0.05) = NS		
Fert (F)	HSD (0.05) = 0.28			HSD (0.05) = 0.08		
V x F	HSD (0.05) = 0.39			HSD (0.05) = 0.12		

Means bearing the same letters within a column are not significantly different at 5% level of significance; CV = coefficient of variation; HSD = Highest significant difference at 5%; DAP = Days after planting; x = interaction; CM = chicken manure; LB = Leuceana Biochar

4.6 Correlation matrix analysis

4.6.1 Correlation analysis between growth and yield and yield components of carrot

Table 4.19 presents the correlation coefficients between various growth, yield, and yield components of carrots during the 2021 minor cropping season. Root yield was strongly and significantly positively correlated with plant height, number of leaves per plant, canopy width, root length, root diameter, plant biomass at harvest, and marketable root weight per plot. However, it showed a weak and non-significant correlation with non-marketable root weight and harvest index (HI).

Plant height was significantly and positively correlated with the number of leaves per plant (0.78***), canopy width (0.89***), root length (0.59***), root diameter (0.67***), plant biomass at harvest (0.83***), marketable root weight (0.60***), and root yield (0.77***). The

number of leaves per plant had significant positive correlations with canopy width (0.74***), root length (0.55***), root diameter (0.60***), plant biomass at harvest (0.71***), marketable root weight (0.51***), and root yield (0.65***).

Canopy width, root length, root diameter, plant biomass, marketable root weight, and root yield all showed significant positive correlations with each other and with other variables in the study. On the other hand, non-marketable root weight and harvest index did not exhibit significant correlations with most of the other variables. Specifically, harvest index did not show significant correlations with the majority of the other variables.

Table 4.20 presents the correlation between growth, yield, and yield component variables of carrots during the 2022 major cropping season. Root tuber yield showed a significant and highly positive correlation with plant height, number of leaves per plant, canopy width, root diameter, plant biomass at harvest, marketable root weight, and harvest index. However, it was weakly correlated with root length and non-marketable root tuber weight.

Plant height was significantly and positively correlated with all growth and yield components, except for non-marketable root weight per plot (-0.23ns), which showed no significant correlation. The number of leaves per plant had strong positive correlations with canopy width (0.81***), root length (0.77***), root diameter (0.78***), plant biomass at harvest (0.57***), marketable root weight (0.71***), harvest index (0.47***), and root yield (0.66***).

Canopy width, root length, root diameter, plant biomass, marketable root weight, harvest index, and root yield all demonstrated significant positive correlations with each other and other variables in the study. Non-marketable root weight and harvest index did not show

significant correlations with most of the other variables. Root yield exhibited strong positive correlations with plant biomass at harvest (0.93***), marketable root weight (0.96***), and moderate positive correlations with other variables in the study.

Table 4.19: Correlation matrix among growth and yield and yield parameters of carrot as influenced by different fertilizer rates and biochar during 2021 minor cropping season

	1	2	3	4	5	6	7	8	9	10
1. Plant height										
2. Number of leaves per plant	0.78***									
3. Canopy width	0.89***	0.74***								
4. Root length	0.59***	0.55***	0.66***							
5. Root diameter	0.67***	0.60***	0.75***	0.57***						
6. Plant biomass at harvest	0.83***	0.71***	0.82***	0.56***	0.75***					
7. Marketable root tuber weight	0.60***	0.51***	0.68***	0.47***	0.73***	0.62***				
8. Non-marketable root tuber weight	-0.23ns	-0.41ns	-0.32ns	-0.41ns	0.03*	-0.10ns	-0.06ns			
9. Harvest index	-0.50ns	-0.47ns	-0.54ns	-0.39ns	-0.58ns	-0.63ns	-0.37ns	0.15ns		
10. Root tuber yield (t/ha)	0.77***	0.65***	0.78***	0.53***	0.58***	0.79***	0.66***	-0.19ns	-0.31ns	

*Numbers against the parameters in columns correspond with variables in rows; NS – Not significant * = Significant at $P \leq 0.05$
 ** = Significant at $P \leq 0.01$ *** = Significant at $P \leq 0.001$*

Table 4.20: Correlation matrix among growth and yield and yield parameters of carrot as influenced by different fertilizer rates and biochar during 2022 major cropping season

	1	2	3	4	5	6	7	8	9	10
1. Plant height										
2. Number of leaves per plant	0.85***									
3. Canopy width	0.81***	0.79***								
4. Root length	0.77***	0.77***	0.70***							
5. Root diameter	0.78***	0.77***	0.79***	0.69***						
6. Plant biomass at harvest	0.61***	0.57***	0.47***	0.40**	0.50***					
7. Marketable root tuber weight	0.72***	0.71***	0.56***	0.57***	0.64***	0.88***				
8. Non-marketable root tuber weight	-0.23ns	-0.33ns	-0.15ns	-0.37ns	-0.34ns	-0.03ns	-0.33ns			
9. Harvest index	0.50***	0.47***	0.43**	0.39**	0.44**	0.29*	0.61***	-0.09ns		
10. Root tuber yield (t/ha)	0.69***	0.66***	0.55***	0.49***	0.58***	0.93***	0.96***	-0.06ns	0.62***	

Numbers against the parameters in columns correspond with variables in rows; NS – Not significant * = Significant at $P \leq 0.05$
 ** = Significant at $P \leq 0.01$ *** = Significant at $P \leq 0.001$

CHAPTER FIVE: DISCUSSION

5.1 Effect of amendments on soil chemical and physical properties

The application of chicken manure, either alone or combined with biochar, enhanced the soil's chemical properties compared to other treatments in both cropping seasons. Chicken manure boosted the soil's organic matter content, leading to increased levels of nutrients such as total nitrogen, available phosphorus, and higher concentrations of exchangeable cations like potassium, calcium, magnesium, and sodium. Dhaliwal *et al.* (2018) observed that the addition of chicken manure improves organic matter, which in turn enhances the availability of both macro- and micronutrients essential for plant growth.

The use of both organic and inorganic fertilizers also led to an increase in soil pH across all treatments, with pH rising from 4.05 to values between 6.16 and 6.82 in both seasons. This finding aligns with the work of Okon *et al.* (2016), who stated that organic matter improves cation exchange capacity, buffering pH fluctuations and enhancing soil nutrient availability. Similarly, a study by Liu *et al.* (2024) demonstrated that biochar application (3 or 6 kg/m²) raised soil pH from 5.2 to 6.7. Adeleye *et al.* (2010) also reported that poultry manure application increased soil pH, organic matter, total nitrogen, available phosphorus, exchangeable cations, and base saturation, consistent with the results of this study.

When compared to the initial soil sample, all amended plots showed higher levels of available phosphorus (P), total nitrogen (N), total exchangeable bases (TEB), exchangeable acidity (EA), organic carbon, and organic matter than the control plot (Table 4.3). These improvements in soil nutrient composition are attributed to the amendments, which enriched the soil compared to the unamended plots. Sandy loam soils typically have low water-holding

capacity and poor nutrient retention, but amending the soil with organic matter significantly improved both water retention and nutrient-holding capacity (Vahedi *et al.*, 2022).

5.2 Effect of chicken manure, NPK fertilizer and biochar on Vegetative growth of two carrot varieties

Tokita outperformed Technisem in terms of plant height, shoot fresh and dry weight, and canopy width across both cropping seasons. These differences are likely due to genetic variations between the two carrot varieties, as well as climatic and soil factors. Climatic conditions, soil quality (including nutrient availability and water retention), and the genetic characteristics of the varieties all significantly influence crop growth and development. However, no significant differences in root fresh and dry weight were observed between the two varieties during the 2022 major cropping season.

Data from both the 2021 and 2022 cropping seasons revealed that planting the carrot varieties in plots treated with 10 t/ha of chicken manure (CM) or a combination of 5 t/ha CM + 5 t/ha biochar (LB) significantly promoted vegetative growth. This was reflected in increased plant height, more leaves, wider canopy, and greater dry matter accumulation in both seasons. The improvement in growth is likely due to the higher organic matter content in soils amended with either chicken manure alone or a mixture of manure and biochar, both of which enhanced the soil's nutrient profile and water retention capacity. Chicken manure, rich in nitrogen, phosphorus, and potassium, provided essential nutrients for vigorous plant growth (Piash *et al.*, 2022). This aligns with Okon *et al.* (2016), who highlighted that organic manures not only serve as nutrient sources but also help buffer soil pH fluctuations, thus creating optimal conditions for plant growth.

In addition to its nutrient and water retention properties, biochar fosters a beneficial environment for microbes that support root development (Anyanwu *et al.*, 2021). Its porous structure, large surface area, and high surface charge density enhance nutrient retention, improve soil moisture, and contribute to better soil structure. This, in turn, boosts overall plant growth, leading to increased plant height, broader canopy, more leaves, and greater dry matter (Zhang *et al.*, 2021). For example, Gandahi *et al.* (2015) observed that adding rice husk biochar with macronutrient fertilizers increased maize height, with the best results occurring when biochar was combined with 25% less than the recommended NPK fertilizer rate.

Chicken manure supplied essential nutrients for plant growth, while biochar retained those nutrients in the soil and supported root development. Frempong *et al.* (2016) reported that poultry manure improves the availability of phosphorus, potassium, calcium, organic matter, and magnesium, all of which are vital for healthy vegetative growth. The interaction of Tokita and Technisem with 10 t/ha CM and 5 t/ha LB + 5 t/ha CM treatments led to substantial increases in vegetative growth, including taller plants, more leaves, wider canopy spread, and greater dry matter accumulation compared to other amended and control plots. The combination of chicken manure and biochar likely provided a richer supply of key nutrients, such as nitrogen, phosphorus, and potassium, which are essential for plant growth. These nutrients support critical physiological processes like cell division and photosynthesis, enhancing dry matter accumulation and overall plant development. The synergistic effects of these amendments likely boosted photosynthetic activity, resulting in taller plants, more leaves, and a larger canopy (Legendre *et al.*, 2021). Healthy plants with optimal access to nutrients and water experience improved photosynthesis, which promotes better canopy development. Chicken manure also enhances soil fertility by improving soil structure, water

retention, and nutrient availability, which in turn supports better root development, nutrient uptake, and overall plant health (Rayne *et al.*, 2020). Healthy root systems are crucial for efficient water and nutrient absorption, contributing to improved plant height, canopy spread, leaf number, and overall growth.

5.3 Effect of chicken manure, NPK fertilizer and biochar on physiological growth of two carrot varieties.

Tokita exhibited significantly higher crop growth rates (CGR) compared to Technisen from 77 days after planting (DAP) to harvest, as well as during the periods of 49-63 DAP and from 77 DAP to harvest in both the 2021 minor and 2022 major cropping seasons. These differences in growth rates are likely attributable to the distinct genetic traits of each variety, which affect factors such as photosynthetic efficiency, root structure, and nutrient uptake. This observation is consistent with the findings of Islam *et al.* (2019), who linked variations in CGR between different maize varieties to genetic differences.

No significant differences in relative growth rate (RGR) were observed between the two carrot varieties across both cropping seasons, which aligns with the results of Essilfie *et al.* (2023), who found no significant variation in RGR between two maize varieties. However, carrot plants treated with 10 t/ha chicken manure (CM) and 5 t/ha CM + 5 t/ha biochar (LB), along with their interactions with Tokita, demonstrated significantly higher CGR and RGR compared to unamended plots and interactions involving Technisen and Tokita with unamended plots in both seasons. The improved nutrient availability in soils amended with manure and biochar likely promoted more robust growth and increased biomass accumulation, leading to higher growth rates.

It was also observed that both CGR and RGR were highest during the early growth stages and gradually decreased as the plants matured. This decline can be attributed to the shift in the distribution of assimilates toward the economically valuable parts of the plant, coupled with a reduction in photosynthetic efficiency as the plant ages (Tanveer *et al.*, 2014). Consequently, leaf and stem senescence occurred, which led to a decrease in both CGR and RGR by harvest time.

5.4 Effect of chicken manure, NPK fertilizer and biochar on yield and yield components of two carrot varieties

The carrot variety had no significant effect on the number of plants harvested, non-marketable root weight, number of forked or deformed roots, plant biomass at harvest, or harvest index across both cropping seasons. However, during the 2021 minor cropping season, Tokita demonstrated significantly greater root length, diameter, marketable root weight, root weight per plot, and root yield compared to Technisen. These variations are likely attributed to genetic differences between the two varieties and their distinct responses to soil water and nutrient availability.

Overall, carrot plants treated with 10 t/ha chicken manure (CM) or a combination of 5 t/ha CM + 5 t/ha biochar (LB), along with the interactions of these treatments with Tokita and Technisen, showed significant improvements in yield and related components. This included higher plant counts, reduced non-marketable root weight, fewer forked and deformed roots, increased plant biomass at harvest, improved harvest index, and greater root length, diameter, marketable root weight, and total root yield compared to control plots across both cropping seasons. These enhancements can be attributed to the improved nutrient content and water

retention capacity provided by poultry manure, which releases both macro- and micronutrients during decomposition (Ntsoane *et al.*, 2022). Additionally, organic matter helps convert inorganic nutrients into more bioavailable forms, improving soil structure and physical properties (Agbede *et al.*, 2017). The continuous nutrient supply throughout the growing season likely contributed to the observed better plant growth and higher yields in treatments with poultry manure and poultry manure + biochar (Quilty & Cattle, 2011).

In a similar study, Essilfie *et al.* (2023) found that 10 t/ha CM and 1.25 t/ha GB + 5 t/ha CM, in combination with maize varieties Omankwa and Obatanpa, significantly boosted yields compared to other amended and control treatments across both cropping seasons. Their research also showed that soils treated with chicken manure and biochar created a nutrient-rich environment, ensuring a consistent nutrient supply, especially during critical growth stages like grain filling, which led to higher yields.

The improved yield and yield characteristics seen with poultry manure are likely due to its rapid nitrogen release, supporting essential plant processes such as carbohydrate formation. Adeleye *et al.* (2010) suggested that organic manures promote phytohormone production, which enhances plant growth and nutrient uptake, ultimately boosting crop yields. Similarly, Choudhary *et al.* (2013) reported similar findings. Rawat *et al.* (2020) also highlighted that organic manure's high organic matter content increases cation exchange capacity, enhances microbial activity, improves water retention, reduces soil compaction, and stabilizes soil pH, all contributing to better plant growth and higher yields. For instance, Boateng *et al.* (2017) found that using poultry manure (6-8 t/ha) instead of conventional NPK fertilizer resulted in higher maize yields due to improved soil properties and nutrient release. Arif *et al.* (2021)

also observed that applying 10 t/ha of poultry manure led to higher maize yields compared to applying standard inorganic N and P fertilizers.

Further research supports the idea that combining poultry manure with biochar can significantly improve carrot growth, yield, and related characteristics. The use of both poultry manure and biochar has been shown to enhance root length, diameter, yield, and biomass production (Biswas *et al.*, 2020). Vahedi *et al.* (2022) demonstrated that biochar-treated soils increased water-holding capacity, promoting root development and improving microbial activity, which in turn boosted yields. Similarly, Wisnubroto *et al.* (2017) found that combining farmyard manure with biochar improved growth and yield in red chili, attributed to the synergistic effects of both amendments. Kalu *et al.* (2021) also reported a modest but significant increase in grain yield from biochar application, with enhanced soil water retention and liming effects playing key roles in improving yields.

5.5 Correlation matrix analysis

The strong positive correlations observed between vegetative growth parameters (such as plant height, number of leaves per plant, and canopy width) and yield components (including root length, root diameter, marketable root weight, and root yield) suggest that as vegetative growth improves, other yield components tend to increase as well (Negero et al., 2017). This indicates a strong connection between vegetative growth and overall plant productivity. Similarly, Wilkinson et al. (2020) found a significant positive correlation between plant height and other vegetative and yield components in sweet potato.

The positive correlations between the number of leaves per plant and other variables, such as canopy width, root length, root diameter, marketable root weight, and root yield, highlight the importance of foliar development in influencing overall plant growth and yield. This aligns with Meghashree et al. (2018), who reported a significant positive correlation between plant biomass, number of leaves, root weight, and core diameter in carrots. Leaves play a crucial role in photosynthesis, providing the energy needed for plant growth, and a denser leaf canopy appears to support stronger and more productive carrot plants. Additionally, the interrelated growth of canopy width, root length, root diameter, plant biomass, marketable root weight, and root yield emphasizes how different parts of the plant contribute to overall development, with each influencing the others positively, leading to enhanced productivity.

The lack of significant correlations between harvest index and most other variables suggests that this parameter may not be directly impacted by the measured growth and yield components.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Based on the findings of the study, the following conclusions can be drawn:

- The application of 10 t/ha chicken manure (CM) and 5 t/ha CM + 5 t/ha biochar (LB) enhanced soil chemical properties, including increases in organic carbon, organic matter, and nutrient concentrations (N, P, K, Ca, Mg) when compared to the control treatment.
- Carrot plants treated with 10 t/ha CM exhibited higher crop growth rate (CGR) and relative growth rate (RGR) than those in unamended plots across both cropping seasons.
- The interaction between Tokita and 5 t/ha CM + 5 t/ha LB resulted in significantly higher CGR ($P \leq 0.05$) compared to both Tokita and Technisen with unamended plots, as well as those treated with 250 kg/ha NPK, during the 0-35 DAP and 77 DAP to harvest periods of the minor cropping season.
- The Tokita variety treated with 10 t/ha CM achieved the highest CGR, significantly outperforming both varieties in unamended plots across both seasons ($P \leq 0.05$).
- During the 2021 minor cropping season, Tokita outperformed Technisen in terms of root length, diameter, marketable root weight, root weight per plot, and root yield.
- The application of 10 t/ha CM or 5 t/ha CM + 5 t/ha LB, along with their interactions with Tokita and Technisen, significantly increased plant biomass, root weight, root yield, marketable root yield, and harvest index, outperforming all other amended plots and control treatments in both cropping seasons.

6.2 Recommendations

The following recommendations are made based on the findings of this study:

- Farmers are encouraged to use either sole chicken manure (10 t/ha CM) or a combination of chicken manure and biochar (5 t/ha CM + 5 t/ha LB) to improve soil chemical properties for better carrot production.
- To enhance vegetative growth, which can lead to higher yields, farmers should apply 10 t/ha CM and/or 5 t/ha CM + 5 t/ha LB.
- For improved root yield and marketable root yield, farmers should grow the Tokita and Technisen varieties and apply 10 t/ha CM and/or 5 t/ha CM + 5 t/ha LB.
- Further research should focus on analyzing the partial benefits of the treatments used and provide farmers with recommendations on the most profitable treatment combinations for carrot production in Ghana and West Africa.

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LIST OF APPENDICES

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 Matter (%)	
< 1.5	Low
1.6 – 3.0	Moderate
3.0	High
Nitrogen (%)	
< 0.1	Low
0.1 – 0.2	Moderate
> 0.2	High
Exchangeable Potassium (cmol (+)/kg)	
< 0.2	Low
0.2 – 0.4	Moderate
> 0.4	High

Source : (SRI, 2007)

Appendix 2: Climatic conditions for experimental site (1) during 2021 minor cropping season

Month	Total Rainfall (mm)	Relative Humidity (%)	Mean Temperature (°C)	
			Max	Min
August, 2021	169.5	77	29.7	22.7
September	225.1	77	30.3	23.2
October	208.7	72	32.1	22.3
November	73.4	68	33.1	23.4
December	0.0	58	34.3	23.7
Total	676.7			

(Ghana Meteorological Agency– Mampong Ashanti, 2021)

Appendix 3: Climatic conditions for experimental site (2) during 2022 major cropping season

Month	Total Rainfall (mm)	Relative Humidity (%)	Mean Temperature (°C)	
			Max	Min
March, 2022	109.2	67	34	23.9
April	79.6	66	33.1	23.5
May	147.8	71	32.7	23.8
June	149.0	74	31	23.3
July	203.6	74	30	22.7
Total	694.6			

(Ghana Meteorological Agency– Mampong Ashanti, 2022)