EFFECT OF BIOCHAR AND INORGANIC FERTILIZER ON GROWTH, YIELD, AND QUALITY OF BEETROOT *(Beta vulgaris* L.*)* IN KENYA

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented to this University or any other for the award of a degree.

Signature…   Date:13th September2023

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Recommendation

This thesis has been submitted with our approval as University supervisors

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DEDICATION

I dedicate this work to my lovely parents, siblings, my uncle and the entire family.

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ABSTRACT

Beetroot (*Beta vulgaris* L.) is crop grown for its antioxidant properties. It also contributes to the improvement of livelihoods of stakeholders in its value chain. However, beetroot farming has faced various challenges that negate the root yields in Kenya. The high cost of inorganic fertilizers has resulted in the continuous use of ineffective combinations of synthetic fertilizers and soil amendments resulting in low soil fertility. This study aimed at determining the effect of biochar and NPK on the growth, yield, and quality of beetroot. A 2- seasons experiment was conducted at Egerton University's Field 3. The experiment was laid out in a randomized complete block design (RCBD) in a factorial arrangement with 3 replications. Each replicate had twelve (12) treatments. Biochar was applied at three levels (0, 5, and 10 t ha^{-1}), while inorganic fertilizer (NPK) was applied at four levels (0, 200, 300, and 400 kg ha^{-1}). Initial characterization of soil and biochar for macro and micronutrients were done, before planting. Data was collected for plant height, leaf area and the number of leaves at two weeks intervals starting from two weeks after emergence. Data on yield and quality parameters were collected after harvesting. Folin Denis reagent was used to analyse beetroot's total phenolic content, A hand-held refractometer (RHB; Shanghai Precision and Scientific Instrument Co. China) was used to measure total soluble solids (TSS). The spectrophotometric and complexometric method were used to analyse phosphorus and calcium content. Atomic Absorption Spectrophotometry used to analyse iron content. The Shapiro-Wilk test was used to ascertain the normality of data and analysis of variance using Proc GLM in Statistical Analysis Software (SAS). Tukey's Honestly Significant Difference was used to compare the means. Application of all rates of biochar (0, 5 and 10 t ha^{-1}) did not increase significantly beetroot growth, while NPK at 200, 300 and 400kg ha^{-1} significantly increased beetroot growth in seasons one and two. Moreover, biochar combined with NPK significantly increased beetroot growth in terms of height at 75 and 90 days and leaf area 45, 60, 75 and 90 days in season two. Biochar at 5 t ha^{-1} (B5) resulted in 61.1 t ha^{-1} of marketable yield. Treatment B5 showed iron content of 713.4mg kg^{-1} in the beetroot in season one. However, in season two was 720.7mg kg^{-1}. Additionally, biochar at 5 t ha^{-1} also had the highest concentration of total soluble solids (10.8 ^{o}Brix), compared with the other treatments. Therefore, biochar at 5 and 10 t ha^{-1} combined with NPK at (200, 300 and 400kg ha^{-1}) were not statistically different from each other to increasing beetroot growth, yield and quality. Based on findings of this study, B5N200 can be recommended for beetroot production in Kenya.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
DM	Dry Matter
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
KES	Kenyan Shillings
NPK	Nitrogen, Phosphorus and Potassium
RCBD	Randomized Complete Block Design
SDG	Sustainable Development Goals
USA	United States of America

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Vegetables are succulent sections of plants grown in gardens and served as a side dish with starchy foods. They are particularly nutritious because they are the primary sources of vitamins, minerals, dietary fibre, and proteins (Mwadzingeni *et al*., 2021). Beetroot (*Beta vulgaris* L.) is a taproot vegetable that belongs to the *Chenopodiaceae* family, like Swiss chard and spinach (Piegat & Tomaszewska, 2015). It is grown on about 7 million hectares of land across the world, with a total production of 240 million tonnes seasonally (Shahbandeh, 2021).

In Africa, beetroot production has increased by an average of 6.28% annually, increasing from 1.21 million tonnes in 1970 to 14.3 million tonnes in 2019 (Akan *et al.*, 2021). Farmers have become more interested in beetroot production due to the higher market demand for the crop. The benefits realized from beetroot include health-promoting properties such as betacyanin, which has anti-cancer properties and also acts as a suppressor against the development of various bladder cancers; nitrate content also promotes blood flow (Kumar,2017; Lewin, 2021; Mirmiran *et al.*, 2020). In addition, the purple-crimson colour of beetroot increases its ability to reduce arterial stiffness and blood dilatation, hence potentially lowering blood pressure and preventing heart diseases and stroke (Hussain *et al.*, 2018; Kumar, 2017). Beetroot is also rich in antioxidants, and hence a good choice for human consumption as this contributes to the inhibition of carcinogen synthesis which is critical in cancer formation (DePace & Colombo, 2019).

To reduce poverty in rural regions, the Kenya government has consistently supported the growth of high-value and resistant crop types among farmers (Mandere *et al*., 2020). Beetroot is one of the crops that significantly contribute to smallholder farmers' income and the country's economy (Ndunge, 2019). Beetroot cultivation has become popular in Kenya, with Nakuru, Kiambu, and Tharaka Nithi counties being the leading producers. As well, the increasing production of beetroot has been proven to be successful due to its being widely available on the market and inexpensive prices, which increases household net income (Gassner *et al.*, 2019). Due to the short growth cycle, beetroot as a crop provides possibilities for farmers and actors throughout the chain to be employed and earn income regularly while also contributing to food security (FAO, 2020).

Fertilization is among the most significant factors of beetroot growth that impact the quantity of yield obtained (Abdelaal, 2015). The major nutrients or macronutrients include nitrogen, phosphorus, and potassium; secondary nutrients include calcium, magnesium, and sulfur; and the micronutrients include boron, copper, iron, manganese, molybdenum, zinc, and nickel. In beetroot, nitrogen is required for protein synthesis or amino acid production (Pandita *et al.*, 2020).

Apart from nitrogen, phosphorus is present in plant and animal cells and is vital to all plants for harvesting the sun's energy and converting it into adenosine triphosphate (ATP); for growth and reproduction. In beetroot, phosphorus is an essential part of sugar phosphates. It is involved in respiration and energy transfer via ATP; and is a part of ribonucleic acid (RNA), deoxyribonucleic acid (DNA), and membrane phospholipids. Without an adequate supply of P, beetroot growth is diminished; maturity is delayed, and yield is reduced (Débia *et al.,* 2020). Potassium aids photosynthesis, the process by which the carbohydrates and energy required for beetroot growth are generated and transformed. Potassium also regulates the water status of the plant by controlling the opening and shutting of the leaf stomata (Hozayn *et al.,* 2020). Biochar, which is made from the pyrolysis of waste materials such as agricultural debris and animal wastes, can also improve soil nutrient availability by lowering nutrient leaching (Yaashika *et al.,* 2020). Furthermore, biochar has been proven to increase soil phosphorus and total nitrogen concentrations when used as a soil amendment (Rawat *et al.,* 2019). When used in beetroot farming, biochar can be resourceful in aiding red beetroot development and yield by retaining nitrogen and phosphorus longer and hence boosting the availability. In most circumstances, crop growth is inhibited by the loss of nitrogen due to leaching, denitrification, and volatilization. Incorporating biochar into the soil can solve these problems, as it helps to improve nitrogen and phosphorus mineralization and hence increases basic cations in the soil (Pan *et al.,* 2021).

Despite the importance of macronutrients, other various factors influence the growth, yield, and quality of horticultural crops like beetroot (Rajaram & Dubin, 2021). Among these factors, sowing, harvesting dates, water availability, cultivation system, plant density, and fertilizer type are considered to be critical factors. Continuous use of chemical fertilizers has had a deleterious impact on soil fertility. This directly affects the performance of beetroot production by lowering the beetroot yield trend in the growing season (Sharma *et al.,* 2014). Overuse of phosphorus fertilizer including NPK, inhibits the uptake of micronutrients such as zinc and iron by plants, resulting in poor development or growth (Brar *et al.*, 2015). On the other hand, using insufficient amounts of organic and inorganic fertilizer depletes critical soil nutrients and minerals found naturally in fertile soil.

Farmers in Kenya get an average of 25 to 30 t ha^{-1} of beetroot production (Muthini et al., 2020), which is lower compared to the crop's potential yield of 68 t ha^{-1} (Mirmiran *et al.*, 2020). Continuous use of inorganic fertilizers and improper synthetic fertilizer combination rates and application of insufficient quantities of soil amendments are among the major reasons for the reduced yield and quality of beetroot in Kenya (Tim, 2021). However, because of these problems, the study on the response of beetroot after the application of biochar and NPK was designed. This study, therefore, seeks to narrow this knowledge gap by investigating if the application of charcoal dust combined with chemical fertiliser (NPK) affects beetroot production in Nakuru County, Kenya.

1.2. Statement of the Problem

Beetroot (*Beta vulgaris* L.) is an important crop with a variety of health benefits and significantly contributes to household income of farmers in Kenya. Despite its importance, Kenyan farmers get about 25 -30 t ha^{-1} which is significantly lower than the potential yield of 68 tonnes/ha. Continuous use of poor and inappropriate combination rates of synthetic fertilizers and soil amendment has resulted in low soil fertility hence affecting the growth, yield, and quality of beetroot. In an attempt to increase yields, farmers have adopted the use of inorganic fertilizers, especially NPK (17-17-17) due to their potential of supplying nutrients that aid in the growth and development process of the beetroot. Nevertheless, there is insufficient knowledge regarding the appropriate rates in terms of the combination of the biochar and NPK. However, several studies have recommended the use of biochar as an organic soil amendment.

1.3. General Objective

To contribute towards food security and nutrition by enhancing production of beetroot

1.3.1. Specific Objectives

i. To determine the effects of biochar and NPK fertilizer rates on the growth of beetroot

ii. To determine the effects of biochar and NPK fertilizer rates on the yield of beetroot

iii. To determine the effects of biochar and NPK fertilizer rates on the quality of beetroot

1.3.2. Hypotheses

i. Biochar and NPK fertilizer rates have no significant effect on the growth of beetroot.

ii. Biochar and NPK fertilizer rates have no significant effect on the yield of beetroot

iii. Biochar and NPK fertilizer rates have no significant effect on beetroot quality

1.4. Justification of the Study

Agriculture is the basis of Kenya's economy as it significantly contributes to the GDP of the country. The Kenyan horticultural sector is the highest contributor to export earnings and GDP respectively. One of the major aspects of the economic pillar of Kenya's Vision 2030 blueprint is to increase the value of agriculture to achieve food and nutrition security. In Kenya, only 4% of all horticultural produce (Fruits and vegetables) is exported while 96% is consumed locally (Adeyanju *et al.,* 2023). Over 90% of all this produce consumed locally is being produced by small-scale farmers (Oluoch *et al.,* 2023). In Kenya, improving the horticultural sector (fruits and vegetables) contributes to reducing food insecurity. However, zero poverty, zero hunger and good health are among the sustainable development goals in Kenya. More so, this study guided the small-scale farmers and other stakeholders involved in beetroot production. This plays a vital role to minimize poverty and hunger among small-scale farmers. Apart from increasing vegetable production, environmental pollution is found to be a factor in reducing good health in East African countries. In Kenya, charcoal sellers pollute the environment by putting the dust charcoal alongside the road or everywhere. These studies contribute to reducing environment pollution through recycling the charcoal dust (biochar) and use it as the soil amendment. In developed countries like the USA, biochar is being used as a soil amendment to increase crop yield and enhance carbon sequestration. Yet, in Kenya, the adoption of biochar had slowed due to insufficient knowledge about its importance in improving soil health and crop yield. This study aimed to assess the response of beetroot growth, yield and quality after the application of biochar and NPK.

CHAPTER TWO
LITERATURE REVIEW

2.1 Overview of Beetroot Crop

2.1.1 Origin of Beetroot

Beetroot (*Beta vulgaris L.*) is a biennial vegetable that is typically farmed as an annual crop. During the first growing season, it produces roots, stems, and leaves; while in the second it produces flowers, fruits, and seeds (Vasconcellos *et al.,* 2016). According to Nayik and Gull (2020), beetroot descended from *Beta Maritim*e, often known as the wild beet or sea beet, which was native to southern Europe and the Mediterranean coastlines. According to Assimiti (2019), the Greeks, such as the Romans, grew beetroot for their leaves because it was used for medicinal purposes, but also ate them and called them teutlon or teutlion because the foliage looked like squid tentacles. These white and black beetroots came to be known as Roman beetroot. Cultivated beetroot was prevalent throughout Europe by the end of the 15th century, and was used for both its leaves and its roots (Kumar & Brooks, 2018).

2.1.2 Classification and Botany of Beetroot

Beetroots are members of the Dicotyledonae family of flowering plants. The Caryophyllales order belongs to this class, and beetroot belongs to the *Chenopodiaceae* family, which is also in this class (Shakeel *et al*., 2020). Spinach (*Spinacia oleracea)*, quinoa (*Chenopodium quinoa*), orache or orach (*Atriplex hortensis*), and Good King Henry (*Atriplex hortensis*) are all edible plants in the *Chenopodiacea*e or goosefoot family (*Chenopodium bonusHenricus*). Beetroots are members of the Beta genus and the *vulgaris species* (Pandita *et al*., 2020). Leaf beetroot (spinach beet and chard), beetroot (table beet or garden beet), fodder beet, and sugar beet are all the farmed varieties of *Beta vulgaris.*

2.1.3 Nutrient Composition of Beetroot

Several studies including those by Piegat and Tomaszewska (2015); Yordanova and Gerasimova (2016);Daisy (2020) found that red beetroot grows best in well-drained, light, loose soils under temperatures ranging from 15^{o}C to 25^{o}C, although it may to some extent survive the heat and freezing. A study by Vasconcellos *et al*.(2016) reported that the beetroot planted in well-drained soil and well-fertilised with ammonium fertiliser in Nigeria performed better compared to the control where there was no fertiliser applied. Another study conducted by Álvarez *et al.* (2021) revealed that the nutritional composition of beetroot is influenced by a range of factors, including fertilization. When fertilizer is optimally supplied to red beetroot, increased iron, carbohydrate, fibre, and water are attained (Elaine, 2019).

Table 1: Nutritional Composition in 136g of Raw Beetroot

No	Element	Units	Value
1	Vitamin C	mg	6
2	Phosphorus	mg	54.4
3	Protein	g	2.19
4	Carbohydrates	g	9.6
5	Sugar	g	6.8
6	Fibre	g	5
7	Fats	g	1
8	Potassium	mg	380
9	Magnesium	mg	23
10	Vitamin B-6	mg	0.06
11	Vitamin A	mg	2.7
12	Zinc	mg	0.35

Source: Abdo *et al.* (2020)

2.2 Economic Importance of Beetroot

Among several vegetable markets worldwide and in Kenya, red beetroot has a big market. This is due to its high demand by the people because of its medicinal properties (Giampaoli *et al.,* 2021). Red beetroot is grown on a total land area of about 7 million hectares around the world, with a total production of 240 million tonnes (Shahbandeh, 2021). A consistently increasing trend has been observed in Africa's beetroot production over years. This has seen a shift from about 1.21 million tonnes in 1970 to 14.3 million tonnes in 2019 hence an average annual growth of 6.28 per cent in productivity (Akan *et al.*, 2021). According to Ranawana *et al*. (2018), beetroot is ranked among the world’s largest vegetable crops contributor to improved food and nutrition security and poverty reduction among smallholder farmers through income generation. Its production is an avenue of employment for numerous groups of people employed directly as farmers and indirectly along the value chain as workers, dealers, beetroot traders, and drivers among others (Irandu, 2019).

In Kenya, beetroot is mainly grown in Nakuru, Kiambu, Tharaka Nithi, and Nyandarua Counties. Farmers in these counties have the potential of earning KES 325,000 from beetroot annually by selling at KES 325 per kilogram (Elaine, 2019; Wamucii, 2021). Besides, the red beetroot has the potential to reduce food shortage significantly due to its short growth cycle of 7 to 12 weeks (Adrian, 2020). Smallholder farmers dwelling on the production can easily market the red beetroot produce on spot markets and formal markets on contractual terms and economically access other household food necessities.

2.3. Types of Biochar

Biochar has different biological, physical and chemical properties (Alexandre *et al*., 2023), depending on the type of biomass i.e. feedstock used for their production and the production temperatures at which the pyrolysis was carried out (Yang *et al*., 2023). The physical characteristics of biochar are greatly associated with the biomass used while the chemical and biological features of biochar are as result of both the biomass used and production temperatures used (Cay *et al*., 2020). Different temperatures are used in the production of biochar usually ranging from 300^{o}C to 800^{o}C and this has a significant effect on the quality of the biochar with higher production temperatures producing biochar with less nutrients available in the amendment (Bai *et al*., 2015). Biochar produced at low temperatures (slow pyrolysis) i.e. below 500^{o}C is richer in cation exchange capacity, nitrogen, phosphorus, magnesium than the biochar produced under fast pyrolysis i.e. above 500^{o}C (Adekiya *et al.*, 2020). At higher production temperatures, some mineral elements undergo volatilization, organic matter composition is broken down thereby reducing the quality of the biochar formed (Simms *et al*., 2020). However, biochar produced at higher temperatures has a higher carbon content than one formed under low temperatures (Shetty&Prakash, 2020).Different biomass used in biochar pyrolysis have different sizes of pores, varying ash levels and varying chemical characteristics (Adekiya *et al*., 2020). Biochar feedstock can either be of plant or animal origin (Pan *et al*., 2021) . Plant biomass commonly used as feedstock includes wood that produces charcoal, rice straws (Geng *et al*., 2022), acacia stems and branches, corncob and orchard pruning . The most commonly used animal origin feedstock is poultry litter and cow manure (Agarwal *et al*., 2022). In Kenya, the most commonly used feedstock for biochar production are banana pseudo stems, maize residues of cobs and stovers, collard green stalks and woody herbaceous trees farmers use for firewood and charcoal (Blanco-Canqui, 2017). Plant based biochar has higher nutrient content than the animal-based biochar. However, animal based biochar has some higher nutrients such as total nitrogen in poultry litter (R. Singh *et al*., 2019). For biomass to produce high quality biochar it should meet the following parameters: black carbon content should be more than 15%, hydrogen: carbon ratio less than 0.6; and oxygen: carbon ratio less than 0.4 with a surface area greater than >100 m^2 g^{-1} (Adekiya *et al*., 2020).

2.3.1. Effect of Biochar on Soil Chemical Properties

2.3.2. Effect of Biochar on Soil Nitrogen

Addition of biochar to soils increases the nitrogen content in the soil whereby nitrogen is released from the soil stores where biochar influences nitrogen transformations leading to the release of the nutrient to the soil (Mukherjee & Lal, 2013). Addition of biochar to the soil brings about variation in the soil's nitrogen through affecting soil inorganic nitrogen such as nitrate and ammonium. Plant roots absorb soil inorganic nitrogen for crop nutrition. Application of biochar either leads to an increment, reduction or no effect on soil inorganic nitrogen (Arif *et al*., 2017). This is attributed to many factors such as biochar duration in the soil, biochar type, its application rate and soil properties (Trupiano *et al*., 2017). In some instances, nitrogen becomes readily available after some long period of biochar application in which the nutrient gets desorbed into the soil solution. This is because mineralization rate is proportional to time. Biochar of plant origin usually lowers nitrogen mineralization due to the low C: N ratio. Nitrogen mineralization occurs when C: N ratio is below 20 and a C: N ratio beyond 20 results into N immobilization (Premalatha *et al*., 2023). Biochar lowers soil acidity thereby encouraging microbial activities and population of nitrifiers which is usually lowered at soil pH below 5. Optimum soil aeration encourages mineralization by inhibiting denitrification and promoting nitrogen microbial respiration (Quilliam *et al*., 2013). For a farmer to obtain high crop yield, N should be readily supplied and be in available forms in the soil for crops to readily take up the nutrient (Zhang *et al*., 2020).

2.3.3. Effect of Biochar on Soil Phosphorus

Biochar readily supplies phosphorus to the soil through different mechanisms. Phosphorus is not readily available in acidic soils as it is fixed and adsorbed onto the iron and aluminum oxides. However, biochar decreases soil acidity by making P readily available. Available P increased from 570 mg kg^{-1} in unamended soil to 722.1 mg kg^{-1} when biochar was added to the soil. The experiment took forty days (Premalatha *et al*., 2023). Increase of available phosphorus and nitrogen in biochar amended soils is also as a result of the increased cation exchange capacity or increased exchangeable bases (Are, 2019). Integration of biochar with synthetic fertilizers reduces P sorption on soil particles leading to an increase in P use efficiency. Furthermore, biochar provides conducive environment for the microbes such as phosphate solubilizing microorganisms responsible for phosphorus mineralization. An experiment done on maize for two successive seasons showed that addition of biochar at three rates of 33, 66 and 133 mg dm^{-3} did not increase phosphorus use efficiency when combined with TSP fertilizer granules at three P rates of 100, 200, and 400 mg dm^{-3}. This therefore called for measures to control P fixation (Sun *et al*., 2023). However, these findings contradict those by Walter and Rao (2015)which showed biochar use increased PUE whereby biochar controlled P fixation on iron and aluminum oxides, biochar increased PUE by increased mycorrhizal-fungal associations. In addition, biochar addition raises the soil pH that makes soil P available by reducing its sorption. In association, the charged surface sites of P which are positively charged facilitate on the availability of soil P and this improves crop nutrition since the nutrient will be readily available to the crop roots (Lee *et al*., 2021).

2.3.4. Effect of Biochar on Other Soil Chemical Properties

Biochar when incorporated in soils increases soil cation exchange capacity. The soil amendment is able to retain nutrients which is also supplemented by its sorption capacity (Omondi *et al*., 2016). Owing to its high surface charge density, biochar is able to improve the cation exchange capacity through holding cations. This high surface charge density raises the amendment's surface sorption capability and its base saturation. The high charge density of biochar leads to an increase in the soil CEC which is coupled by formation of carboxylic groups when the aromatic carbon on the surface of the biochar is oxidized, this leads to increase in CEC (X. Peng *et al*., 2011). The biochar has got numerous exchange sites for cations (Trupiano *et al.*, 2017). In addition, it increases cation exchange capacity and nutrient use efficiency by improving water holding capacity due to its spongy nature and increased organic matter content (Wang *et al*., 2017).

Incorporation of biochar in soils influences soil pH where it decreases acidity by acting as a liming agent. Biochar is known to increase soil pH (Lee *et al*., 2021). This favors growth of crops that do not thrive well in acidic soils (Wang *et al*., 2017). Biochar gains its ability to change pH from its pH itself, most biochar is alkaline thus end up increasing on the pH of acidic soils. Biochar also has an ash content that enables to increase soil pH, this ash is enriched with carbonates and other metal ions such as calcium and magnesium which gives it that liming effect (Sepúlveda-Cadavid *et al*., 2021).

The study by Basak and Kundu (2013) found out that use of biochar in a potato garden leads to reduced amount of heavy metals found in both the potato flesh and peel. Biochar retains the heavy metals by lowering their mobility and bioavailability in the soil thereby minimizing the hazardous effects to human health (Cornelissen *et al*., 2018). In addition, biochar is also known for adsorbing environmental resistant pollutants, dyes, pharmaceuticals onto its surfaces lowering their release into the soil, environment thus it has received recognition in conservation (Pan *et al*., 2021)

2.3.5. Effects of Biochar on Soil Physical Properties

Incorporation of biochar into the soil elevates crop growth and yield through lowering bulk density and increasing specific surface area which are necessary for proper crop growth (Sun *et al.*, 2023). Low bulk density enables proper root proliferation and high specific surface area enables high nutrient absorption (Trupiano *et al*., 2017). Biochar has an impact on soil bulk density which it reduces by about 3 to 31%, the more biochar applied, the further decline in bulk density (Blanco-Canqui, 2017).This reduction in bulk density is attributed to two main mechanisms; the low bulk density of biochar about less than 0.6 g cm^{-3} which leads to the reduction of the soil's bulk density which is around 1.25g cm^{-3}. Therefore, thorough mixing of the two, soil bulk density is reduced through the dilution effect which is achieved through mixing of soil and biochar of two different densities. However, this mechanism works best when the difference between the densities of soil and biochar is high (Hale *et al*., 2020).

The other mechanism in which biochar reduces bulk density is when biochar mixes with soil, there is a further development of porosity and aggregation improvement. Biochar boosts soil porosity by about 14 to 64% (Sepúlveda-Cadavid *et al*., 2021). All these two mechanisms are determined by the soil type and biochar rate applied. Furthermore, the mixing of soil with biochar increases the soil porosity, which is a result of the porous spongy nature of biochar. The improvement in soil porosity facilitates nutrient and water movement in the soil (Zhang *et al*., 2020).

Biochar has an effect on soil structure that influences penetration resistance (Huang *et al*., 2021). Biochar undergoes interaction with the soil's inorganic particles and in this way lowers soil compaction enabling crop roots to penetrate to the deeper layers with ease in order to acquire nutrients and water (Wang *et al.*, 2017). Conversely this is usually not achieved in short growing periods but rather after lengthy application of biochar such as biochar application for more than two years and in higher quantities (Blanco-Canqui, 2017). The water holding capacity of the soil is enhanced by biochar additions. This enhancement can go up to 90% and is due to the operative absorption power of the biochar units (Kimani *et al*., 2021).

2.3.6. Effect of Biochar on Soil Biological Properties

2.3.7. Effect of Biochar on General Microbial Population and Activities

Biochar also enhances soil microbial population and activity by providing the microbes shelter due to its porous nature and nutrition (Durukan *et al.*, 2020). Soil microbial populations and activities normally increase after application of biochar which is attributed to substrate availability and habitat (Li *et al*., 2023). Soil microbes play a major role of nutrient cycling (Das *et al.,* 2022). The biochar is source of substrates in form of nutrients from the organic matter to the soil microbes. In addition, the biochar provides shelter to the microorganisms from some soil predators such as mites, protozoans, and nematodes due to the small pore size of the biochar that is usually less than 5 mm in diameter. In addition to the biochar pore size, the soil microbes are protected against harm from the pesticides and heavy metals (Carter *et al.*, 2013). In a study by Riaz *et al*. (2018) found that increasing biochar added to the soil increased microbial colonization and diversity, leading to increased mineral transformations. This observation was due to the biochar providing substrate to the soil organisms. This increase in soil microorganisms by biochar is evidenced by an increase in carbondioxide levels which is an indicator of organic matter decomposition that is catalysed by soil microbes (Adebayo *et al*., 2017). Biochar incorporation is one of the factors which influences the population of different soil organisms alongside other factors such as soil temperature, moisture, root exudates (Trupiano *et al*., 2017) . This is because different types of the organisms have different ecological conditions such as pH, water stress and their nutritional needs under which they thrive. For example, bacteria require neutral to alkaline conditions, which are provided by biochar so that in such a condition bacteria population is higher than the fungi population (Cay *et al*., 2020). A study by Yang *et al*. (2020) showed that application of biochar encourages arbuscular mycorrhiza colonization in roots that stimulates beetroot growth and increases tuber biomass. In another study, Hlisnikovsky *et al*. (2021) showed that addition of biochar led to absorption of antibiotics that are poisonous to beetroot tubers, and increased beet starch, fat, protein, and vitamins content leading to high beetroot quality.

2.3.8. Effect of Biochar on Growth and Yield of Beetroot.

Biochar is a type of charcoal made by pyrolyzing biomass in the absence of oxygen (Zhang *et al.*, 2020). Sänger *et al.* (2017) revealed that to produce good quality biochar, which is vital for improving agricultural output, 250^{o}C must be used in the manufacturing process. Manka'abusi *et al.* (2019) and Zama *et al*. (2018) reported that the application of biochar showed improvement in the chemical and physical properties of soil, soil microorganisms, and root respiration; and these aspects significantly enhanced the growth and yield of crops. According to Asadabadi *et al.* (2021), the application of 7 and 10 t ha^{-1} of biochar increased beetroot yield by 48%. This increase resulted from the decomposition of organic matter in the biochar that helped sustain soil organic nitrogen during the growth period, hence enhancing the uptake of inorganic nitrogen (Asadabadi *et al.*, 2021). Biochar can stimulate the growth of fine roots that can change the carbon cycle, fertilizer effectiveness, and water nutrient absorption respectively, and hence increased growth and yields of beetroot are attained (Akoto *et al.*, 2019).

The use of biochar in production has several other benefits to the soil and the growth of beetroot. Biochar can be crucial in sustaining nutrient storage or availability in soil, therefore contributing to crop yield (Danso *et al.*, 2019). Several authors including Wani *et al. (*2021), and Werner *et al*. (2019) found that the accumulation of salt in the soil negates beetroot growth and yield. The application of biochar in soil with excessively accumulated salts counteracts the inhibitory effect of the salts on the root activity of beetroot. In turn, the absorption of nutrients and sugar content by the beetroots are improved thus increasing the yield and quality of the produce. Waste charcoal dust or biochar acts as an organic soil amendment considering the benefits of biochar such as improvement of soil structure, water-holding capacity, and nutrient retention (Bekchanova *et al*., 2021). The use of waste charcoal dust as a soil amendment contributes to an increased concentration of basic cations including magnesium, calcium, and potassium in the soil, and these results in promoting vegetative and reproductive growth of beetroot (Durukan *et al.*, 2020). Biochar also acts as a sorbent for organic and inorganic impurities from contaminated waterways (Rodrigues & Horan, 2018). According to Mulabagal *et al*. (2020), the presence of functional groups and charges on the surface of biochar such as aromaticity ensure contaminant elimination from the soil. The use of biochar in beetroot and any other agricultural production, therefore, helps promote sustainable agriculture, food and nutrition security, and environmental conservation.

Studies by Bair *et al.* (2020) and Macdonald *et al*. (2014) show that numerous elements including nutrients, temperature, light, and water affect the growth and yield of *Beta vulgaris* L. Biochar has the potential to improve soil aggregation, soil microorganisms, and cation exchange capacity thus boosting the availability of soil nutrients that have positive significant impacts on beetroot growth. Numerous studies including Rawat *et al.* (2019), and Peter (2018) reported that soil amended with 5 tonnes ha^{-1} of waste charcoal dust increased beetroot yield by 28-30% due to its potential of ensuring storage, retention, or availability of several nutrients including calcium, phosphorus, zinc, and copper for absorption by plants roots. Further, the addition of 5 tonnes ha^{-1} of biochar in the soil influences the availability of micronutrients by 72% (Rawat *et al.*, 2019). Among these micronutrients, is boron, which is important to beetroot growth and higher biomass increment in production.

2.3.9. Effect of Nitrogen Application on Growth and Yield of Beetroot

Growth is a consolidative physiological trait that is determined by several environmental factors which dictate the viability of a given plant in an agroecosystem (Herrmann & Bucksch, 2014). Furthermore, nitrogen application provides 18-39 % of root and sugar output in beetroots (Abdo *et al*., 2020). Nitrogen ensures the growth of the leaf canopy, resulting in an increased light interception which promotes sucrose formation through photosynthesis (Agapit *et al.*, 2018).

To achieve the appropriate growth and higher yield of beetroot, sufficient nitrogen in the soil is needed. This is relevant since nitrogen is considered the most important element responsible for the growth and yield of beetroot. A study by Blumenthal *et al*. (2015) reported that optimal amounts of nitrogen result in the growth of broader leaves. Broader leaves increase the leaf area index which readily impacts the photosynthates formation during the photosynthesis process. For farmers to obtain 68 t ha^{-1} of beetroot yield, about 120 kg/ha of nitrogen should be available in the soil (Rahimi, 2021).

Nitrogen is contained in chlorophyll molecules wherein it plays a significant role in the growth of beetroots through the absorption of sunlight for use in photosynthesis. In addition, nitrogen is crucial in the formation of beetroot protein. This occurs when nitrogen is in ammonium or nitrate form where it is incorporated with carbohydrate metabolites to form amino acids and proteins. According to Musyoka *et al*. (2017), nitrogen increases root yield by 46%. However, nitrogen is highly lost from the soil through leaching, immobilisation, denitrification, crop removal, and volatilization, and this culminates in nitrogen deficiency in many farms.

According to Prado (2021), the formation of sucrose, amino acids, and proteins highly relies on nitrogen levels in the soil. Adequate nitrogen supply enhances higher leaf index and dry matter in beetroot growth hence higher yield. During beetroot production, plants with more leaves during the growth cycle period are more likely to present higher yields (Katroschan *et al.*, 2014). Sapkota *et al.* (2021) reported that the application of 100- 180kg N/ha increased both beetroot yield and its sugar content compared to the control. Therefore, beetroot growth and yield substantially increase as the fertilization of the crops with nitrogen increases (Sapkota *et al.*, 2021). However, increasing nitrogen fertilization beyond the recommended optimum levels results in a sequential reduction in beetroots' sugar content. According to Marajana *et al*. (2017), the inappropriate supply of nutrients can decrease beetroot yield and size. On the other hand, a nitrogen deficiency results in stunted growth, inhibition of root growth, dropping of photosynthate production and reduced quality of the harvestable materials.

2.3.10. Effect of Phosphorus on Growth and Yield of Beetroot

Phosphorus and nitrogen are major nutrients often used by farmers during production to boost crop growth and yield (Haneklaus & Schnug, 2016). Phosphorus is another essential crop nutrient that influences root development, energy storage, transport, and disease resistance (Shahane *et al.*, 2020). It is vital in the transportation of sugars in beetroot production, and its timely application during the early stages of the crop results in rapid root development and uptake of other nutrients. Phosphorus contributes to the proper growth of beetroot. According to Halla (2016), farmers should use about 50-90kg/ha of P_2O_5 to obtain the optimum beetroot yield of 68 t ha^{-1}. Phosphorus is an essential nutritive content useful for the proper growth and development of roots, canopy establishment, and building resistance against diseases (Mwangi *et al*., 2020). Thus, an adequate supply of phosphorus increases growth parameters such as the number of leaves and root growth in beetroot. A study conducted by Rantao (2016) proves that plants with a larger and greater number of leaves are leveraged for higher yields. An inadequate supply of phosphorus ensures reduced growth and yields of beetroot, stunted plants with a stiff appearance, and variation in the colour of leaves of affected plants from dark green to dull blue-green. The general nutritive content of plants depends on the presence of phosphorus, in that P impacts the uptake of other nutrients that are key for the growth of crops, such as nitrogen and magnesium (Bouras *et al*., 2021).

2.3.11. Effect of Potassium on Growth of Beetroot

Potassium is the third most important agricultural nutrient, which is associated with the movement of water, nutrients and carbohydrates in plant tissue and aids the plant to resist fungal diseases such as *Alternaria* (Kihara *et al.*, 2017). Potassium is a macronutrient that can make up to 10 % of the dry weight of plants (Sustr *et al.*, 2019). It is a significant inorganic cation in the cytoplasm of plants which is essential in numerous enzymatic activities such as primary metabolism (Ahanger *et al.*, 2017). Findings from Moterle *et al*. (2016) indicated that the application of potassium fertilizer such as NPK increased the leaf number and chlorophyll content in treated beetroots as compared to the control. These aspects help in the formation and storage of food and sugar content which results in increased growth and yield. The application of 150kg of potassium increases beetroot yield and its sugar content by 2% and 29% respectively (Awad *et al*., 2013). Further, according to Hlisnikovský *et al*. (2021) application of 114kg/ha of potassium increases the leaves' surface area and chlorophyll content thus significantly increasing the sugar content and beetroot yield. Potassium has a valuable effect on the production of beetroot since it plays a significant role in increasing the photosynthesis rate, and this results in increasing the growth and yield of beetroots.

2.3.12. Effect of Biochar and NPK on the Quality of Beetroot

Previous studies have pointed out the benefits of biochar and NPK use in beetroot production or farming. According to Sincik (2016), joint application of biochar and NPK increases sucrose and betalains contents in beetroots. Similarly, Ismail and Badr (2019) found that the use of waste charcoal dust alongside nitrogen fertilizer (NPK) at a rate of 80kg N / ha increased the root diameter by 18%. These results were attained due to the ability of NPK to increase photosynthates formation during photosynthesis. However, the application of nitrogen fertilizer beyond optimum levels causes a reduction in ferrous ions (Fe^{3+}) in beetroots (Babagil *et al.,* 2018). According to Babagil *et al.* (2018), a 160kg ha^{-1} fertilization of NPK gives an increase in the amount of flavonoid antioxidant matter in beetroots.

The combination of biochar and NPK fertilizer also plays a crucial role in improving the quality of beetroot during production by increasing the number of betalains, which contain high antioxidant properties that are crucial in the reduction of chronic inflammations such as liver disease in humans (Mridula *et al.,* 2016). Waste charcoal dust enhances the availability of N and P in soil. This improves the nutritive capacity of beetroot by more amounts of sugar and protein contents. During early growth stages, a sufficient supply of NPK is necessary for the formation of cell components such as nucleic and fatty acids in crops. These cell components aid in the secretion of carbohydrates in the beetroots (Mirmiran *et al.,* 2020). Zhang *et al*. (2018) found that the use of waste charcoal dust and inorganic fertilizers enables the absorption of any accumulated heavy metals and organic contaminants in the soil. This removal absorption is effective in improvement of chemical fertilizer use efficiency by the crops.

According to Zhang *et al*. (2020), the simultaneous application of biochar and nitrogen fertilizer creates a synergy by availing functional groups on the surface area of biochar which counteracts the inhibitory effects of heavy metals, salts, and acid stress to the root. Waste charcoal dust application increases photosynthetic pigments, gaseous exchange, and photosystem II activity, leading to high sugar content in beetroots (Zhang *et al.,* 2020). According to Wang *et al*. (2012), biochar-based organic fertilizer leverages the nitrogen uptake by the roots such that inorganic soil nitrogen is conserved by biochar for a consistent supply. Biochar uses equally boosts antioxidant enzyme activity which is responsible for the elimination of excess reactive oxygen species and boosting of root function. Furthermore, the combination of biochar and nitrogen-based fertilizers can substantially increase the accumulation of dry matter by improving photosynthesis and thereby increase agricultural quality (Oluwole & Ademuyiwa, 2021). Intensive agriculture reduces the organic matter in the soil and this leads to lower beetroot quality (Hlisnikovský *et al*., 2021). To fix this shortcoming, the application of fertilizers is relevant for the replenishment of the nutrients removed from the soil. However, this should be done cautiously and in the right optimal proportions as the inappropriate application of soil amendments and fertilizers reduces sugar.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of Experimental Site

The study was conducted at field three at Egerton University, Njoro, Kenya. The site, with geographic coordinates of 0^{o} 23' S35^{o} 35' E, is in agro ecological zone III. The area lies at an altitude of 2238m above sea level. The site receives annual precipitation of approximately 800-1500 mm with average temperatures of 15.6^{o}C to 23^{o}C (Jaeztold *et al*., 2009). The major soil type in the experimental area is Mollic Andosols, characterized by dark reddish clays, moderate organic matter, and low phosphorus content and slightly acidic. The site provided suitable conditions for beetroot growth. The experiment was conducted in two seasons, where season one was from March to June 2022 and the second season conducted from August to November 2022 in the same plots. Supplement irrigation was provided whenever necessary.

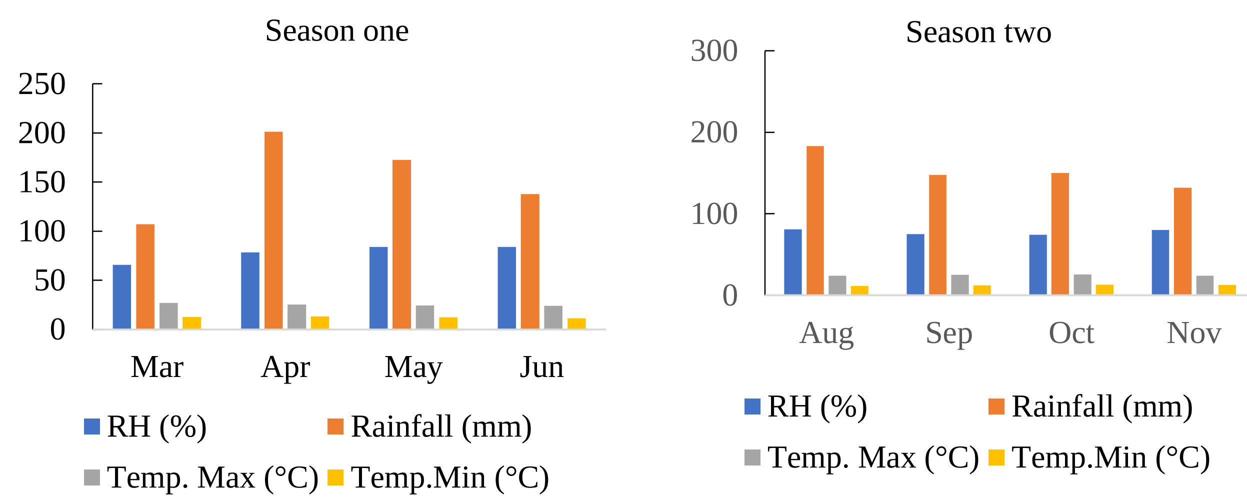


Figure 1 : Weather data in season one and two in 2022

3.2 Biochar Characterization

Biochar which was obtained from Cooks Well Company in Nairobi, Kenya, was the waste product of mostly acacia trees through the pyrolysis process. The temperature used to burn the acacia trash is 250^{o}C and the process of burning took approximately one hour and fifteen minutes. It was analysed for pH, total nitrogen and Phosphorus. A sample was tested for pH (both in water and potassium chloride), organic carbon was determined by the Walkley – Black method using sulphuric acid and aqueous potassium dichromate. Total nitrogen and phosphorus were also determined in a digester where biochar was treated with hydrogen peroxide, sulphuric acid, selenium and salicylic acid (Okalebo *et al.*, 2002).

3.3 Experimental Design and Treatments Combination

The study was set in a randomized complete block design (RCBD) in a factorial experiment with two factors (3×4) biochar at three levels and NPK at four levels and was replicated three times. Each block had twelve (12) treatments; while each plot was 1.8×1.6 m with six rows. The land was prepared on the 25^{th} and 26^{th} of February, 2021 using conventional tillage tools. The row spacing between rows within a plot was 30 cm and that between plants within a row was 20 cm, as recommended by Zelaya *et al.* (2019). Biochar (0, 5 and 10 t ha^{-1}) and NPK (0, 200, 300, and 400 kg ha^{-1}) were each applied before planting in both seasons. In each experimental plot, biochar was mixed with the soil with the use of a hoe and rake. The seeds of Detroit's dark red variety were drilled uniformly in the rows within the plots, and thinning was done two weeks after planting. Additionally in season two, again biochar (0, 5 and 10 t ha^{-1}) and NPK (0, 200, 300, and 400 kg ha^{-1}) were each applied in the same experimental plots. In each plot, biochar was mixed with the soil with the use of a hoe and rake. The seeds were also drilled uniformly in the rows within the plots, and thinning was done two weeks after planting.

Table 2: Treatments Combinations

Treatment (TRT)	**Biochar levels (**t ha^{-1})	**NPK levels (**kg ha^{-1})	**TRT combinations***
1	0	0	B0N0
2	5	0	B5N0
3	10	0	B10N0
4	0	200	B0N200
5	0	300	B0N300
6	0	400	B0N400
7	5	200	B5N200
8	10	200	B10N200
9	5	300	B5N300
10	10	300	B10N300
11	5	400	B5N400
12	10	400	B10N400

Where, * B is the Biochar levels and N is the NPK levels

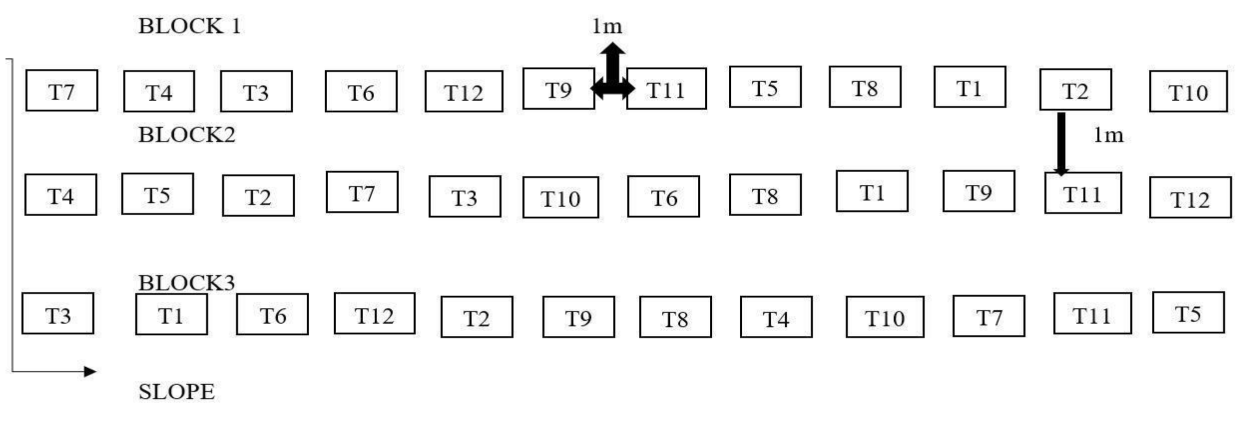


Figure 2: Experimental Field Layout

T1 to T12 in Figure 1 above shows the treatment combinations of biochar and NPK at different levels shown in Table 2.

3.4 Soil Analysis and Sampling

Soil samples were randomly collected at 0-20cm depth using a Zig Zag method to represent the whole field. Seven samples were collected using a soil auger and mixed to get a composite sample for analysis. The samples were air-dried and passed through a 2 mm sieve to remove roots and stones. Total nitrogen was determined by the use of the Kjeldahl method and Mehlich Double Acid was used to analyse phosphorus, potassium, sodium, calcium, magnesium and manganese (Okalebo *et al.*, 2002). Soil pH was measured using a pH meter at a soil: water ratio of 1:1 (volume/volume). Organic carbon was analysed using the Walkley and Black method as described by Okalebo *et al.* (2002).

The soil pH was determined in the laboratory by the electrometric method, with a 1:2.5 soil-to-water ratio. The soil pH was measured by a CPH-102 pH meter with buffers of pH 7 and pH4 (Okalebo *et al.,* 2002). Macro and micro nutrients in biochar were analysed using the same method to that of the soil above. A sample of biochar was tested for pH (in potassium chloride 1:5), The type of solution used in the analysis can affect the pH value: soil pH measured in 1 M KCl solutions generally gives lower pH values than if measured in deionised water (Kome *et al.,* 2018). Similar effects can be expected in biochar.Organic carbon was determined by the Walkley – Black method using sulphuric acid and aqueous potassium dichromate.

Table 3: Initial Characterization of soil and biochar

Parameters	Soil	Biochar
	0-20cm	
pH (H_2O), pH(KCl)	5.7	8.3
Total Nitrogen %	0.3	0.1
Organic carbon %	2.8	3.1
Exchangeable Phosphorus (mg/kg)	20	0.6
Potassium (meq%)	1.24	0.7
Calcium (meq%)	5.2	3.3
Magnesium (meq%)	3.1	0.1
Manganese (meq%)	0.4	663.0
Copper (mg/kg)	1.0	8.3
Iron (mg/kg)	114.0	1343.0
Zinc(mg/kg)	11.2	76.7
Sodium (mg/kg)	0.6	_not determined

3.5 Land Preparation, Planting, and Management

Beetroot seeds of the 'Detroit dark red' variety were sourced from the Pearl Agrocenter - Egerton. The variety was chosen because of its widespread use among farmers and consumers in Nakuru and other counties where it was produced. It also takes a short time to harvest (3 months) (Kumar *et al*., 2012). The experimental site was ploughed and harrowed to provide a good tilth for beetroot planting. Furthermore, the seed was directly sown in the field. However, 5 and 10 t ha^{-1} of biochar were applied before sowing and 200, 300 and 400kg ha^{-1} of NPK were also applied before seed sowing. The seeds of 'Detroit's dark red' were drilled uniformly into the rows within the plots, followed by thinning after two weeks after planting. Earthing up was done three weeks after germination. Hand weeding was done regularly throughout the growth period to keep the crops free of weeds. Whenever insect pests appeared cypermethrin 25% EC was sprayed and it has been sprayed thrice to control pests after planting. The crops were rain-fed with supplemental irrigation provided during dry spells using a drip irrigation system. Drip irrigation was used to ensure that an equal rate of supplementary water was applied to all experimental units. All other necessary crop husbandry measures were undertaken.

3.6 Data Collection

3.6.1 Growth Parameters: Plant Height, Number of Leaves and Leaf Area

Plant height was measured at two weeks intervals starting from two weeks after emergence. Data were collected from 8 randomly selected plants per treatment in the middle rows. The growth parameters (number of leaves, plant height and leaf area index) were measured 30, 45, 75 and 90 days after planting in each season. The number of leaves was counted manually on the 8 sampled plants in the middle rows. A meter ruler was used to measure the plant height starting at the base of the plant to the leaf apex. The length (from the end of the petiole to the leaf apex) and width from the right margin to the left margin of the average leaf were measured to estimate the leaf area and it was estimated using the formula $LA = L \times W \times 0.75$ developed by Varga *et al.* (2021). Where L is the length of the leaf and W is the width of the leaf and 0.75 is the correction factor.

3.6.2 Yield

Harvesting of the sample plants in the middle rows in each respective plot was done after 3 months in every season by uprooting the tubers from the soil and removing the soil by the use of hands. A portable Hangping JA 12002 electronic weighing balance was used to measure the weight of the roots from the sampled plants in the middle rows. Thereafter, the number of beetroots per plot was counted and their diameters were measured by a Vernier calliper. The marketable yield was also separated from the non-marketable yield based on size. These marketable and non-marketable yield sizes were determined based on Yasaminshirazi *et al.* (2020), where the marketable beetroots were the ones without deformation and had the recommended diameter of 60-80 and 80-100mm, and non-marketable ones were those with deformation and a diameter of less than 60mm

3.6.3 Quality

During the harvesting period, well-developed roots were segregated from those with deformations. Therefore, the roots were also categorised based on the size stated by Yasaminshirazi *et al.* (2020). Beetroots were categorised into three classes based on their size (diameter). The large size was 80-100mm, the medium size was 60-80mm, and the small size was less than 60mm. Total phenolic compounds, total soluble solids and minerals content were the internal quality parameters analysed. Folin Denis reagent was used to analyse beetroot's total phenolic content (Fattahi *et al.*, 2014). However, the original extract was generated by weighing

5g of the sample into the test tubes; to which 10 ml of 70% of acetone was added and ultrasonicated for 5 minutes and mixed. A shaker was used for 90 min at 30 ^{o}C to mix. The mixture was centrifuged at 4 ^{o}C for 20 minutes at 3000g. The supernatant was transferred to other tubes without disturbing the residue. They were kept in refrigerator at 4^{o}C and protected from light. A graduated cylinder was used to measure 0.5ml of the extract and then mixed it with 0.5ml of Folin Denis reagent. The solution was kept at 25^{o}C for 5 to 8 mins before adding 2ml of sodium carbonate solution. After 2 hours the absorbance was read at 725nm. The concentrations of gallic acid used to draw the calibration curve were 0, 2, 4, and 8. . Total phenolic was expressed in mg kg^{-1}. Additionally, total soluble solids (TSS) were measured by extracting juice by blending 8 sampled beetroots. A hand-held refractometer (RHB; Shanghai Precision and Scientific Instrument Co. China) was used to measure TSS as described by Tigchelaar (1986). The results were reported as ^{o}Brix. The spectrophotometric method procedure was used to analyse phosphorus content (Jastrzębska, 2009) and the complexometric method was used to analyse calcium (Basak & Kundu,2013).

3.6.4 Data Analysis

The data obtained from this study were tested for normality using the *Shapiro-Wilk* test. They were subjected to the analysis of variance using Statistical Analysis System (SAS) 9.4 general linear model (GLM) technique (Hodges *et al.*, 2022) to check the significant difference between treatments. Where treatments were found significant, means separation for the sole effects and of biochar and NPK as well as their interaction was done using Tukey's Honestly Significant Difference. The relationship between growth, yield, and quality, was determined using a correlation analysis at a 5% significance level.

3.6.5 Statistical Model

The statistical model used:

Y_{ijkl} = μ + T_j + α_k + δ_l + $(\alpha\delta)_{kl}$ + $\mathcal{E}_{ijkl}$

μ: overall mean

T_j: Effect due to the jth block

α_k : Effect due to the kth biochar levels

δ_l: Effect due to the lth NPK levels

$(\alpha\delta)_{kl}$: Interaction due to the kth biochar level and lth NPK levels

ε_{ijkl}: Random error term

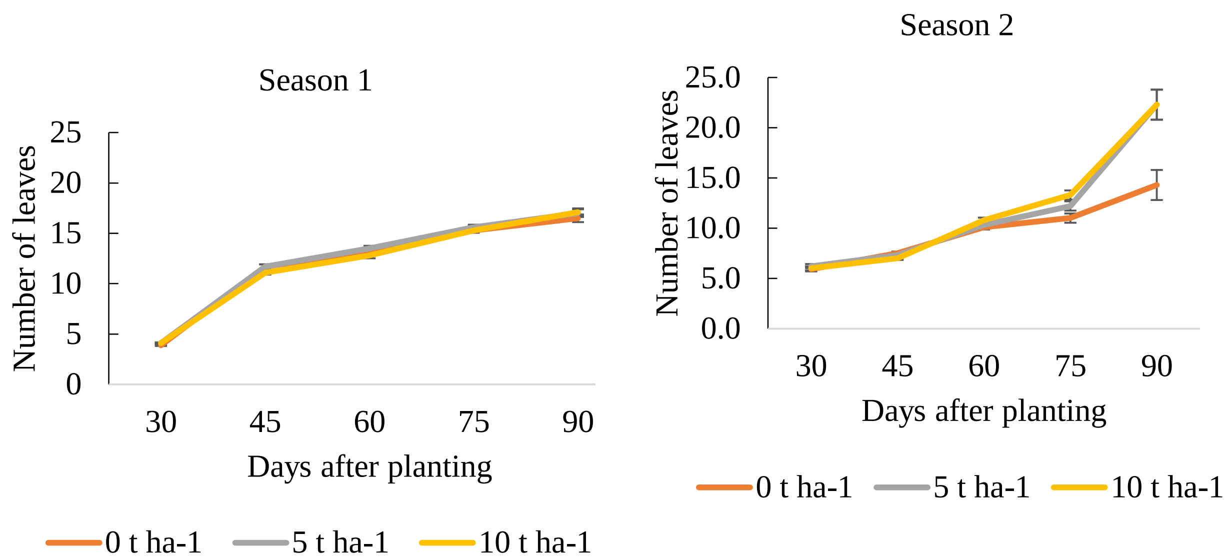
CHAPTER FOUR

RESULTS

4.1. Effect of Biochar and NPK (17-17-17) on Growth Parameters of Beetroot

4.1.1. Effect of Biochar on the Beetroot Number of Leaves

The different applied rates of biochar did not significantly ($p \leq 0.05$) increase beetroot number of leaves in season one. However, a significant difference was recorded in season two. Biochar applied at 5 tonnes was not statistically different from 10 tonnes, but different from the control (Figure 2).



Error bars represent standard error of the mean

Figure 3: Effect of biochar on beetroot number of Leaves.

4.1.2. Effect of NPK on Beetroot Number of Leaves

The application of NPK fertiliser at different rates significantly ($p \leq 0.05$) increased beetroot number of leaves in seasons one and two. In season one, the plant applied with 300kg ha^{-1} of NPK had many leaves of an average of 12.2, while the control resulted in a few leaves of an average of 10.5 at 45 days. At 75 days, NPK (400 kg ha^{-1}) had many leaves compared to the other treatment an average of 16, while the control showed fewer leaves an average of 13.9. At 90 days, NPK (300 kg ha^{-1}) had many leaves with an average of 18.2, and the control had few leaves with an average of 14.3. However, in season two, at 30 days the plant applied with NPK (200kg ha^{-1}) had many leaves of the average of 6.6, and the recorded few leaves of the average of 5.3. At 45 days, 400 kg ha^{-1} showed many leaves compared to the other treatments of an average of 7.8. At 60 days, the plant applied with NPK (300kg ha^{-1}) had many leaves with an average of 11.3, while the control showed few leaves with an average of 6.1. At 75 days, 400kg ha^{-1} had many leaves compared to the other treatments an average of 14.5, while the control resulted in a few leaves an average of 8.8. At 90 days, NPK at 400 kg ha^{-1} had many leaves with an average of 28.4, while the control resulted in a few leaves with an average of 11.6 (Table 4).

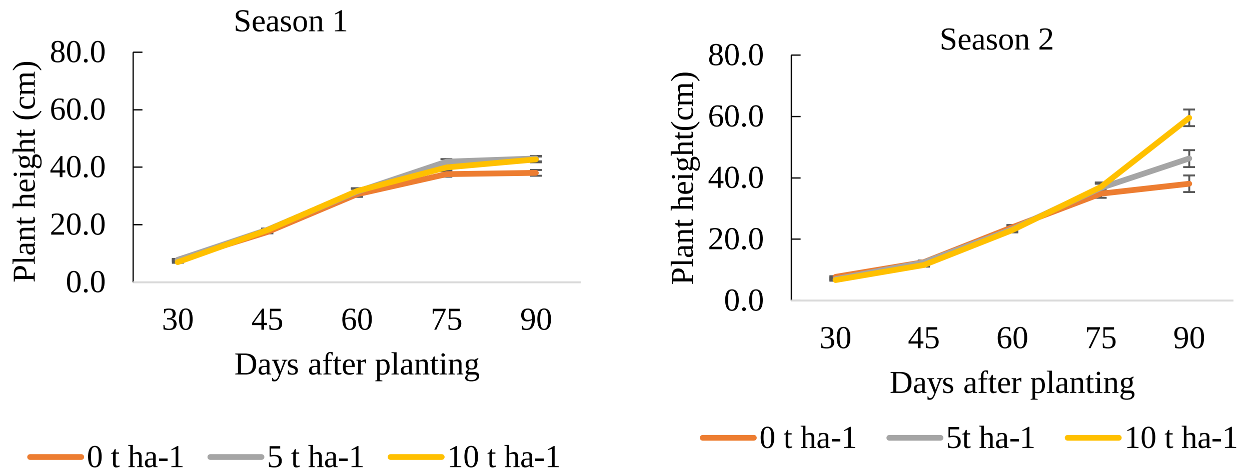
Table 4: Effect of different levels of NPK on the number of leaves of beetroot in seasons one and two

	Season 1					Season 2				
NPK	**Days after planting**					**Days after planting**				
kg ha^{-1}	**30**	**45**	**60**	**75**	**90**	**30**	**45**	**60**	**75**	**90**
0	3.7	10.5b	12.4	13.9b	14.3b	5.3b	6.1b	9.1b	8.8b	11.6c
200	4.2	11.6ab	13.8	15.8a	17.6a	6.6a	7.7a	10.3ab	12.4a	20.1a
300	4.2	12.1a	13.5	15.9a	18.1a	6.3ab	7.5a	11.3a	12.9a	18.4cb
400	4.2	11.7ab	13.0	16.0a	17.6a	6.0ab	7.8a	10.9a	14.5a	28.4a
MSD	**0.5**	**1.4**	**2.0**	**1.5**	**2.0**	**1.3**	**1.1**	**1.5**	**2.2**	**7.0**

Means with the same letter in a column are not significantly different at $p \leq 0.05$.

4.1.3. Effect of Biochar on Beetroot Plant Height

The application of sole biochar rates had no significant effect ($p \leq 0.05$) on beetroot height in season one. However, in season two, biochar rates had a significant effect on beetroot height at 90 days. It was observed that biochar at the rate of 10t ha^{-1} (B10) was statistically different from B5 and the control. Treatment B10 showed the tallest plant with an average of 59.6 cm, while the control resulted in the shortest, the average of 38.1 cm (Figure 3).



Error bars represent Standard error mean

Figure 4: Effect of biochar on the beetroot height.

4.1.4. Effect of NPK on the Height of Beetroot

The application of the different rates of NPK increased significantly ($p \leq 0.05$) beetroot height in seasons one and two. In season one at 45 days, the plots received 200 kg ha^{-1} of NPK recorded 19.3 cm as an average of plant height. The plots received 300kg ha^{-1} of NPK showed 19 cm as the average of the height, the one received 400kg ha^{-1} of NPK showed 18cm and the control showed 15.2cm. At 60 days, the plots received 200 kg ha^{-1} of NPK indicated 33.8 cm as an average of plant height. The plots received 300kg ha^{-1} of NPK showed 33.5 cm as the average of the height, the plots supplied with 400kg ha^{-1} of NPK showed 31.4cm and the control showed 26.2cm. At 75days, the plots received 200 kg ha^{-1} of NPK indicated 41.5cm as an average of plant height. The plots received 300kg ha^{-1} of NPK showed 42.5 cm as the average of the height, the plots supplied with 400kg ha^{-1} of NPK showed 40.6cm and the control showed 34.6cm. At 90 days, the plots applied the treatment of 300 kg ha^{-1} had recorded an average of beetroot height of 44.2 cm, 200kg $ha^{-1}$of NPK showed 42.9cm, 400kg ha^{-1} showed 42.4 cm and the control recorded the average of 35.4cm of beetroot height. However, in season two, 400 kg ha^{-1} had the average of 7.6 cm, 300kgha^{-1}showed 7.3cm and 200kg ha^{-1} of NPK recorded 7.4cm, while the control had an average of 6.1 cm as an average of plant height at 30 days after planting. At 45 days, 400 kg ha^{-1} showed an average of 13.9 cm, 300kg ha^{-1} of NPK recorded 13.3cm, 200kg ha^{-1} of NPK showed 13.4cm, and the control had 8.2 cm as an average of plant height. At 60 days, the plots received 300 kg ha^{-1} of NPK had an average of 25.8cm of the plant height, 200 kg ha^{-1}

showed 24.3cm, 400 kg ha^{-1} recorded 25.5cm, and control had an average of 18 cm of the plant height. At 75 days, 300kg ha^{-1} of NPK showed an average of 42.2 cm, and the control had an average of 23 cm of beetroot height. Moreover, at 90 days the plots applied with 400kg ha^{-1} of NPK had an average of 58.7 cm, and the control resulted in the average of 29.8 cm of plant height (Table 5).

Table 5: Effect of NPK on the height (cm) of beetroot in seasons one and two

	Season 1					**Season 2**				
NPK	**Days after planting**					**Days after planting**				
kg ha^{-1}	**30**	**45**	**60**	**75**	**90**	**30**	**45**	**60**	**75**	**90**
0	6.2	15.2b	26.2b	34.6b	35.4b	6.1b	8.2b	18.0b	23.0c	29.8b
200	8.2	19.3a	33.8a	41.5a	42.9a	7.4ab	13.4a	24.3a	41.2ab	51.7a
300	7.6	19.0a	33.5a	42.5a	44.2a	7.3ab	13.3a	25.8a	42.2a	51.7a
400	7.9	18.0ab	31.4a	40.6a	42.4a	7.6a	13.9a	25.5a	38.6b	58.7a
MSD	**2.1**	**3.0**	**5.0**	**5.4**	**4.8**	**1.4**	**2.8**	**5.5**	**3.3**	**10.1**

Means with the same letter in a column are not significantly different at $p \leq 0.05$.

4.1.5. Interaction of Biochar and NPK on the Height of Beetroot (cm)

The application of biochar and NPK to the plant did not have an interactive effect on the beetroot height in season one. However, the interactive effect was observed at 75 and 90 days after planting in season two. Moreover, the interaction of biochar at 0, 5 and 10 tonnes and NPK at 0,200, 300 and 400kg ha^{-1} were not statistically different among themselves but different from the control. At 75 days after planting, the plots applied with biochar at 5 tonnes combined with NPK 200kg ha^{-1}, showed the average plant height of 42.1cm, B5N300 had the average plant height of 46cm, B5N400 had the average of 40cm, the plots with B10N200 showed the average plant height of 41.2cm, B10N300 recorded the average of 40.2cm and B10N400 had 39cm, while the control resulted in the plant height average of 22.5 cm. At 90 days, the plots with B5N200 had the average plant height of 53.4cm, B5N300 had the average of 46.7cm, B5N400 had the average of 56.4cm. Moreover, the plants applied with the treatment B10N200 had the average plant height of 58.3cm, B10N 300 had the average of 67.2cm, B10N400 had the average plant height of 79.2cm, while the control resulted in the average plant height of 27.6 cm (Table 6).

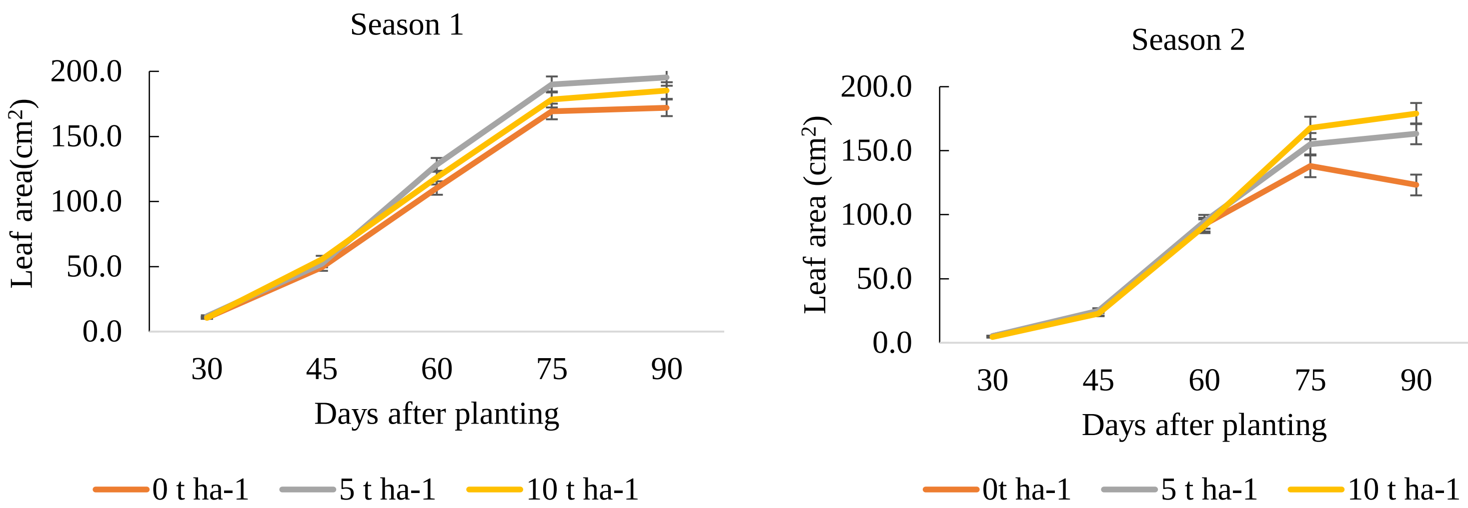
Table 6: Effect of interaction of biochar and NPK on the height (cm) of beetroot in seasons one and two

Biochar	NPK	Season 1					Season2				
		Days after planting					Days after planting				
T ha $^{-1}$	kg ha $^{-1}$	30	45	60	75	90	30	45	60	75	90
0	0	6.1±0.8	15.8±2.1	26.8±6.1	32.1±7.4	31.5±3.9	6.2±0.5	7.6±1.2	18.1±2.6	22.5±0.7cd	27.6±2.4e
0	200	8.6±0.7	19.6±1.2	34.9±1.3	39.1±2.7	41.1±1.1	7.8±1.1	13.8±1.7	24.1±5.3	40.2±0.8ab	43.5±2.7ed
0	300	8.2±2.1	17.5±2.6	31.0±5.3	38.7±4.5	39.8±3.7	8.0±1.3	14.0±2.6	26.7±2.0	40.2±2.1ab	40.8± 3.3ecd
0	400	8.4±0.7	16.9±0.9	29.9±5.3	37.9±5.0	39.7±5.5	8.7±1.1	14.5±1.8	26.6±4.1	36.8± 3.1b	40.4± 1.4ecd
5	0	6.3±1.7	16.2±0.5	28.0±1.7	37.0±4.2	37.8±4.5	6.0±0.4	8.1±2.0	18.5±4.2	18.5±1.4d	28.7± 3.3e
5	200	9.2±0.2	20.2±2.8	34.3±7.4	43.4±6.9	44.9±7.4	8.1±1.4	14.7±1.3	24.1±2.2	42.1±1.6ab	53.4± 4.8bcd
5	300	8.3±2.8	19.4±3.6	34.2±6.7	45.9±4.2	46.7±4.4	6.8±0.4	12.5±2.0	25.9±4.2	46.0±2.4a	46.7± 3.8bcde
5	400	7.1±1.7	16.9±2.8	29.2±7.0	41.3±5.5	42.5±6.1	7.3±1.1	14.5±0.9	24.9±0.4	40.0±2.2ab	56.4± 13.3abc
10	0	6.3±0.3	13.7±1.6	23.8±3.8	32.1±1.1	36.8±4.6	6.2±1.3	8.7±1.0	17.4±6.7	27.8±6.1c	33.2± 7.7ed
10	200	6.9±2.0	18.1±3.4	32.3±5.8	41.9±4.5	42.7±3.8	6.3±0.7	11.8±2.5	24.6±4.4	41.2±1.7ab	58.3± 6.9abc
10	300	6.3±2.2	20.3±1.2	35.2±3.5	43.1±6.8	46.0±4.8	7.2±1.6	13.5±4.1	24.9±3.9	40.2±0.5ab	67.6± 6.8ab
10	400	8.2±1.6	20.2±2.3	35.4±1.4	42.5±5.1	45.0±5.3	7.1±0.9	12.5±2.9	25.2±4.9	39.0±0.7ab	79.2± 16.7a

Means with the same letter in a column are not significantly different at $p \leq 0.05$

4.1.6. Effect of Biochar on the Beetroot Leaf Area (cm^2)

Biochar applied at (5 and 10 t ha^{-1}) increased significantly beetroot leaf area at $p \leq 0.05$ in both seasons one and two. It has been observed that the plots received treatment B10 was not statistically different from B5 but different from the control. Additionally, the plots received biochar at 5 tonnes showed the average leaf area of 195.5 cm^2, while the control resulted in the average of 171.9 cm^2 in season one at 90 days. However, in season two, a significant increase was recorded at 75 and 90 days after planting. All the rates of biochar were statistically different from each other at 75 days. Treatment B10 showed the largest leaf area an average of 167.8 $cm^{2,}$ followed by B5 averaged 155 $cm^{2,}$ while the control showed the lowest average 138.1 cm^2. At 90 days, B5 and B10 were not statistically different from each other, but different from the control (Figure 4).



Error bars denote one standard error of the mean

Figure 5: Effect of different levels of Biochar on beetroot leaf area.

4.1.7. Effect of NPK on the Beetroot Leaf Area (cm^2)

The application of NPK at different rates showed a significant increase ($p \leq 0.05$) in the beetroot leaf area in seasons one and two. In season one; the plots received 300 kg ha^{-1} of NPK had an average leaf area of 64.2 cm^2 at 45 days, 200kg ha^{-1} of NPK recorded an average of 55.7cm^2, 400kg ha^{-1} had an average of 57cm^2, and the control showed an average of 32.5cm^2. At 60 days, the plots received 400 kg ha^{-1} of NPK had the plants with an average leaf area of 135cm^2. The plants planted in the plots applied with 300kg ha^{-1} had the average leaf area of 132.4cm^2, the one in plots applied with 200kg ha^{-1} had an average leaf area of 120.4cm^2, while the plants in control had the average leaf area of 87.4cm^2. At 75 days after planting, the plots received 400 kg ha^{-1} of NPK had the plants with an average leaf area of 179.8cm^2. The plants planted in the plots applied with 300kg ha^{-1} had the average leaf area of 181.7cm^2, the one in plots applied with 200kg ha^{-1} had an average leaf area of 184cm^2, while the plants in control had the average leaf area of 69.2cm^2. At 90 days, the plots received 400 kg ha^{-1} of NPK had the plants with an average leaf area of 185cm^2. The plants planted in the plots applied with 300kg ha^{-1} had the average leaf area of 180.6cm^2, the one in plots applied with 200kg ha^{-1} had an average leaf area of 161.5cm^2, while the plants in control had the average leaf area of 125.5cm^2. Moreover, in season two, NPK rates were not statistically different from each other and the trend was the same as the one in season one (Table 7).

Table 7: Effect of NPK on the leaf area (cm^2) of beetroot in seasons one and two

	Season 1					Season 2				
NPK	**Days after planting**					**Days after planting**				
kg ha^{-1}	**30**	**45**	**60**	**75**	**90**	**30**	**45**	**60**	**75**	**90**
0	7.9	32.5b	87.4b	135.5b	125.5b	3.1b	10.5b	52.1b	69.2b	89.9b
200	13.1	55.7a	120.9a	195.6a	161.5ab	5.1a	29.1a	107.1a	184.0a	176.2a
300	11.8	64.2a	132.4a	188.2a	180.6a	5.3a	26.0a	107.1a	181.7a	177.4a
400	11.2	57.0a	135.1a	197.5a	185.0a	6.1a	29.5a	99.8a	179.8a	177.0a
MSD	**5.6**	**13.3**	**24.2**	**30.5**	**26.1**	**1.7**	**1.0**	**29.8**	**14.8**	**23.7**

Means with the same letter in a column are not significantly different at $p \leq 0.05$

4.1.8. Interaction of Biochar and NPK on the Beetroot Leaf area (cm^2)

The application of different levels of biochar and NPK significantly increased beetroot leaf area at $p \leq 0.05$. The interaction of biochar at 0, 5 and 10 t ha^{-1} and NPK at 0, 200,300 and 400kg ha^{-1} were not statistically different but different from the control (Table 8).

Table 8: Effect of the interaction of biochar and NPK on the leaf area index (cm^2) of beetroot in seasons one and two

		Season 1					**Season 2**				
Biochar	**NPK**	**Days after planting**					**Days after planting**				
T ha $^{-1}$	**kg ha^{-1}**	**30**	**45**	**60**	**75**	**90**	**30**	**45**	**60**	**75**	**90**
0	0	5.6±1.7	26.4±4.6	80.0±16.3	116.0±34.0	119.7±32.0	3.4±0.3	8.2±1.7	48.4±17.7	70.7±7.9d	81.8± 15.7d
0	200	13.1±2.2	56.0±3.4	122.3±23.3	183.5±1.5	184.5±1.4	4.7±0.6	29.3±2.6	104.5±8.6	157.6± 9.5c	121.7± 5.0cd
0	300	12.0±3.5	56.8±15.9	119.8±32.1	190.6±18.0	188.7±14.0	5.7±2.3	24.7±3.3	120.2±28.9	162.2± 30.6cb	140.3± 17.4cb
0	400	11.6±2.0	58.4±7.9	119.1±20.7	186.6±34.3	194.9±35.4	6.9±2.1	30.3±3.7	96.0±11.3	162.1± 8.2cb	149.1± 13.5cb
5	0	11.0±4.0	39.9±6.9	101.0±11.2	156.2±33.2	157.8±34.1	3.1±0.9	9.1±5.1	52.7±29.1	61.3± 13.8d	82.7± 10.6d
5	200	14.6±0.7	56.2±9.8	125.5±17.9	198.0±39.0	199.3±39.5	6.8±2.6	36.4±9.8	112.4±26.9	182.7± 6.5abc	193.6± 16.5ab
5	300	13.2±8.3	64.3±17.1	165.1±41.3	209.2±22.6	227.0±39.6	5.1±1.5	21.1±5.2	101.0±24.2	189.7± 1.3abc	187.5± 18.8ab
5	400	8.9±1.9	48.3±16.0	121.2±39.4	196.7±29.7	197.8±29.8	6.0±2.0	33.8±3.7	112.3±19.4	186.4± 12.5abc	189.0± 15.0ab
10	0	7.0±3.3	31.3±5.1	81.2±15.5	134.3±32.7	137.6±36.7	3.0±1.2	12.4±2.8	55.3±19.9	75.6± 4.3d	105.2± 43.5cd
10	200	11.6±8.1	54.8±9.9	115.1±16.5	205.3±12.7	208.0±10.9	3.9±0.3	21.5±8.7	104.5±27.9	211.7± 2.1a	213.2± 8.9a
10	300	12.2±1.6	67.4±14.1	155.1±23.1	193.5±40.0	212.9±23.2	5.2±2.0	31.2±18.1	113.3±35.1	193.2± 4.3ab	204.5± 8.0a
10	400	11.2±5.2	68.3±15.4	122.3±13.1	180.4±10.1	182.3±11.3	5.5±2.1	24.5±13.5	91.3±33.3	190.8± 4.2abc	193.0± 4.8ab

Means with the same letter in a column are not significantly different at $p \leq 0.05$

4.2. Effect of Biochar and NPK on Beetroot Yield Parameters

4. 2.1. Effect of Biochar on the Beetroot Yield

The application of biochar at 5 and 10 t ha^{-1} increased significantly ($p \leq 0.05$) beetroot marketable yield in season two. The plots received the treatment B5 had an average marketable yield of 61.1 t ha^{-1}, the plots applied with B10 showed an average marketable yield of 56.2 t ha^{-1}, while the control recorded the 52.2t ha^{-1}(Table 9)

Table 9: Effect of biochar on the beetroot yield

Biochar levels	**Total yield (t ha^{-1})**		**Marketable yield (t ha^{-1})**		**Non-marketable yield (t ha^{-1})**	
T ha^{-1}	**Season 1**	**Season 2**	**Season 1**	**Season 2***	**Season1**	**Season2**
0	49.8	68.3	32.3	52.2b	17.4	15.3
5	54.9	70.4	37.5	61.1a	17.5	9.3
10	56.2	67.3	39.7	56.2ab	16.5	11.1
MSD	**11.5**	**10.8**	**2.4**	**14.4**	**14.9**	**6.6**

* Means with the same letter in a column are not significantly different at $p \leq 0.05$

4.2.2. Effect of NPK on Beetroot Yield

The application of different rates of NPK (200, 300, 400 kg ha^{-1}) increased significantly total and marketable yield of beetroot ($p \leq 0.05$) in both seasons one and two. In season one, plots applied with 300kg ha^{-1} of NPK an average total yield of 61.9t ha^{-1}, 200 kg ha^{-1} showed an average of 57.1t ha^{-1}, 400kg ha^{-1} had an average of 57.3 t ha^{-1}, and the control showed 38.3 t ha^{-1}. In season two NPK rates were not statistically different from each other, and the trend was the as season one. Additionally, NPK rates were not statistically different from each other on the beetroot marketable yield in both seasons (Table 10).

Table 10: Effect of NPK on the total, marketable, and non-marketable yield of beetroot in seasons one and two

NPK	**Total yield (t ha^{-1})**		**Marketable yield (t ha^{-1})**		**Non-marketable yield (t ha^{-1})**	
kg ha^{-1}	**Season 1**	**Season 2**	**Season 1**	**Season 2**	**Season 1**	**Season 2**
0	38.3b	50.3b	20.4b	29.4b	17.9	20.9
200	57.1a	70.4a	40.5a	61.0a	16.6	9.3
300	61.9a	83.0a	44.9a	74.3a	17.0	8.7
400	57.3a	70.8a	40.3a	63.3a	17.0	8.5
MSD	**14.7**	**13.8**	**3.0**	**18.3**	**19.0**	**8.4**

Means with the same letter in a column are not significantly different at $p \leq 0.05$

4.2.3. Interaction of Biochar and NPK on Beetroot Yield

The application of biochar and inorganic fertilizer (NPK) had a significant ($p \leq 0.05$) effect on beetroot marketable yield and non – marketable yield in season two. The rates were not statistically different from each other (Table 11).

Table 11: Effect of the interaction of biochar and NPK on the total yield of beetroot in seasons one and two

Biochar	NPK	Total yield (t ha^{-1})		Marketable yield (t ha^{-1})		Non-marketable yield (t ha^{-1})	
t ha^{-1}	kg ha^{-1}	Season 1	Season 2	Season 1	Season 2	Season 1	Season 2
0	0	33.0±9.6	46.3±4.1	16.0±8.2	2.6±4.4c	17.0±1.6	43.8±3.6a
0	200	54.6±8.4	78.0±17.2	38.2±7.7	71.7± 22.0ab	16.4±1.4	6.3± 5.5b
0	300	56.1±4.8	73.9±12.9	38.4±16.3	66.3±15.9ab	17.7±2.2	7.6±7.3 b
0	400	55.4±22.5	75.0±20.4	36.7±16.5	71.4± 21.2ab	18.7±1.5	3.6± 6.2b
5	0	44.1±10.3	56.9±15.4	25.3±7.2	48.3± 15.8ab	18.8±2.6	8.7± 3.4ab
5	200	59.9±20.8	67.5±8.8	43.3±21.5	60.1 ± 7.0ab	16.6±3.3	7.4± 7.3ab
5	300	61.8±12.2	94.4±16.7	44.2±15.6	84.0± 19.4a	17.6±5.0	10.3±2.6b
5	400	54.0±10.4	62.8±10.0	37.1±18.2	52.2 ± 8.5ab	16.9±1.9	10.6± 1.7ab
10	0	37.7±11.5	47.8±9.8	19.8±10.5	37.5±15.0 b	17.9±0.6	10.3± 7.0ab
10	200	56.9±5.2	65.8±8.9	40.1±9.6	51.4± 8.6ab	16.7±2.0	14.4± 6.5b
10	300	67.7±11.5	80.8±20.7	51.9±12.1	72.6± 13.3ab	15.8±1.8	8.2± 7.5ab
10	400	62.6±13.7	74.7±8.1	47.1±12.6	63.2± 3.2ab	15.6±0.6	11.5± 9.7ab

Means with the same letter in a column are not significantly different at $p \leq 0.05$

4.3. Effect of Biochar and NPK on Beetroot Quality Parameters

4.3.1. Effect of Biochar on Calcium, Phosphorus, and Iron Content of Beetroot

The application of sole biochar at 5 and 10t ha^{-1} did not increase the beetroot phosphorus, and calcium content in seasons one and two at $p \leq 0.05$. On the other hand, the beetroot iron content was increased by the application of biochar in seasons one and two. But the rates of biochar were not statically different from each other (Table 12).

Table 12: Effect of biochar on calcium, phosphorus, and iron content of beetroot in seasons one and two

	Calcium (mg kg^{-1})		Phosphorus (mg kg^{-1})		Iron (mg kg^{-1})	
Biochar levels	**Season 1**	**Season 2**	**Season 1**	**Season 2**	**Season 1**	**Season2**
0t ha^{-1}	15.5	64.3	3.4	6.1	536.5b	578.3b
5t ha^{-1}	13.8	65.5	4.6	6.5	713.4a	720.7a
10t ha^{-1}	16.2	61.7	4.8	5.9	639.1ab	674.3ab
MSD	**6.8**	**16.1**	**1.7**	**1.7**	**148.2**	**140.1**

Means with the same letter in a column are not significantly different at $p \leq 0.05$

4.3.2. Effect of NPK on the Calcium, Phosphorus, and Iron Content of Beetroot

The application of different rates of NPK at 200, 300, and 400 kg ha^{-1}, did not show a statistical difference among themselves on the phosphorus and iron content of beetroot in season one but were different from the control. However, in season two there was a significant difference at ($p \leq 0.05$) of phosphorus and iron contents among the treatments. The rates were not statistically different from each other (Table 13).

Table 13: Effect of NPK on the calcium, phosphorus, and iron content of beetroot in seasons one and two

NPK	Calcium (mg kg^{-1})		Phosphorus (mg kg^{-1})		Iron (mg kg^{-1})	
kg ha^{-1}	**Season 1**	**Season 2**	**Season 1**	**Season 2**	**Season 1**	**Season2**
0	8.9	67.8	3.7	4.8a	580.5	476.6b
200	7.5	56.6	4.5	6.7ab	656.5	712.2a
300	8.1	75.1	4.6	6.3ab	613.6	647.5ab
400	8.5	55.9	4.5	7.0a	668.0	794.7a
MSD	**7.9**	**20.1**	**2.1**	**2.1**	**189.1**	**178.6**

Means with the same letter in a column are not significantly different at $p \leq 0.05$

4.3.3. Interactive effects of Biochar and NPK on Calcium, Phosphorus, and Iron Content of Beetroot

Biochar and NPK significantly ($p \leq 0.05$) increased beetroot calcium, phosphorus, and iron content in season two. Moreover, different rates of the combined biochar and NPK were not statistically different from each other (Table 14).

Table 14: Effect of biochar and NPK on the mineral content of beetroot in seasons one and two

Biochar	NPK	Calcium (mg kg^{-1})		Phosphorus (mg kg^{-1})		Iron (mg kg^{-1})	
T ha^{-1}	kg ha^{-1}	Season 1	Season 2	Season 1	Season 2	Season 1	Season2
0	0	24±5.8	60.6± 36ab	3.0±0.8	2.3± 0.4b	406.1±37.2	237.7±29.0 b
0	200	12.3±10.3	50.5± 16.9ab	3.8±0.4	8.2± 1.1a	555.3±10.9	544.0± 50.8ab
0	300	15.5±5.1	80.6± 7.8a	4.2±2.7	6.7± 2.7ab	567.4±99.2	626.7± 70.7ab
0	400	10.4±2.4	65.5± 13.4ab	2.8±1.4	7.1±1.6 a	617.2±87.1	904.8± 4.8a
5	0	16±5.8	75.1± 7.6a	4.1±0.9	6.7±1.0 ab	852.4±61.4	575.8± 50.0ab
5	200	15±8.2	58.2± 15.6ab	4.2±1.1	5.9± 0.7ab	698.1±82.3	803.9± 72.1a
5	300	12.8±4.2	53.7± 5.6ab	5.0±0.6	6.2± 1.5ab	630.7±27.3	701.1± 80.2a
5	400	11.2±2.8	75.2± 15.4a	5.2±0.9	7.1± 2.1a	672.4±80.2	802.1± 74.5a
10	0	12.8±3.2	67.6± 6.6ab	3.9±1.2	5.3± 1.0ab	483.2±50.9	616.3± 37.6ab
10	200	21.9±9.3	61.0± 18.8ab	5.5±2.1	6.0± 0.6ab	716.1±3.7	788.8± 40.5a
10	300	9.1±1.8	91.1± 1.0a	4.5±2.7	5.9± 0.8ab	642.7±90.3	614.8± 30.5ab
10	400	20.8±1.6	27.0± 8.6b	5.5±3.2	6.6± 3.2ab	714.5±20.4	677.2± 39.1a

Means with the same letter in a column are not significantly different at $p \leq 0.05$

4.3.4. Interaction of Biochar and NPK on Beetroot Total Soluble Solids (^{o} Brix) and Total Phenolic compound (g kg^{-1})

Different rates of biochar and NPK increased the total soluble solids of beetroot in season two at $p \leq 0.05$. The rates of interaction were not statically different from each other (Table 15).

Table 15: Effect of the interaction of biochar and NPK on beetroot TSS (^{o}Brix) and total phenolic compound in seasons one and two

Biochar	NPK	TSS (^{o}Brix)		Phenolic (g kg^{-1})	
t ha^{-1}	kg ha^{-1}	Season 1	Season 2	Season 1	Season 2
0	0	9.2±1.1	7.3± 1.1b	12.0±5.8	16.9± 2.9b
0	200	7.6±1.6	9.7± 2.2ab	9.1±5.2	22.5± 2.4ab
0	300	8.0±0.8	9.2± 2.0ab	7.1±6.0	23.8± 3.8ab
0	400	8.9±1.1	8.9± 0.1ab	3.3±1.1	25.8± 3.1ab
5	0	9.6±2.3	10.8± 0.7a	10.3±2.8	19.0± 7.0b
5	200	7.6±1.9	10.7± 1.1ab	4.9±4.1	23.4± 4.5ab
5	300	7.8±0.4	8.6± 0.9ab	5.6±5.0	25.8± 8.6ab
5	400	9.4±2.3	9.5± 0.6ab	7.5±2.6	25.6± 6.2ab
10	0	7.9±1.5	10.7± 1.8ab	8.6±4.3	37.0± 4.6a
10	200	7.3±1.5	8.9± 1.1ab	9.0±2.2	18.9± 3.9b
10	300	8.5±0.6	8.7± 0.6ab	10.7±4.7	26.3± 9.3ab
10	400	7.0±1.7	8.6± 1.4ab	10.7±4.7	27.7± 7.0ab

Means with the same letter in a column are not significantly different at $p \leq 0.05$

4.3.5. Effect of NPK on Beetroot Diameter

The use of NPK fertilisation during beetroot cultivation recorded a significant increase at $p \leq 0.05$ in the diameter in seasons one and two. All NPK rates were not statistically different from each other but different from the control in both seasons one and two (Table 16).

Table 16: Effect of NPK on the Diameter of Beetroot

NPK	Diameter(mm)	
kg ha^{-1}	Season 1	Season 2
0	64.0b	71.1b
200	77.3a	84.8a
300	78.1a	86.3a
400	75.7a	84.2a
MSD	**7.5**	**7.2**

Means in the same column with the same letter are not significantly different at $p \leq 0.05$

4.3.6. Interaction of Biochar and NPK on Beetroot Diameter

The application of biochar and NPK did not show an interactive effect ($p \leq 0.05$) on the beetroot diameter in season one. The interactive effect was observed in season two. The rates of interaction of biochar and NPK were not statistically different from each other but different from the control (Table 17).

Table 17: Effect of the interaction of Biochar and NPK on Beetroot Diameter in seasons one and two

Biochar	**NPK**	**Diameter(mm)**	
T ha^{-1}	**kg ha^{-1}**	**Season 1**	**Season 2**
0	0	62.4±11.2	65.8± 8.9c
0	200	75.8±6.2	84.3± 1.6ab
0	300	74.2±8.5	79.0± 4.8ab
0	400	74.1±5.5	85.2± 3.5ab
5	0	66.9±6.6	71.2±4.2cb
5	200	77.2±9.5	84.0± 7.0ab
5	300	78.4±7.6	95.7± 1.9a
5	400	73.8±11.9	81.4± 7.0abc
10	0	62.7±8.9	77.5± 2.4bc
10	200	78.9±6.7	86.2± 5.9ab
10	300	81.8±4.0	84.2± 2.0ab
10	400	79.3±2.2	86.1± 9.8ab

Means in the same column with the same letter are not significantly different at $p \leq 0.05$

CHAPTER FIVE

DISCUSSION

5.1. Effects of Biochar and NPK on Beetroot Growth

The application of biochar and NPK had a significant influence on the beetroot growth in both seasons one and two. Biochar (5 t ha^{-1}) affected or increased beetroot growth parameters (leaves, height, and leaf area) better than 10 t ha^{-1}. In our study, the difference in growth between the plots treated with biochar and the control could be attributed to biochar's ability to increase soil pH. However, the increase in soil pH contributes to the improvement of cation exchange capacity (Hossain *et al.,* 2020). CEC contributes to holding basic cations in the soil such as calcium, which improves plants' leaves. A study by Pérez *et al*.(2016) reported that the application of organic amendment improves potato growth, and attributed the results to the capacity of the amendment to increase soil pH. This affects different soil processes such as soil stability and nutrient absorption. Zhang *et al*. (2020), Olszyk *et al*. (2020) and Arif *et al*. (2012) reported an increased leaves number and height of carrots and maize, when the soil was amended with biochar. They attributed these results to the capability of biochar to reduce water runoff and increase soil structure which resulted to the increase in nutrient absorption by the crops' roots. Numerous studies including Agbede (2021) and *Zelaya et al.* (2019) recommended the use of biochar as a soil amendment because it plays an important role in removal of toxic elements (cadmium, lead, nickel) in the soil which leads to increase of the crop growth parameters.

Additionally, different rates of NPK (200, 300, 400 kg ha^{-1}) increased beetroot growth and were not statistically different from each other but differed from the control. The difference might be attributed to the supply of the required nutrients by NPK such as nitrogen, phosphorus, and potassium which are responsible for vegetative growth. Okonwu and Mensah (2012) reported a tremendous increase in carrot leaves after the application of NPK. Similar findings were reported by Hariyadi *et al*. (2011) who observed increased tomato leaves number after the application of NPK. Umami *et al*. (2019), Khalofah *et al.* (2022) and Olowoboko *et al.* (2017) reported an increased number of leaves of *Cichorium intybus* and attributed the results to the ability of NPK to provide phosphorus which facilitates the absorption of the nutrients from the soil by the roots. A study by Dubey *et al.* (2017) reported that the application of NPK increased the leaf's number of capsicum, and attributed the results to the availability of nitrogen, phosphorus, and potassium.

The difference in beetroot growth parameters (height, leaves, and leaf area) in seasons might be due to the biochar's slow release of nutrients for plant growth. A study by Schulz *et al.* (2013) reported that biochar demonstrated a significant impact on plant height due to its ability to reduce aluminium effects on plant height such as phytotoxic effects, which can impede root elongation. Additionally, biochar can also reduce oxidative stress, interrupt the plasma membrane performance and cell wall, disruption of calcium homeostasis, obstruction of the transduction pathways, and lowering DNA activities, which contribute to the reduction of all plant growth parameters (Wen *et al.*, 2018). Similar findings were obtained in our study, where the results revealed that the application of biochar significantly increased the height of the beetroot. Biochar at 5t ha^{-1} was not significantly different from 10t ha^{-1} but was different from the control. A study by Berihun *et al*. (2017) reported an increase in the height of Garden peas in southern Ethiopia after the application of rice husk biochar and said that this is because rice husk holds a substantial quantity of silicon, which showed valuable effects on height. Similar results were reported by Arif *et al.* (2017) who documented a significant increase in the height of onions after the application of the combined biochar and chemical fertilizer. They attributed their results to the ability of biochar to recycle organic matter in the soil. They have also reported that biochar as a soil amendment contributes to the absorption of heavy metals in agricultural soil. This explains clearly that biochar combined with inorganic fertilizer rapidly provided nutrients for growth. This is because biochar applied as the soil amendment has the potential to improve some of the soil's chemical properties like pH, organic matter (OM), and microbial activity. The results in our study conform to those of Shetty and Prakash (2020) who reported increased height of rice plants after the application of biochar, and attributed the results to biochar's capacity to reduce soil bulky density. However, this contributes to the breakdown of soil hardpans, which leads to the improvement of water conservation. It also favours deeper penetration of the roots to absorb nutrients.

On the other hand, beetroot height was greatly influenced by NPK (200, 300,400) application. The difference in plant height could be attributed to the ability of NPK to supply the essential macronutrients for plant growth such as nitrogen, phosphorus, and potassium. This is following Adhikari (2014) statement that each plant needs nutrients to grow to the maximum. If the plants do not get nutrients the metabolism activities of the plants get disturbed and cannot work at all. Therefore, N, P, and K cannot be replaced by other nutrients. Nafiu *et al.* (2011) and

Rajput (2019) reported that the application of chemical fertiliser (Di-ammonium Phosphate) increased the height of eggplant and capsicum. The increase was because DAP provides essential elements (nitrogen, and phosphorus) for plant growth and development. Another reason could be that DAP is a very reactive compound, it dissolves very fast in the soil when the moisture content is enough. Due to this, it is readily available for absorption through plants 'roots. The author also ascribed their results to the ability of DAP to provide phosphorus which influenced the absorption of the other nutrients elements such as calcium, and magnesium which increases the plant's growth. A study by Kwon *et al*. (2019) found that the significant increase in height of the two species of Bellflower (*Platycodon grandiflorum* and *Campanula persicifolia*) after the application of NPK fertilizer is in agreement with our study which indicated increased beetroot height after the application of NPK.

The combination of biochar at 5 and 10 t ha^{-1} with all the rates of NPK (200, 300, and 400 kg ha^{-1}) performed better than a single application of biochar and NPK. This is because combining biochar with inorganic fertilizer has a synergistic impact, which contributes to the improvement of nutrient absorption by plant roots. Similar findings were reported by Wing and Rao (2015) who reported an increase in the height of sweet potatoes after combining biochar at 7 and 12 t ha^{-1} with inorganic fertilizers (phosphate) at 350 and 500 kg ha^{-1} and attributed this growth to biochar's capacity to improve microbial activity and increasing soil aeration which allows root penetration to absorb plant beneficial nutrients. Hamzah and Shuhaimi (2018) reported that when biochar at 8 t ha^{-1} was combined with nitrogen fertilizers (NPK) at 300 kg ha^{-1}, maize plants grew taller.

Numerous types of research demonstrate that the synergistic impact between biochar and inorganic fertilizers promotes crop growth. The utilization of biochar together with inorganic fertilizer demonstrated a great impact to increase beetroot growth due to its capability to increase the soil's macro and micronutrients, and soil texture, and reduce nutrient leaching. Pandian *et al.* (2016) and Ghorbani *et al.* (2019) documented the same results on the influence of biochar and synthetic fertilizer to increase the growth of sugar beet. Both B5N300 and B10N300 recorded a significant increase in beetroot growth, however, B10N300 increased more growth than B5N300 and this could be attributed to the increase of nutrients caused by the increase of biochar from B5N300 to B10N300 (Ghorbani *et al*., 2019). In comparison to only biochar, which releases nutrients slowly, the inorganic fertilizer NPK provided the nutrients needed for beetroot growth. Inorganic fertilizers are in abundant the nutrients that plants need and which are easily released. However, the application of B0N200 did not increase beetroot height as B0N300 and B0N400 because of an inadequate supply of nutrients. The application of 5 or 10 t ha^{-1} biochar alone increased beetroot height with time; this might be explained by the biochar's delayed release of nutrients. Carpenter and Nair (2014) pointed out that the utilization of charcoal dust as the soil conditioner increased the growth of the carrots. An increase of sole biochar from B5N0 to B10N0 resulted in an improvement in beetroot growth because of the rise in nutrient content.

A significant increase in beetroot leaf area was observed after the application of biochar. This is because biochar enhances the plant metabolism process which contributes to the formation of plant structures. A Study by Zhu *et al.* (2019) reported an increase in the leaf area of potatoes and grapes after the application of biochar and said that it was because biochar increased photosynthetic rate and water use efficiency. Biochar and chemical fertiliser (NPK) improve the photosynthetic rate and electron transport of the cells in the leaf (Zhang *et al.*, 2020).

5.2. Effects of Biochar and NPK on Beetroot Yield

The application of charcoal dust (biochar) and inorganic fertiliser (NPK) significantly increased the yield of beetroot. This could be attributed to its ability to increase soil physical and chemical properties such as water-holding capacity and enzymatic activity (Arabi *et al.*, 2018). From our study biochar took time to show to effect on the development and production of beetroot, this is because of its high nutrient immobilization or sorption, and non-availability of key nutrients such as nitrogen and phosphorus, for plant uptake. The results from this study recorded a slight increase in the growth and yield of beetroot when sole biochar was applied, this is validated by Manka *et al.*(2019), who documented a slight increase in the yield of carrots when biochar was applied alone at the rates of 5t/ha in Burkina Faso. However, an increase in beetroot yield was detected when the combination of biochar and NPK was applied, indicating a strong harmonizing effect of this pairing. This might be attributed to both the plant's greater access to nutrients and the capability of biochar to reduce soil acidity. The soil type in our study was slightly acidic (pH = 5.73) which was lower than 6.5 the ideal pH for beetroot production, suggesting that it would benefit from biochar's liming properties as well as perhaps counteracting the acidic condition that results from its co-application with NPK. This soil habituation brought on by the application of biochar is anticipated to also ameliorate the physical properties of the soil, promote prodigious growth of the root, and increase the chemical properties such as soil nutrients. Additionally, the beneficial effects of biochar contributed to the improvement of soil microbial colony which normally plays a big role decomposition process leading to the increase in organic matter content in the soil.

Numerous studies including Karer *et al.* (2013),Akoto *et al.* (2019), Gao *et al.* (2022)and Diatta *et al.* (2020) have documented that biochar plays a very great influence on soil nutrient cycling such as carbon, nitrogen, and also increasing the activities of the enzymatic in the soil which greatly affect the environment for crop growth. The studies by Lychuk *et al.*(2015) and Sekar *et al.* (2014) also documented a rise in crop yield following an application of biochar and NPK. The results from our study conform with Prapagdee and Tawinteung (2017), who reported that the application of combined biochar and chemical fertiliser in infertile soil was proven to have a more positive influence on the yield of green beans than when fertiliser or biochar applied alone. This may be attributed to the biochar amendment's positive effects on the increase of soil chemical and physical properties of the soil and fertiliser use efficiency (Frišták *et al.*,2014; Rizhiya *et al.*, 2020). The strong interactive effects of biochar and NPK on beetroot production at all biochar dosages (5, 10 t/ha), and NPK fertilizer at the rates (200, 300, 400 kg /ha), can be attributed to the ability of biochar and NPK to condition the soil and increase fertiliser-use-efficiency of the beetroot cultivar in this study (Ahmed & Schoenau, 2015). Biochar and NPK fertiliser recorded a valuable increase in the growth and yield of beetroot at ($p < 0.05$) in seasons one and two although it was not statistically different in season one but significant in season two. The treatment N5B300 indicated a good performance on the growth and yield of beetroot compared to the control and other treatment.

5.3. Effects of Biochar and NPK on Beetroot Quality

The beetroot diameter was affected by the co-application of biochar and NPK. This could be because biochar and NPK act as a nutrient source. Biochar as a nutrient sink can retain nutrients, thereby reducing their losses through leaching and gaseous emission. The nutrient retention capacity of biochar depends on its porosity and surface charge (cation and anion exchange capacity) (Lychuk *et al.*, 2015). Biochar application reduces the loss of N, P, and K through leaching, and N through nitrous oxide emission.

A study conducted by Li *et al.* (2023) reported that the application of biochar and nitrogen fertiliser , increased the diameter of sugar beet, and ascribed the results to the increase of cation exchange capacity. The application of biochar and NPK influences various soil properties including soil pH, bulky density, water retention, cation exchange capacity, and biological activities (Farooque *et al.*, 2020). Shi *et al.* (2023) reported increased diameter of potatoes in China, after the application of organic manure and NPK at the rates of 8 t ha^{-1} and 400 kg ha^{-1}, and attributed the results to the capacity of organic manure and inorganic fertiliser to increase the microbial activity. This contributes to fastening the decomposition process of agricultural waste and biomass to boost soil nutrient available for plant absorption (Abriz & Torabian, 2018) .

The results from this study confirmed that proper fertilization influences beetroot quality. To get a big and well beetroot, it is very important to choose the proper ideal rate and timing for the application of macro and micronutrients (Azadi & Raiesi, 2021). However, nitrogen is the most crucial component to note when preparing to apply the fertilizer. This is due to its impact on the chlorophyll content which increases the photosynthesis process and leads to an increase in beetroot size (Varga *et al.*, 2021). Similar observations were made by Gondwe *et al.* (2020) who reported that the sugar beet diameter increased with increasing the application of combined organic manure and NPK fertilizer. However, the soil amended with biochar and NPK increased the microbial community, and thus it impacts nutrient cycling and uptake by plants (Wedlich *et al*. 2016). However, due to these various changes in the soil's chemical properties, the beetroot quality parameters including diameter are affected. Han *et al.* (2021) the application of rice husk biochar (10 t ha^{-1}) increased soil porosity by decreasing bulk density and increasing available water. This facilitates the penetration of the plant's roots for nutrient absorption. Another possible reason for increasing in beetroot diameter after the application of biochar and NPK is supported by Schulz *et al.* (2013) who reported that the application of biochar (12 t ha^{-1}) in Mollic soil increased the diameter of cassava. The author attributed the results to the capacity of biochar to reduce the tensile strength and cracks of surface soil (Zhang *et al.*, 2020), and suppressed soil shrinkage by increasing the ability of the soil to hold water; thus, soil structure was improved. Due to these effects of amendment on the soil structure, the mobility of nutrients in soil improved. Therefore, beetroot size was increased because of the nutrient availability.

On the other hand, the mineral content in beetroot was greatly affected by the application of biochar and NPK. Dan and Brix (2017) reported that soil pH is the main factor that influences minerals availability in soil and their accumulation in plant tissues. In our study, the plant supplied with 10 t ha^{-1} of biochar and 300kg/ha of NPK, had the highest concentration of calcium compared to the other treatments. This could be because the soil amendments (biochar and NPK) applied increased pH. This makes calcium available for plant root absorption. Geng *et al*. (2022) reported that when soil pH is between 7.5-8.0, calcium is available for plant uptake. Like calcium, phosphorus is also affected by the pH of the soil. Sadak and Talaat (2021) reported that for phosphorus to be available, soil pH must not be low or high. In our study, the treatment B0N200 had the highest concentration of phosphorus. This clearly explains that since our soil had low pH (5.7), the treatment applied contributed to increasing pH. A study by Peng *et al.* (2021) stated that the carrots grown in soil with neutral pH (7.0), had the highest concentration of phosphorus. Additionally, the availability of iron in soil affects its accumulation in plant tissues (Vernaya *et al.,* 2019). Treatment B0N400 had the highest concentration of iron content compared to the other treatments. This means that treatment did not contribute to the increase in soil pH. Zhang *et al.* (2022) reported that potatoes grown in soil with a pH of 5.0 had the highest concentration of iron, after the application of foliar fertiliser. The author explains that foliar did not increase pH.

Hosseini *et al*. (2019) reported that the application of organic manure and chemical fertilizer (phosphate) increased the Mg, Ca, and K content of onions. This could be because of the capacity of the amendments to improve nutrient mobility in soil. Apart from mineral content, a total soluble solid (TSS) was affected by the application of biochar and NPK in our study.

Christou *et al.* (2022) reported that the application of organic manure and nitrogen fertiliser increased the sugar content of carrots. The results were attributed to the capability of the amendments to increase photosynthesis. In our study, treatment (B5N0) had the highest concentration of TSS (10.8^{o}Brix) compared to the other treatments. This could be because of the ability of biochar to increase leaf area. This influences the absorption of light, which facilitate the synthesis of sugar. Furthermore, phenolic content in beetroot was influenced by biochar and NPK application in our study. Biochar at 10 t ha^{-1} had the highest concentration of phenolic content (37 g kg^{-1}) compared to the other treatments. This is due to the capability of biochar to increase the activity of phenylalanine ammonia-lyase (PAL), which is an enzyme that contributes to phenolic synthesis (Singh *et al*., 2014). Another study by Trandafir and Cosmulescu (2020) reported an increase in phenolic content in tomatoes, after the application of organic manure. The results were associated with the availability of Cu in soil. Another reason for the increase of phenolic content in beetroot, after the application of biochar and NPK, is associated with the availability of trace elements such as copper and iron. Therefore, increased levels of phenolic compounds in beetroot tissues are associated with a mechanism of tolerance to Cu, since Cu is a catalyst for redox reactions that can generate free radicals harmful to the plant (Ates *et al.*, 2022).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

This study had the broad objective of contributing towards food security and nutrition by enhancing production of beetroot. Based on the results of this study, the following conclusions were formulated:

i. Application of biochar at 5 and 10t ha^{-1} and $NPK_{17-17-17}$(200,300 and 400kg ha^{-1}) significantly improved beetroot growth compared to the control.

ii. The application of biochar at 5 and 10t ha and NPK (200, 300, and 400kg ha^{-1}) significantly improved the yield of beetroot compared to the control.

iii. Biochar 5 and 10t ha^{-1} and NPK (200,300 and 400kg ha^{-1}) significantly improved beetroot quality compared to the control. However, these combined rates of biochar and NPK did not differ statistically.

6.2. Recommendations

Upon completion of this study, the following recommendations were made:

(i) Based on the results of this study, farmers or other stakeholders involved in the beetroot value chain can consider first the combination of biochar at 5 t ha^{-1} and 200kg ha^{-1} of NPK to increase beetroot growth, yield, and quality.

(ii) Future research should be done on the residual effect of biochar and the influence of the co-application of different types of biochar and NPK on beetroot growth, yield, and quality.

(iii) Assessment of the cost analysis should be done to come up with the optimal treatment for small-scale farmers.

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APPENDICES

Appendix A: Data for the Beetroot Number of Leaves

Season one

Biochar (T ha^{-1})	NPK (kg ha^{-1})	Block	**30 days**	**45days**	**60 days**	**75days**	**90days**
0	0	1	3.80	9.50	13.63	15.13	16.13
5	0	1	4.00	11.50	14.38	16.63	17.62
10	0	1	4.20	10.25	14.63	15.50	16.30
0	200	1	4.10	11.25	14.88	15.63	18.63
5	200	1	4.30	12.38	14.88	17.00	19.00
10	200	1	4.30	10.88	13.50	15.75	18.75
0	300	1	5.10	12.38	16.63	15.63	19.63
5	300	1	4.60	13.63	14.00	17.50	19.80
10	300	1	4.10	11.50	13.00	15.38	18.38
0	400	1	4.50	11.88	10.13	16.88	17.78
5	400	1	4.10	10.63	14.00	16.75	18.75
10	400	1	3.70	10.13	12.38	16.50	19.50
0	0	2	3.20	10.00	11.63	13.00	13.00
5	0	2	4.20	11.50	13.38	13.50	13.70
10	0	2	3.80	11.88	12.38	13.13	13.20
0	200	2	4.30	11.13	13.88	14.00	14.90
5	200	2	4.50	11.75	16.13	16.63	17.63
10	200	2	4.20	11.38	13.00	16.75	19.85
0	300	2	4.10	11.75	13.25	17.63	18.69
5	300	2	3.60	10.38	13.13	16.00	17.00
10	300	2	4.30	11.13	12.50	15.25	16.25
0	400	2	4.30	12.00	16.13	17.00	17.80
5	400	2	3.80	11.00	13.00	14.88	15.88
10	400	2	4.70	11.63	13.25	17.00	19.00
0	0	3	3.20	9.75	9.75	12.63	12.63
5	0	3	3.60	11.00	10.38	12.75	12.90
10	0	3	3.60	9.38	11.38	12.70	12.90
0	200	3	3.50	13.38	14.38	17.00	18.00
5	200	3	4.10	10.75	10.88	13.00	14.00
10	200	3	4.00	11.75	12.38	16.50	17.50
0	300	3	3.30	12.00	12.13	14.50	15.50
5	300	3	4.30	14.75	13.88	16.63	18.63
10	300	3	4.00	12.13	12.88	14.25	19.25
0	400	3	3.80	15.13	12.50	14.75	15.75
5	400	3	3.70	11.00	13.38	15.63	18.63
10	400	3	4.60	11.50	12.50	14.75	14.90

Season two

Biochar (T ha^{-1})	NPK (kg ha^{-1})	Block	**30 days**	**45 days**	**60 days**	**75 days**	**90 days**
0	0	1	5.13	6.13	7.63	7.38	10.75
5	0	1	4.63	4.63	6.63	6.75	9.89
10	0	1	5.38	6.13	9.50	9.13	11.25
0	200	1	7.88	8.38	9.25	9.63	12.75
5	200	1	8.38	7.88	9.50	16.91	25.34
10	200	1	6.00	7.75	10.00	13.63	26.88
0	300	1	7.88	8.25	10.13	11.25	13.75
5	300	1	8.25	8.13	12.38	13.75	20.86
10	300	1	6.63	7.88	11.75	14.50	25.25
0	400	1	7.38	7.75	11.75	13.38	17.88
5	400	1	6.38	8.50	10.75	15.01	28.50
10	400	1	7.50	8.13	11.00	14.90	21.91
0	0	2	4.75	6.25	9.75	8.25	13.50
5	0	2	6.50	6.50	10.01	7.75	11.38
10	0	2	5.50	6.63	11.75	14.38	16.63
0	200	2	7.38	9.00	10.75	10.25	14.00
5	200	2	8.88	7.38	8.63	12.13	22.47
10	200	2	6.63	6.75	12.43	12.50	24.96
0	300	2	6.13	8.00	12.25	12.38	14.63
5	300	2	7.00	5.75	13.56	10.50	27.89
10	300	2	5.25	5.75	11.30	12.13	15.38
0	400	2	5.88	7.75	10.75	11.13	12.88
5	400	2	5.25	7.75	10.25	14.25	37.50
10	400	2	6.50	7.88	10.88	15.50	36.56
0	0	3	4.50	5.75	7.38	8.00	10.38
5	0	3	5.25	7.38	9.45	9.25	11.63
10	0	3	5.63	5.50	10.16	8.38	9.13
0	200	3	5.00	7.25	10.88	11.00	16.75
5	200	3	4.38	7.88	11.63	12.38	21.68
10	200	3	5.13	6.88	9.38	13.25	16.22
0	300	3	4.50	7.88	9.75	13.75	16.25
5	300	3	4.63	8.38	10.50	13.63	15.53
10	300	3	6.13	7.75	10.50	14.63	15.88
0	400	3	4.88	7.63	11.13	15.75	17.50
5	400	3	5.25	7.75	10.75	13.63	35.50
10	400	3	5.38	6.75	11.13	16.75	47.38

Appendix B: Data for the Beetroot Height (cm)

Season one

Biochar (T ha^{-1})	NPK (kg ha^{-1})	Block	**30 days**	**45days**	**60days**	**75days**	**90days**
0	0	1	6.73	17.49	32.94	39.75	34.63
5	0	1	5.77	16.00	29.31	41.13	41.75
10	0	1	5.92	12.15	26.63	32.63	39.88
0	200	1	8.36	21.04	36.44	42.25	42.30
5	200	1	9.45	23.41	40.75	50.88	53.13
10	200	1	6.47	17.50	36.31	46.88	46.90
0	300	1	9.55	19.24	32.19	38.00	39.50
5	300	1	9.47	21.54	41.56	50.63	51.38
10	300	1	3.77	19.38	39.15	50.63	51.75
0	400	1	8.10	17.20	28.75	37.88	41.63
5	400	1	8.68	19.86	36.75	47.00	48.88
10	400	1	6.28	19.09	35.63	38.25	41.38
0	0	2	6.27	16.45	26.69	38.00	32.81
5	0	2	8.22	16.71	28.63	32.75	32.89
10	0	2	6.52	15.33	25.25	32.75	39.00
0	200	2	9.36	18.89	33.99	37.38	40.88
5	200	2	9.11	18.84	36.06	42.13	42.81
10	200	2	9.08	21.74	34.92	40.88	41.75
0	300	2	9.22	18.71	35.56	43.50	43.70
5	300	2	5.17	15.21	28.36	42.63	42.80
10	300	2	7.85	19.88	32.63	37.38	43.38
0	400	2	9.22	15.85	35.63	43.00	43.94
5	400	2	7.43	16.74	22.81	40.75	41.94
10	400	2	8.80	18.45	36.63	48.25	51.13
0	0	3	5.21	13.49	20.75	26.13	27.06
5	0	3	4.97	15.86	26.13	37.25	38.69
10	0	3	6.45	13.68	19.53	30.81	31.56
0	200	3	8.10	18.94	34.25	37.81	40.13
5	200	3	9.08	18.38	26.23	37.25	38.88
10	200	3	5.21	15.09	25.68	38.13	39.50
0	300	3	5.76	14.41	25.19	34.50	36.25
5	300	3	10.40	21.51	32.73	44.38	45.59
10	300	3	7.28	21.64	33.89	41.19	43.38
0	400	3	7.86	17.50	25.25	32.94	33.44
5	400	3	5.27	14.23	28.15	36.13	36.69
10	400	3	9.37	22.71	33.88	41.13	42.49

Season two

Biochar (T ha^{-1})	NPK (kg ha^{-1})	Block	**30 days**	**45 days**	**60 days**	**75days**	**90 days**
0	0	1	6.68	7.50	16.50	21.88	29.38
5	0	1	6.48	6.46	16.50	18.84	25.45
10	0	1	4.76	7.61	10.06	28.00	33.75
0	200	1	6.78	12.19	18.06	39.41	42.09
5	200	1	9.38	16.16	24.06	41.75	51.30
10	200	1	6.15	14.09	29.63	39.81	52.25
0	300	1	9.16	16.63	28.69	40.88	37.00
5	300	1	6.49	14.44	30.75	45.25	42.75
10	300	1	8.83	16.85	29.13	40.88	74.88
0	400	1	9.95	14.69	31.13	37.75	42.00
5	400	1	8.35	15.50	25.19	39.38	48.05
10	400	1	6.80	14.88	27.88	39.63	87.78
0	0	2	5.71	8.88	21.13	23.34	28.46
5	0	2	5.94	7.51	15.63	17.00	28.63
10	0	2	7.14	9.06	23.13	33.88	40.63
0	200	2	8.98	15.54	27.94	40.29	41.88
5	200	2	8.20	14.00	22.00	43.85	58.90
10	200	2	5.64	9.08	21.63	40.66	65.88
0	300	2	8.33	13.85	26.88	37.80	42.75
5	300	2	6.58	10.38	23.50	44.08	47.00
10	300	2	5.65	8.94	21.38	39.83	61.34
0	400	2	8.06	12.69	23.19	33.31	39.38
5	400	2	7.04	13.63	24.38	38.25	49.38
10	400	2	8.04	13.38	28.13	38.25	59.98
0	0	3	6.15	6.49	16.75	22.41	24.81
5	0	3	5.59	10.38	23.31	19.68	32.00
10	0	3	6.68	9.55	19.06	21.64	25.19
0	200	3	7.69	13.81	26.38	40.96	46.63
5	200	3	6.64	13.86	26.38	40.74	50.01
10	200	3	7.11	12.30	22.63	43.14	56.78
0	300	3	6.56	11.46	24.63	41.91	42.72
5	300	3	7.26	12.66	23.31	48.71	50.43
10	300	3	7.00	14.75	24.13	40.60	66.63
0	400	3	7.99	16.25	25.50	39.39	39.89
5	400	3	6.08	14.40	25.01	42.55	71.75
10	400	3	6.33	9.31	19.50	39.01	89.90

Appendix C: Data for Beetroot Leaf Area (cm^2)

Season one

Biochar ($T\ ha^{-1}$)	NPK ($kg\ ha^{-1}$)	Block	**30days**	**45days**	**60days**	**75days**	**90days**
0	0	1	5.5	26.5	92.7	154.9	155.4
5	0	1	6.9	47.6	108.6	179.0	182.4
10	0	1	5.9	35.9	93.4	172.0	180.0
0	200	1	12.7	57.7	137.4	185.0	186.1
5	200	1	14.8	66.6	145.9	241.0	242.9
10	200	1	7.3	58.8	134.0	210.0	211.0
0	300	1	10.4	66.9	139.6	187.1	188.1
5	300	1	13.0	75.0	209.2	213.0	265.0
10	300	1	13.0	74.5	179.0	213.0	231.0
0	400	1	10.7	67.2	124.1	184.2	206.6
5	400	1	11.0	63.7	165.9	228.0	229.2
10	400	1	5.2	74.2	130.2	184.3	185.1
0	0	2	7.3	31.0	85.7	109.0	110.1
5	0	2	11.1	37.7	106.3	171.5	172.0
10	0	2	10.8	32.3	86.6	114.0	114.9
0	200	2	11.1	52.1	95.5	183.4	183.8
5	200	2	15.2	47.2	113.1	188.0	189.0
10	200	2	20.9	62.1	103.8	215.0	217.1
0	300	2	16.0	65.1	136.9	210.0	203.0
5	300	2	5.0	44.6	127.2	229.7	230.0
10	300	2	10.4	51.2	132.9	147.6	186.7
0	400	2	10.2	56.0	136.9	222.0	223.0
5	400	2	8.3	49.6	106.1	193.0	194.2
10	400	2	14.7	50.9	107.2	188.0	192.0
0	0	3	3.9	21.8	61.7	84.0	93.6
5	0	3	15.0	34.3	88.2	118.2	118.9
10	0	3	4.4	25.8	63.7	117.0	118.0
0	200	3	15.4	58.2	134.0	182.0	183.6
5	200	3	13.8	54.8	117.3	165.0	166.0
10	200	3	6.6	43.5	107.5	191.0	196.0
0	300	3	9.7	38.5	82.8	174.7	175.0
5	300	3	21.6	73.5	159.0	185.0	186.0
10	300	3	13.2	76.5	153.3	220.0	221.0
0	400	3	13.8	52.0	96.3	153.6	155.2
5	400	3	7.4	31.7	91.5	169.0	170.0
10	400	3	13.6	79.9	129.4	169.0	169.9

Season two

Biochar (T ha^{-1})	NPK (kg ha^{-1})	Block	**30 Days**	**45 Days**	**60 Days**	**75 Days**	**90 Days**
0	0	1	3.47	8.76	35.63	66.19	91.76
5	0	1	4.10	5.22	21.32	49.27	71.18
10	0	1	1.99	9.25	49.97	80.51	104.91
0	200	1	4.28	26.77	106.31	158.95	118.63
5	200	1	9.85	47.51	143.46	185.20	211.47
10	200	1	3.82	23.93	128.86	212.08	218.09
0	300	1	7.57	25.97	152.60	179.70	131.61
5	300	1	6.67	27.12	127.01	190.95	205.13
10	300	1	7.38	52.33	150.66	196.22	213.66
0	400	1	9.39	27.60	100.41	156.80	152.38
5	400	1	8.26	38.04	134.63	193.17	197.86
10	400	1	7.02	39.91	125.70	195.42	198.07
0	0	2	3.52	9.68	68.58	79.89	89.87
5	0	2	2.86	7.11	58.03	58.30	84.81
10	0	2	4.36	14.60	77.34	73.40	148.94
0	200	2	5.37	29.31	112.03	147.53	119.06
5	200	2	5.50	32.78	95.70	187.61	190.22
10	200	2	4.16	11.87	74.09	209.48	218.63
0	300	2	6.43	27.24	110.77	126.87	128.84
5	300	2	4.83	18.75	79.15	189.89	167.72
10	300	2	3.46	17.01	80.91	195.13	198.69
0	400	2	5.85	28.87	83.06	158.06	134.34
5	400	2	4.81	31.93	101.74	171.96	171.56
10	400	2	6.44	18.78	88.78	189.93	192.38
0	0	3	3.06	6.33	41.07	66.09	63.74
5	0	3	2.24	14.85	78.68	76.43	92.17
10	0	3	2.70	13.36	38.63	72.92	61.85
0	200	3	4.30	31.91	95.04	166.42	127.44
5	200	3	5.17	28.89	97.99	175.35	179.08
10	200	3	3.67	28.77	110.53	213.54	203.02
0	300	3	3.20	20.92	97.13	180.08	160.34
5	300	3	3.80	17.47	96.94	188.31	189.53
10	300	3	4.70	27.24	108.40	188.22	201.16
0	400	3	5.58	34.49	104.39	171.52	160.70
5	400	3	4.81	31.34	100.41	194.10	197.34
10	400	3	3.07	14.80	59.34	187.09	188.52

Appendix D: Data for the Beetroot Yield (T ha^{-1})

Season one

Biochar (T ha^{-1})	NPK (Kg ha^{-1})	block	Total yield	Marketable yield	Non-marketable yield
0	0	1	40.16	22.92	17.24
5	0	1	54.21	32.81	21.40
10	0	1	47.81	29.58	18.22
0	200	1	57.95	40.83	17.12
5	200	1	82.23	67.50	14.73
10	200	1	51.42	34.69	16.73
0	300	1	62.08	46.35	15.73
5	300	1	76.29	61.56	14.73
10	300	1	79.42	64.69	14.73
0	400	1	51.82	33.13	18.69
5	400	1	71.61	56.88	14.73
10	400	1	74.63	59.90	14.73
0	0	2	33.43	18.13	15.31
5	0	2	43.45	24.58	18.87
10	0	2	38.33	21.15	17.18
0	200	2	46.83	29.58	17.24
5	200	2	56.04	35.63	20.41
10	200	2	65.98	51.25	14.73
0	300	2	66.45	49.27	17.18
5	300	2	54.69	31.35	23.34
10	300	2	58.32	40.52	17.80
0	400	2	74.83	54.69	20.14
5	400	2	51.33	33.23	18.10
10	400	2	62.19	46.46	15.73
0	0	3	25.55	6.98	18.58
5	0	3	34.75	18.54	16.20
10	0	3	27.09	8.75	18.34
0	200	3	59.00	44.27	14.73
5	200	3	41.40	26.67	14.73
10	200	3	53.16	34.38	18.78
0	300	3	39.72	19.69	20.04
5	300	3	54.52	39.79	14.73
10	300	3	65.36	50.63	14.73
0	400	3	39.45	22.21	17.24
5	400	3	39.07	21.15	17.92
10	400	3	51.00	34.79	16.20

Season two

Biochar (T ha^{-1})	NPK (kg ha^{-1})	block	Total yield	Marketable yield	Non marketable yield
0	0	1	41.67	0.71	6.49
5	0	1	72.92	7.94	3.30
10	0	1	58.33	7.11	2.97
0	200	1	75.00	8.07	3.30
5	200	1	65.63	8.13	0.71
10	200	1	60.21	6.49	4.36
0	300	1	91.67	8.81	3.88
5	300	1	108.33	10.02	2.97
10	300	1	100.42	9.29	3.88
0	400	1	54.38	7.41	0.71
5	400	1	73.33	7.83	3.61
10	400	1	66.67	7.94	2.16
0	0	2	47.92	0.71	6.96
5	0	2	55.83	7.18	2.30
10	0	2	46.04	6.49	2.21
0	200	2	62.50	7.39	2.97
5	200	2	77.08	7.94	3.88
10	200	2	76.04	7.67	4.27
0	300	2	56.25	6.96	2.97
5	300	2	75.83	7.94	3.72
10	300	2	82.92	8.57	3.24
0	400	2	95.21	9.78	0.71
5	400	2	61.67	7.25	3.18
10	400	2	74.38	8.20	2.87
0	0	3	49.38	2.87	6.49
5	0	3	42.08	5.63	3.37
10	0	3	38.96	4.62	4.32
0	200	3	96.46	9.85	0.71
5	200	3	59.79	7.25	2.87
10	200	3	61.04	7.39	2.72
0	300	3	73.75	8.62	0.71
5	300	3	98.96	9.49	3.14
10	300	3	59.17	7.72	0.71
0	400	3	75.42	8.07	3.37
5	400	3	53.33	6.65	3.18
10	400	3	82.92	7.80	4.80

Appendix E: Data for the Beetroot Diameter (mm)

Season one

Biochar (T ha^{-1})	NPK (kg ha^{-1})	Block	Diameter
0	0	1	73.72
5	0	1	74.03
10	0	1	68.71
0	200	1	81.14
5	200	1	85.68
10	200	1	74.69
0	300	1	73.79
5	300	1	84.97
10	300	1	84.71
0	400	1	77.58
5	400	1	86.99
10	400	1	81.20
0	0	2	62.13
5	0	2	65.55
10	0	2	66.89
0	200	2	68.96
5	200	2	79.03
10	200	2	86.62
0	300	2	82.96
5	300	2	79.99
10	300	2	77.21
0	400	2	76.96
5	400	2	70.88
10	400	2	79.74
0	0	3	51.33
5	0	3	61.05
10	0	3	52.51
0	200	3	77.29
5	200	3	66.99
10	200	3	75.40
0	300	3	65.95
5	300	3	70.10
10	300	3	83.40
0	400	3	67.69
5	400	3	63.63
10	400	3	76.95

Season two

Biochar (T ha^{-1})	NPK (kg ha^{-1})	Block	Diameter
0	0	1	74.7
5	0	1	76.1
10	0	1	74.8
0	200	1	82.9
5	200	1	89.7
10	200	1	79.5
0	300	1	77.8
5	300	1	89.8
10	300	1	82.0
0	400	1	81.2
5	400	1	87.6
10	400	1	80.1
0	0	2	65.7
5	0	2	68.7
10	0	2	78.6
0	200	2	83.9
5	200	2	86.0
10	200	2	90.6
0	300	2	84.3
5	300	2	87.7
10	300	2	85.0
0	400	2	86.6
5	400	2	82.8
10	400	2	97.4
0	0	3	57.0
5	0	3	68.9
10	0	3	79.1
0	200	3	86.1
5	200	3	76.2
10	200	3	88.6
0	300	3	74.8
5	300	3	91.5
10	300	3	85.7
0	400	3	87.7
5	400	3	73.9
10	400	3	80.8

Appendix F: Data for Beetroot Internal Quality Parameters (Minerals Content, TSS and Phenolic Content)

Season one

Biochar (T ha^{-1})	NPK (kg ha^{-1})	Block	TSS (^{o}BRIX)	Calcium (g kg^{-1})	Phosphorus (g kg^{-1})	Iron (g kg^{-1})	Phenolic (g kg^{-1})
0	0	1	10.40	22.44	2.01	371.05	5.56
5	0	1	12.20	20.84	3.24	820.10	7.33
10	0	1	6.20	16.03	5.21	553.12	3.78
0	200	1	5.80	24.05	3.28	626.35	14.67
5	200	1	6.20	8.02	3.11	767.63	9.56
10	200	1	7.00	11.22	4.42	719.71	11.11
0	300	1	7.20	17.64	2.23	579.05	5.56
5	300	1	7.60	14.43	5.54	405.23	2.00
10	300	1	8.20	8.02	2.82	318.01	5.33
0	400	1	10.00	12.83	3.02	710.20	4.44
5	400	1	6.80	12.83	4.30	701.57	4.67
10	400	1	6.20	19.24	3.00	618.09	12.44
0	0	2	8.80	19.24	3.73	445.08	16.89
5	0	2	8.60	9.62	5.01	813.84	10.89
10	0	2	8.60	12.83	3.31	454.31	12.22
0	200	2	8.00	8.02	4.02	425.07	8.22
5	200	2	6.80	12.83	5.21	414.14	2.00
10	200	2	9.00	27.25	4.12	716.30	6.67
0	300	2	8.00	19.24	3.10	380.01	13.78
5	300	2	7.50	16.03	5.00	565.46	11.33
10	300	2	9.20	8.02	7.62	723.31	14.22
0	400	2	7.80	8.02	1.29	604.09	2.22
5	400	2	10.80	12.83	5.23	504.10	8.00
10	400	2	9.00	22.44	4.34	723.20	5.33
0	0	3	8.40	30.46	3.14	402.17	13.56
5	0	3	8.00	17.64	4.16	923.24	12.89
10	0	3	9.00	9.62	3.13	442.02	9.78
0	200	3	9.00	4.81	4.10	614.34	4.44
5	200	3	9.80	24.05	4.15	912.43	3.11
10	200	3	6.00	27.25	7.82	712.42	9.33
0	300	3	8.80	9.62	7.22	743.13	2.22
5	300	3	8.20	8.02	4.40	921.45	3.56
10	300	3	8.00	11.22	3.11	886.91	12.44
0	400	3	9.00	10.22	4.14	537.39	3.33
5	400	3	10.60	8.02	6.10	811.54	9.78
10	400	3	5.90	20.84	9.11	802.15	14.22

Season two

Appendix G: Analysis of variance for the Beetroot Leaves 30 days After Planting

Season one

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Block	2	1.11500000	0.55750000	3.92	0.0349
Biochar	2	0.23166667	0.11583333	0.82	0.4554
NPK	3	1.14305556	0.38101852	2.68	0.0717
Biochar*NPK	6	0.79277778	0.13212963	0.93	0.4930
R-Square		0.512290	9.325093		
Coeff Var					

Season two

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Block	2	19.13807222	9.56903611	10.19	0.0007
Biochar	2	0.61253889	0.30626944	0.33	0.7252
NPK	3	9.16669722	3.05556574	3.25	0.0411
Biochar*NPK	6	4.58319444	0.76386574	0.81	0.5711
R-Square		0.618470			
Coeff Var		16.02521			

Appendix H: Analysis of Variance for the Beetroot Leaves 45 days After Planting

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	2.57490556	1.28745278	1.13	0.3423
Biochar	2	2.47220556	1.23610278	1.08	0.3566
NPK	3	13.05468889	4.35156296	3.81	0.0245
Biochar*NPK	6	12.79686111	2.13281019	1.87	0.1325
R-Square		0.551223			
Coeff Var		9.299388			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	0.74367222	0.37183611	0.55	0.5855
Biochar	2	1.67907222	0.83953611	1.24	0.3093
NPK	3	16.67627500	5.55875833	8.20	0.0008
Biochar*NPK	6	1.69528333	0.28254722	0.42	0.8599
R-Square		0.582338			
Coeff Var		11.32577			

Appendix I: Analysis of Variance for the Beetroot Leaves 60 days After Planting

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	17.67740000	8.83870000	3.81	0.0379
Biochar	2	2.52886667	1.26443333	0.55	0.5873
NPK	3	9.73655556	3.24551852	1.40	0.2694
Biochar*NPK	6	6.27464444	1.04577407	0.45	0.8364
R-Square		0.415218			
Coeff Var		11.56168			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	6.78020556	3.39010278	2.73	0.0875
Biochar	2	3.05948889	1.52974444	1.23	0.3115
NPK	3	25.03161111	8.34387037	6.71	0.0022
Biochar*NPK	6	9.72568889	1.62094815	1.30	0.2967
R-Square		0.619813			
Coeff Var		10.69858			

Appendix J: Analysis of Variance for the Beetroot Leaves 75 days After Planting

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	15.34440556	7.67220278	5.47	0.0118
Biochar	2	0.60195556	0.30097778	0.21	0.8084
NPK	3	27.47067778	9.15689259	6.53	0.0025
Biochar*NPK	6	6.39035556	1.06505926	0.76	0.6088
R-Square		0.617664			
Coeff Var		7.690684			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	3.5761056	1.7880528	0.61	0.5536
Biochar	2	31.5792389	15.7896194	5.37	0.0127
NPK	3	155.6124972	51.8708324	17.63	<.0001
Biochar*NPK	6	15.2285611	2.5380935	0.86	0.5373
R-Square		0.760859			
Coeff Var		14.10750			

Appendix K: Analysis of Variance for the Beetroot Leaves 90 days After Planting

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	40.74653889	20.37326944	9.06	0.0013
Biochar	2	2.35842222	1.17921111	0.52	0.5991
NPK	3	84.09273333	28.03091111	12.47	<.0001
Biochar*NPK	6	5.91013333	0.98502222	0.44	0.8454
R-Square		0.729072			
Coeff Var		8.881836			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	21.968550	10.984275	0.39	0.6838
Biochar	2	520.376617	260.188308	9.16	0.0013
NPK	3	1286.667389	428.889130	15.10	<.0001
Biochar*NPK	6	375.615161	62.602527	2.20	0.0814
R-Square		0.779193			
Coeff Var		27.14917			

Appendix L: Analysis of Variance for the Beetroot Height 30 days After Planting

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	5.54561667	2.77280833	1.07	0.3598
Biochar	2	6.00740000	3.00370000	1.16	0.3318
NPK	3	21.03095556	7.01031852	2.71	0.0698
Biochar*NPK	6	13.02977778	2.17162963	0.84	0.5532
R-Square		0.444765			
Coeff Var		21.47013			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	3.17655000	1.58827500	1.47	0.2524
Biochar	2	6.14495000	3.07247500	2.84	0.0802
NPK	3	12.25122222	4.08374074	3.77	0.0253
Biochar*NPK	6	6.73402778	1.12233796	1.04	0.4289
R-Square		0.542955			
Coeff Var		14.62361			

Appendix M: Analysis of Variance for the Beetroot Height 45 days After Planting

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	11.74642222	5.87321111	1.12	0.3429
Biochar	2	3.89927222	1.94963611	0.37	0.6928
NPK	3	93.77965556	31.25988519	5.98	0.0038
Biochar*NPK	6	46.82692778	7.80448796	1.49	0.2264
R-Square		0.576175			
Coeff Var		12.77438			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	16.9369556	8.4684778	1.90	0.1733
Biochar	2	5.4380222	2.7190111	0.61	0.5522
NPK	3	197.1436222	65.7145407	14.75	<.0001
Biochar*NPK	6	20.8373111	3.4728852	0.78	0.5950
R-Square		0.710276			
Coeff Var		17.30512			

Appendix N: Analysis of Variance for the Beetroot Height 60 days After Planting

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	299.8159722	149.9079861	10.39	0.0007
Biochar	2	7.2264222	3.6132111	0.25	0.7807
NPK	3	334.6929194	111.5643065	7.73	0.0010
Biochar*NPK	6	130.1492222	21.6915370	1.50	0.2235
R-Square		0.708508			
Coeff Var		12.15533			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	5.5890167	2.7945083	0.16	0.8564
Biochar	2	4.7125167	2.3562583	0.13	0.8774
NPK	3	363.2144528	121.0714843	6.76	0.0021
Biochar*NPK	6	7.9020389	1.3170065	0.07	0.9981
R-Square		0.591923			
Coeff Var		18.06898			

Appendix O: Analysis of Variance for the Beetroot Height 75 days After Planting

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	255.5741722	127.7870861	7.51	0.0033
Biochar	2	111.8696056	55.9348028	3.29	0.0564
NPK	3	344.8680222	114.9560074	6.75	0.0021
Biochar*NPK	6	66.9636611	11.1606102	0.66	0.6855
R-Square		0.675424			
Coeff Var		10.36508			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	4.599022	2.299511	0.36	0.6998
Biochar	2	31.503472	15.751736	2.49	0.1064
NPK	3	2178.022011	726.007337	114.54	<.0001
Biochar*NPK	6	186.657239	31.109540	4.91	0.0025
R-Square		0.945106			
Coeff Var		6.946482			

Appendix P: Analysis of Variance for the Beetroot Height 90 days After Planting

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	263.7507167	131.8753583	9.84	0.0009
Biochar	2	184.1106500	92.0553250	6.87	0.0048
NPK	3	426.5649556	142.1883185	10.61	0.0002
Biochar*NPK	6	35.8007944	5.9667991	0.45	0.8405
R-Square		0.755317			
Coeff Var		8.882345			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	54.664039	27.332019	0.46	0.6390
Biochar	2	2824.639756	1412.319878	23.62	<.0001
NPK	3	4254.897364	1418.299121	23.72	<.0001
Biochar*NPK	6	1038.679978	173.113330	2.89	0.0310
R-Square		0.861336			
Coeff Var		16.11474			

Appendix Q: Analysis of Variance for the Beetroot Leaf Area 30 days After Planting

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	30.8123167	15.4061583	0.83	0.4477
Biochar	2	15.8329167	7.9164583	0.43	0.6569
NPK	3	148.7996528	49.5998843	2.68	0.0716
Biochar*NPK	6	60.0893722	10.0148954	0.54	0.7707
R-Square		0.485941			
Coeff Var		39.11947			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	31.84661667	15.92330833	9.68	0.0010
Biochar	2	5.24871667	2.62435833	1.60	0.2254
NPK	3	43.63387500	14.54462500	8.84	0.0005
Biochar*NPK	6	12.99241667	2.16540278	1.32	0.2914
R-Square		0.721432			
Coeff Var		25.98457			

Appendix R: Analysis of Variance for the Beetroot Leaf Area 45 days After Planting

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	936.585539	468.292769	4.56	0.0220
Biochar	2	219.821039	109.910519	1.07	0.3601
NPK	3	4950.119764	1650.039921	16.07	<.0001
Biochar*NPK	6	839.703694	139.950616	1.36	0.2730
R-Square		0.754552			
Coeff Var		19.35577			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	319.149600	159.574800	2.77	0.0347
Biochar	2	39.519200	19.759600	0.34	0.7136
NPK	3	2326.470808	775.490269	13.45	<.0001
Biochar*NPK	6	644.961600	107.493600	1.86	0.1327
R-Square		0.724112			
Coeff Var		27.13673			

Appendix S: Analysis of Variance for the Beetroot Leaf Area 60 days After Planting

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	6868.00757	3434.00379	10.07	0.0008
Biochar	2	1928.80967	964.40484	2.83	0.0807
NPK	3	15926.22187	5308.74062	15.57	<.0001
Biochar*NPK	6	2497.65942	416.27657	1.22	0.3333
R-Square		0.783936			
Coeff Var		15.52256			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	3394.85337	1697.42669	3.28	0.0568
Biochar	2	75.78834	37.89417	0.07	0.9297
NPK	3	20317.12367	6772.37456	13.08	<.0001
Biochar*NPK	6	1413.89448	235.64908	0.45	0.8337
R-Square		0.688638			
Coeff Var		24.56459			

Appendix T: Analysis of Variance for the Beetroot Leaf Area 75 days After Planting

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	7510.02144	3755.01072	6.92	0.0047
Biochar	2	2624.35861	1312.17930	2.42	0.1123
NPK	3	23387.72752	7795.90917	14.37	<.0001
Biochar*NPK	6	1561.07937	260.17990	0.48	0.8161
R-Square		0.746213			
Coeff Var		12.99596			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	404.16224	202.08112	1.58	0.2283
Biochar	2	5309.32276	2654.66138	20.77	<.0001
NPK	3	85683.93566	28561.31189	223.41	<.0001
Biochar*NPK	6	2558.59364	426.43227	3.34	0.0172
R-Square		0.970936			
Coeff Var		7.357123			

Appendix U: Analysis of Variance for the Beetroot Leaf Area 90 days After Planting

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	10820.55054	5410.27527	13.63	0.0001
Biochar	2	3336.17404	1668.08702	4.20	0.0284
NPK	3	26731.90163	8910.63388	22.45	<.0001
Biochar*NPK	6	2348.39203	391.39867	0.99	0.4583
R-Square		0.832000			
Coeff Var		10.81392			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	370.50957	185.25479	0.57	0.5755
Biochar	2	19824.19601	9912.09800	30.32	<.0001
NPK	3	51044.75832	17014.91944	52.05	<.0001
Biochar*NPK	6	5331.80319	888.63387	2.72	0.0395
R-Square		0.914136			
Coeff Var		11.65529			

Appendix V: Analysis of Variance for the Beetroot Total Yield

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	2016.634756	1008.317378	11.16	0.0005
Biochar	2	280.815289	140.407644	1.55	0.2339
NPK	3	2956.061075	985.353692	10.90	0.0001
Biochar*NPK	6	278.210667	46.368444	0.51	0.7920
R-Square		0.735572			
Coeff Var		17.71953			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	267.453617	133.726808	0.65	0.5336
Biochar	2	61.383650	30.691825	0.15	0.8630
NPK	3	4946.831164	1648.943721	7.97	0.0009
Biochar*NPK	6	1341.747194	223.624532	1.08	0.4038
R-Square		0.592501			
Coeff Var		20.95055			

Appendix W: Analysis of Variance for the Beetroot Marketable Yield

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	2072.538339	1036.269169	9.33	0.0012
Biochar	2	344.685756	172.342878	1.55	0.2342
NPK	3	3243.285497	1081.095166	9.73	0.0003
Biochar*NPK	6	308.018844	51.336474	0.46	0.8286
R-Square		0.709512			
Coeff Var		28.86278			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	244.504172	122.252086	0.58	0.5692
Biochar	2	405.604422	202.802211	0.96	0.3987
NPK	3	9925.841400	3308.613800	15.65	<.0001
Biochar*NPK	6	4685.275867	780.879311	3.69	0.0109
R-Square		0.766377			
Coeff Var		25.61489			

Appendix X: Analysis of Variance for the Beetroot Non -Marketable Total Yield

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	13.89200556	6.94600278	1.30	0.2923
Biochar	2	7.57717222	3.78858611	0.71	0.5026
NPK	3	8.65565278	2.88521759	0.54	0.6595
Biochar*NPK	6	19.25807222	3.20967870	0.60	0.7262
R-Square		0.296067			
Coeff Var		13.47855			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	3.606050	1.803025	0.04	0.9571
Biochar	2	231.957800	115.978900	2.83	0.0807
NPK	3	980.360586	326.786862	7.97	0.0009
Biochar*NPK	6	2359.841489	393.306915	9.59	<.0001
R-Square		0.798499			
Coeff Var		53.90476			

Appendix Y: Analysis of Variance for the Beetroot Diameter

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	774.853539	387.426769	11.92	0.0003
Biochar	2	99.590906	49.795453	1.53	0.2383
NPK	3	1178.554789	392.851596	12.09	<.0001
Biochar*NPK	6	95.204494	15.867416	0.49	0.8101
R-Square		0.750238			
Coeff Var		7.726729			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	103.961667	51.980833	1.72	0.2031
Biochar	2	180.721667	90.360833	2.98	0.0715
NPK	3	1269.952222	423.317407	13.97	<.0001
Biochar*NPK	6	507.882778	84.647130	2.79	0.0357
R-Square		0.755698			
Coeff Var		6.737001			

Appendix Z: Analysis of Variance for the Beetroot TSS

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	3.29055556	1.64527778	0.69	0.5101
Biochar	2	5.54055556	2.77027778	1.17	0.3293
NPK	3	9.49000000	3.16333333	1.33	0.2887
Biochar*NPK	6	9.33500000	1.55583333	0.66	0.6850
R-Square		0.346544			
Coeff Var		18.68723			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	9.40055556	4.70027778	3.37	0.0527
Biochar	2	7.59055556	3.79527778	2.72	0.0877
NPK	3	5.74750000	1.91583333	1.38	0.2765
Biochar*NPK	6	23.42500000	3.90416667	2.80	0.0352
R-Square		0.601013			
Coeff Var		12.68714			

Appendix AA: Analysis of Variance for the Beetroot Calcium Content

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	5.2478000	2.6239000	0.07	0.9303
Biochar	2	37.3458167	18.6729083	0.52	0.6039
NPK	3	143.1611861	47.7203954	1.32	0.2935
Biochar*NPK	6	576.1038056	96.0173009	2.65	0.0432
R-Square		0.589014			
Coeff Var		29.68208			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	311.507222	155.753611	0.63	0.5403
Biochar	2	93.193889	46.596944	0.19	0.8287
NPK	3	2334.647500	778.215833	3.16	0.0447
Biochar*NPK	6	6526.721667	1087.786944	4.42	0.0044
R-Square		0.631328			
Coeff Var		24.56758			

Appendix BB: Analysis of Variance for the Beetroot Phosphorus Content

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	14.12666667	7.06333333	2.66	0.0923
Biochar	2	13.53431667	6.76715833	2.55	0.1010
NPK	3	4.92690000	1.64230000	0.62	0.6103
Biochar*NPK	6	7.18335000	1.19722500	0.45	0.8365
R-Square		0.495101			
Coeff Var		30.90645			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	5.86166667	2.93083333	1.13	0.3408
Biochar	2	1.91166667	0.95583333	0.37	0.6958
NPK	3	25.84083333	8.61361111	3.32	0.0384
Biochar*NPK	6	40.85500000	6.80916667	2.63	0.0448
R-Square		0.566359			
Coeff Var		26.14163			

Appendix CC: Analysis of Variance for the Beetroot Iron Content

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	173602.7768	86801.3884	4.16	0.0294
Biochar	2	189371.3738	94685.6869	4.54	0.0224
NPK	3	43756.7476	14585.5825	0.70	0.5627
Biochar*NPK	6	222795.6761	37132.6127	1.78	0.1500
R-Square		0.578248			
Coeff Var		22.94314			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	41888.3072	20944.1536	1.12	0.3436
Biochar	2	126563.7606	63281.8803	3.39	0.0521
NPK	3	491742.3142	163914.1047	8.78	0.0005
Biochar*NPK	6	351418.8017	58569.8003	3.14	0.0224
R-Square		0.711241			
Coeff Var		20.77232			

Appendix DD: Analysis of Variance for the Beetroot Phenolic Content

Season one

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	26.7238500	13.3619250	0.71	0.5047
Biochar	2	44.0732167	22.0366083	1.16	0.3309
NPK	3	53.9096667	17.9698889	0.95	0.4342
Biochar*NPK	6	129.3730500	21.5621750	1.14	0.3734
R-Square		0.478796			
Coeff Var		32.77277			

Season two

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Block	2	120.9155556	60.4577778	2.00	0.1594
Biochar	2	179.7172222	89.8586111	2.97	0.0721
NPK	3	113.2333333	37.7444444	1.25	0.3165
Biochar*NPK	6	606.9650000	101.1608333	3.34	0.0170
R-Square		0.605369			
Coeff Var		22.55065			

Appendix EE: Research Permit From NACOSTI

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Date of Issue: 07/June/2022

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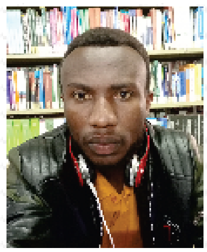

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Appendix FF: Ethical Clearance

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EGERTON UNIVERSITY INSTITUTIONAL SCIENTIFIC AND ETHICS REVIEW COMMITTEE

EU/RE/DVC/009
Approval No. EUREC/APP/183/2022 ***14th July, 2022***

Enock Kwizera
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Dear Enock,

RE: ETHICAL APPROVAL: EFFECT OF BIOCHAR AND INORGANIC FERTILIZER ON THE GROWTH, YIELD AND QUALITY OF BEETROOT

This is to inform you that ***Egerton University Institutional Scientific and Ethics Review Committee*** has reviewed and approved your above research proposal. Your application approval number is *EUREC/APP/183/2022*. The approval period is ***14th July, 2022 –15th July, 2023***.

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by ***Egerton University Institutional Scientific and Ethics Review Committee***.
iii. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to ***Egerton University Institutional Scientific and Ethics Review Committee*** within 72 hours of notification
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to ***Egerton University Institutional Scientific and Ethics Review Committee*** within 72 hours.
v. Clearance for Material Transfer of biological specimens must be obtained from relevant institutions.

"Transforming Lives through Quality Education"

Appendix GG: Published Paper

International Journal of Horticultural Science 2023, 29: 37-45.
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Effects of biochar and inorganic fertiliser on the growth and yield of beetroot (*Beta vulgaris* L.) in Kenya

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Summary: Beetroot (*Beta vulgaris* L.) is a root vegetable packed with many nutritional benefits such as minerals and vitamins. Despite its importance in Kenya, farmers get about 30-35 t/ha which is significantly lower than the potential yield (68 t/ha). This is mostly attributed to low soil fertility. This study aimed to determine the response of the beetroot growth and yield on biochar and NPK. A 3×4 factorial experiment was carried out at Egerton University farm over two seasons to test the effects of biochar and NPK (17-17-17), under supplemental irrigation. Biochar (0, 5, 10 t/ha) was combined with NPK (0, 200, 300, 400 kg/ha). The combination of Biochar and NPK increased significantly ($p \leq 0.05$) beetroot growth and yield in two seasons. Treatment B10N400 showed the tallest plants (79.2 cm) at 90 days in season two, while the control resulted in the shortest (27.6 cm). Treatment B10N200 showed the biggest (213.2 cm^2) leaves at 90 days. The treatment B5N300 recorded the highest marketable yield (84 t/ha) in season two and the lowest was B0N0 with 2.6 t/ha. Sole application of NPK rates (200, 300, 400 kg/ha) increased significantly the growth and yield of beetroot compared to the control in both seasons. In season one, N300 (300 kg/ha) had 61.9 t/ha of the total yield, the control had the lowest. In season two, 300 kg/ha had 83 t/ha of total yield. Biochar increased beetroot growth and yield in season 2. Treatment B5 recorded the highest marketable yield of 61.2 t/ha, while the control showed the lowest of 53 t/ha.

Kwizera, E., Opiyo, A. M., Mungai, N. W. (2023): Effects of biochar and inorganic fertiliser on the growth and yield of beetroot (*Beta vulgaris* L.) in Kenya. International Journal of Horticultural Science 29: 37-45. https://doi.org/10.31421/ijhs/29/2023/12499