EFFECTS OF CHARGED BIOCHAR AND SELECTED ORGANIC FERTILISERS ON GROWTH, YIELD, QUALITY, AND PROFITABILITY OF LETTUCE (*Lactuca sativa* L.)

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A Thesis Submitted to the Graduate School in Partial Fulfilment for the Requirement of the Master of Science Degree in Horticulture of Egerton University

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DECLARATION AND RECOMMENDATION

Declaration

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

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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 parents, wife, children, and entire family for their encouragement, love, and support.

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ABSTRACT

Poor soil fertility due to excessive use of synthetic fertilisers poses challenges to sustainable production of vegetables, including lettuce (*Lactuca sativa* L.) in many tropical regions. This research aimed at assessing the agronomic and economic potential of organic fertilisers in enhancing lettuce production. Its specific objectives were to determine the effects of selected organic fertilisers (nutrient source) on soil properties, productivity, quality, and profitability of lettuce. It was done in a randomized complete block design with six treatments (negative control-soil, positive control-NPK+Urea, charged biochar, compost, poultry and farmyard manures) replicated three times in two production seasons from October, 2024 to January, 2025, and February to May, 2025 in Field-3 at Egerton University, Kenya. Iceberg lettuce variety was used in this experimentation. Data was collected pre- and post-production on soil and organic fertilisers; bi-weekly on lettuce growth components; and in the 9th week on head diameter, biomass yield, nutritional quality, and net economic benefit (NEB). Data was subjected to analysis of variance using JMP Pro 7th edition program. Results showed decreased N, P, pH, OC, OM, but increased K, Ca, Mg, CEC, and C: N in soil post-production. All treatments had a pH of 6.1 - 6.5 that was optimal for lettuce growth. In both seasons, results showed a significant difference in lettuce leaf diameter (P = 0.023, 0.041), plant height (P = 0.002, 0.004), leaves (P = 0.032, 0.0002), as well as head diameter (P = 0.012, 0.011). Similarly, marketable fresh weight yield was significantly (P = 0.010; 0.019) different and ranged from 1.4 - 2.6 ton/ha and 1.1 - 2.6 ton/ha. In this regard, poultry manure promoted the highest marketable fresh weight yield of 2.3 and 2.6 ton/ha. In contrast, charged biochar led to intermediate marketable fresh weight yield of 2.0 and 1.8 ton/ha, while negative control had the lowest of 1.4 and 1.1 ton/ha. Lettuce leaf tissue analysis showed significant (P = 0.001; P = 0.048) differences in vitamin C, ranging from 2.0 – 3.2 and 1.0 – 1.4 meg/100 mg. However, there were no significant (P> 0.05) differences in nutritional minerals (N, P, K, Mg, Ca). The NEB, ranging from Ksh 217 – 778 and Ksh 224 – 833, was significantly (P = 0.001; 0.011) different. Positive control (Ksh 778) and poultry manure (Ksh 833) had the highest NEB, while charged biochar (Ksh 217) and compost (Ksh 224) had the lowest. This study highlights varied effects of charged biochar and organic fertilisers on lettuce production. The amendments approach enhanced productivity and promoted organic lettuce production. It also recommends adoption of poultry manure and long-term (residual) effects of charged biochar on lettuce production enterprises.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
FAO	Food and Agriculture Organizations of the United Nations
FYM	Farmyard Manure
GDP	Gross Domestic Product
KSh	Kenyan Shillings
LDC	Least Developed Countries
LSD	Least Significant Differences
NEB	Net Economic Benefit
OC	Organic Carbon
RCBD	Randomized Complete Block Design
RHB	Rice Husk Biochar
SDGs	Sustainable Development Goals of the United Nations
USA	United States of America
USD	United States Dollar

CHAPTER ONE
INTRODUCTION

1.1. Background Information

Lettuce (*Lactuca sativa* L.) is a salad vegetable crop, which provides both high nutritional and economic values. Lettuce benefits the ecosystem as well as humans; the wild and domesticated cultivars provide food for diverse organisms such as insects (larvae of some *Lepidoptera*), rabbits, and other herbivores. Also, humans usually consumed as cooked or raw 'as a salad' without any restriction to daily intake which are gaining more popularity as a culinary trend (Xiao *et al*., 2012). In some Sub-Saharan Africa countries, lettuce farming is among the most prevalent agricultural activities, serving as an important source of employment and livelihood for rural people (Abdulai *et al*., 2017; Quansah *et al*., 2020). In Kenya, as stated by USDA 2019 lettuce production was 2,591 metric tons while in other countries like China and US produced 16,314,499 and 3,688,520 metric tons, respectively. Vegetable production in the Gambia is estimated to be 13,515 metric tons per cropping season (FAO, 2019). Fatty and Ode, (2018) reported that vegetable production in the dry and wet seasons in the "Sukuta". In Gambia, most of the women vegetable garden produce different crop varieties, as stated by Fatty and Ode, 2018 lettuce production yield 201.2 ton/ha. In addition, lettuce is an important component of human diet with a significant amount of minerals, proteins, and vitamins (Das & Bhattacharjee, 2020). The successful growth and yield of lettuce heavily depend on soil fertility. Therefore, poor soil fertility affects lettuce production enterprises.

Poor soil nutrient on smallholder farms causes a decline in food production in Africa (Sanchez *et al*., 1996). The low yield is also attributed to factors such as poor soil health, insect pests, diseases, price fluctuation, and poor storage facilities (Bosco-Bua *et al*., 2017; Mubiru *et al.*, 2015). Liu *et al*. (2010) stated that the use of synthetic fertilisers has played a crucial role in crop production and productivity since the advent of the Green Revolution. On the other hand, Breugem *et al*. (2024) observed that the excessive use of synthetic fertilisers accelerates soil acidification and affects soil micro-organisms, biochemical processes, the environment, and crop production. In a similar vein, Hernandez *et al*. (2010) stated that excessive use of synthetic fertiliser in agricultural land is an issue of concern which results in crop pollutants such as nitrate accumulation in vegetative tissues, decrease in soil fertility, as well as groundwater pollution. Mia *et al.* (2007)

reported crop yield decline for many years due to nutrient and organic matter depletion, as well as reduction in soil aggregation.

The several practices that have been proven to increase soil health and fertility include, manure application, cover cropping, and zero-tillage (Ding *et al*., 2016). Soil amendments such as rice husk biochar (RHB), poultry manure, compost, and farmyard manure are potential sustainable materials for maintaining and increasing soil health and crop yields (Trupiano *et al*., 2017). This has led to growing interest in use of RHB and other organic fertilisers as a sustainable strategy to improve crop growth, yield, nutrition, as well as soil health.

Biochar is an innovative method of enhancing soil health and is gaining popularity as a sustainable alternative to synthetic fertilisers. It is also used to reduce carbon emissions in the atmosphere through carbon sequestration (Crombie *et al*., 2015). The use of RHB in vegetable production has positive effects on yield (Yan *et al*., 2021). Zheng *et al*. (2011) stated that application of biochar is similar to the traditional "slash-and burn system" of crop production. Rombel *et al*. (2022) reported that the use of RHB helps to retain nutrients (nitrogen, phosphorus, carbon) in the soil and makes them available for plant growth and development, which paves the way for the reduction of synthetic fertiliser use. Therefore, RHB has a high potential to improve soil health and productivity in agriculture (Rombel *et al*., 2022).

Poultry manure is one of the organic fertilisers used in soil amendment. Its utilization immensely improves soil fertility. Khan *et al*. (2023) and Wanikar *et al*. (2024) stated that the utilization of poultry manure ameliorates soil degradation, as well as improves organic matter content and essential nutrients. Soil degradation and low fertility problems often arise from farming practices such as over-cropping or continuous cultivation of harvested crops on a particular piece of land (El-Radaideh *et al*., 2014).

Compost is an important soil amendment material that helps to regenerate soil nutrients and maximize crop production. Furthermore, active microbes present in compost materials influence the metabolic activities within the soil (Zhang *et al*., 2020). The positive utilization of compost materials in vegetable production leads to the reduction of synthetic fertiliser application to the soil, thus reducing the risks of soil degradation and nutrient leaching, while maintaining soil quality (García-López *et al.*, 2023).

Farmyard manure (FYM) is one of the most useful organic matter that is formed from different animal wastes such as animal dung and urine alongside litter-beddings and leftover materials from roughage or fodder fed to animals. Masood *et al*. (2014) reported that when farmyard manure is incorporated in the soil, it improves physical and chemical properties. Farmyard manure is not only primarily for improvement of soil nutrient content, cation exchange capacity, or biological aspects of the soil (Zhang *et al*., 2020), but it is also meant to increase soil-available water capacity (Blanco-Canqui *et al*., 2015).

Vegetable production depends on optimum utilization of fertiliser. However, lettuce production farms have poor soil nutrients, which hinder meaningful production. Therefore, this study assessed the use of charged biochar, poultry manure, compost, and farmyard manure in improving production and maximizing yields of lettuce. This research will provide valuable insights into sustainable agricultural practices that enhance lettuce growth, yield, quality, and profitability. Also, it will provide an understanding of the effects of charged biochar, poultry manure, compost, and farmyard manure as eco-friendly farming techniques in promoting soil health as well as long-term sustainable agriculture. In addition, this study will address the porous nature of the soil that persists within lettuce production areas. Therefore, this soil amendment approach will help farmers, agronomists, and policymakers to make informed decisions about use of charged biochar, poultry manure, compost, and farmyard manure. It will also help farmers to maintain the most sustainable and effective approach, while considering environmental and economic factors in the maximization, utilization, and sustainability of lettuce production.

1.2. Statement of the Problem

Lettuce production farms face poor soil fertility due to intensive cultivation and heavy application of synthetic fertiliser. This leads to a deficiency in soil nutrition and microbial activities, especially around the rhizosphere, and ultimately high production costs, low yields, and food insecurity. Lettuce producers put all their efforts into the application of synthetic fertilisers. The excessive application of synthetic fertilisers affects soil fertility. Consequently, a lot of challenges are faced by farmers such as poor soil nutrients. Moreover, excessive application of synthetic fertilisers poses significant risks to human and animal health, as well as the environment by polluting water bodies through leaching and runoff. Excessive application of synthetic fertiliser can lead to accumulation of nitrates in lettuce, especially in the edible leafy part, which can pose health risks to consumers. Additionally, inadequate and inefficient use of synthetic fertilisers impairs the nutritional profile of lettuce, as toxic nitrates accumulate in leaves and reduce overall quality. Poor soil fertility exacerbates these challenges, as it limits the availability of essential minerals and vitamins that are crucial for plant growth and human nutrition, respectively. Despite these observations on adverse effects of synthetic fertilisers, comparison of charged-biochar and other organic fertilisers in restoring poor soil health and fertility in lettuce production farms has not been done. This pending investigation in lettuce constitutes the research gap that this experimentation was aimed to fill.

1.3. Objectives

1.3.1. General objective

To contribute to food security, nutrition, income, and environmental conservation through the use of emerging soil amendment techniques in lettuce production.

1.3.2. Specific objectives

i. To determine the effects of nutrient source (charged biochar and selected organic fertilisers) on soil properties.
ii. To determine the effects of nutrient source (charged biochar and selected organic fertilisers) on the growth, yield, and quality of lettuce.
iii. To determine the net economic benefit (profitability) of using charged biochar and selected organic fertilisers in lettuce production.

1.4. Hypotheses

i. There is no significant difference in effects of nutrient source (charged biochar and selected organic fertilisers) application on soil properties.
ii. There is no significant difference in the effects of nutrient source (charged biochar and selected organic fertilisers) on the growth, yield, and quality of lettuce.
iii. There is no significant difference in the net economic benefit (profitability) of charged biochar and selected organic fertilisers in lettuce production.

1.5. Justification of the Study

Despite the availability of a conducive climate and water distribution system, many lettuce cultivation schemes have not achieved their full crop growth and yield potential of between 10 and 35 tons/ha (Gallo *et al*., 2022) due to poor soil fertility. This poor soil fertility not only affects crop growth and yield but also compromises the nutritional quality of lettuce. The excessive utilization of synthetic fertiliser leads to the porous nature of the soil which results in soil degradation (runoff, leaching, poor ploughing), and low-income generation (Breugem *et al*., 2024; Liu *et al*., 2010). The limited knowledge of farmers on the adverse effects of excessive synthetic fertiliser in production has negatively impacted the growth, yield, and nutrition quality of lettuce. To overcome these challenges, the use of charged biochar and other organic fertilisers was proposed to help improve lettuce production. Organic fertilisers are easily accessible to farmers with less capital involvement compared to synthetic fertilisers. Also, organic farming is more effective in amending the soil for sustainable agricultural production, as well as climate change mitigation.

The aim of this research was to provide insights into sustainable agricultural practices that enhance soil health and boost lettuce production. One of the fundamental approaches to sustainable agricultural production is the amendment and regeneration of soil health (Ding *et al*., 2016; Rombel *et al*., 2022). This study might contribute valuable knowledge on the utilization of charged biochar and organic (compost, poultry, and farmyard manure) fertilisers, which might help to remedy the poor soil fertility by addressing the porous nature of the soil and its nutrient deficiencies. Furthermore, this research aligns with the Kenyan Vision 2030 and the United Nations Sustainable Development Goals (SDGs) (United Nations, 2015). Promoting sustainable agricultural practices directly contributes to achieving SDGs 2, 12, and 13 (Zero hunger; Responsible consumption and production; and Climate action, respectively) by enhancing agricultural productivity and food security through improved crop management, as well as adoption of climate-smart agricultural practices. Climate-smart agricultural practices help minimize environmental degradation and prevent long-term poor soil fertility. The utilization of charged biochar and organic fertilisers might not only address poor soil fertility issues but also contribute to the long-term sustainability of lettuce production enterprises. Therefore, the anticipated outcomes of this research include the regeneration of soil health, as well as increase growth, yield, quality, and profitability of lettuce (*Lactuca sativa* L).

CHAPTER TWO

LITERATURE REVIEW

2.1. Overview of Lettuce (*Lactuca sativa* L.)

Lettuce is the common name given to plants of the genus *Lactuca* in the flowering plant family *Asteraceae* (alternatively called *Compositae*) and mostly refers to *Luctuca sativa* plants with edible, succulent leaves (Katz & Weaver, 2003). The *Asteraceae* family is recognized as one with the most valuable leafy vegetables that are grown globally (Kuo *et al*., 2022; USAID, 2019). There are different varieties of lettuce including black-seeded simpson, butter crunch batavia, and iceberg (Gumisiriza, 2023). Lettuce is an annual and self-pollinating plant. It is grown across the globe, especially in sub-tropical and temperate regions. In this regard, the temperature requirement for lettuce seeds to germinate lies between 7 and 24°C (Hassan *et al*., 2021).

Mou (2008) stated that lettuce production within the globe is approximately 22 million tons and China is the major producer, while Africa roughly produced about 270 metric tons in 2005, which is relatively low. Han *et al*. (2021) also indicated that the USA produces four times less, and almost half of the world's production is done by China. Lettuce has different characteristics such as colour and texture. The vegetative parts are mainly consumed, either fresh as a salad or in cooked form. It is consumed for its nice aroma, crispness, and high phytonutrients (Di Gioia *et al*., 2020), besides its rich minerals, fiber, and vitamin C (Di Gioia *et al*., 2020).

In Sub-Saharan Africa, the population which is roughly 900 million people is expected to increase by 70% and predominantly live in urban and suburban centers, particularly in the Least Developed Countries (Roy *et al*., 2009). With the increase in population, people's requirement of farmland, water, and food are expected to increase (Madulu *et al*., 2004; World Bank, 2017). Therefore, due to the increasing demand for food, especially vegetables in the face of impacts from climate change alongside population pressure (Bizikova *et al*., 2020), there is a need to venture into smart agriculture technologies that will increase crop production and food security in Africa. This fact notwithstanding, the availability of vegetables has steadily been inadequate in Africa to meet the human-recommended consumption rates (Mason-D'Croz *et al*., 2019). In Kenya for instance, lettuce is not widely consumed, compared to other vegetables, due to its low supply and high purchasing price (Muthoni, 2022; Onyango *et al*., 2023).

In the Gambia, which is one of the Sub-Saharan Africa countries, agriculture plays a crucial role in the economy by accounting for approximately 30% of GDP. Nearly 46.4% of the Gambian population is working in the agricultural sector, and more than 80% reside in rural areas of the country (WACOMP, 2023). According to FAO (2019), vegetable production in the Gambia is estimated to be 13,515 metric tons per cropping season. Fatty and Ode (2018) reported that vegetable production in the dry and wet seasons in the "Sukuta" Women's Horticultural Garden varies in terms of yield per hectare (Tables 1 and 2). Of these, lettuce production area and yields per hectare remain very low. This fact justifies the need to develop technologies that would boost acreage and productivity.

Table 1: Dry season vegetable production in Gambia, 2005-08

Crop	Area (ha)	Total yield (ton/ha)	Average yield (ton/ha)
Tomato	1.45	24.30	16.76
Cabbage	0.06	23.90	398.33
Lettuce	0.45	73.80	164.00
Onion	1.25	10.10	8.08
Egg plant	0.75	6.50	8.67

Source: Fatty & Ode, (2018)

Table 2: Wet season vegetable production in Gambia, 2005-08

Crop	Area (ha)	Total yield (ton/ha)	Average yield (ton/ha)
Tomato	0.50	16.20	32.40
Cabbage	0.55	3.70	6.73
Lettuce	0.50	18.60	37.20
Onion	-	-	-
Egg plant	0.55	3.70	6.73

Source: Fatty & Ode, (2018)

2.2. Lettuce Origin, Usage, Distribution and Production

Vernon (1999) stated that lettuce has been in production for more than 500 years and it originated in Europe, Asia, and Northern Africa. Ancient cultivars that are commonly grown on open fields and domesticated for industrial purposes lend weight to this theory. The existence of these cultivars suggests that they descended from wild lettuce, most likely *Lactuca serriola* L.

(pink lettuce). Other researchers indicated that lettuce originated from the Mediterranean region and the Portuguese or the British most likely introduced lettuce to India during the 16th century (Lindqvist, 1960). Presently, lettuce is produced in the entire globe with different soil and climatic conditions. This remarkable distribution requires technology to adapt to such diverse conditions. The different climatic conditions are one of the major reasons producers and researchers have different cultivars that are adaptable to various climates (Masarirambi *et al*., 2012).

Lettuce leaves are most commonly consumed, but in countries like China and Egypt, stems are consumed as well (Bhatta, 2022). Lettuce is rich in vitamins A, B-complex, C and K; thiamine, riboflavin, folate; minerals potassium, calcium, manganese, and iron, and also other benefits such as anti-inflammation, low cholesterol, antioxidants, reduced insomnia, anti-cancer, and anxiety control (Azarmi-Atajan & Sayyari-Zohan, 2020; Cera, 2022; Sapkota *et al.*, 2019). Lettuce leaf is used as a cigarette that does not contain nicotine; seeds are used for oil production, while latex derived from the stem of lettuce is used in making sedatives (Bhatta, 2022). Aćamović-Djoković *et al.* (2011) and Kim *et al.* (2016) stated that lettuce is highly valued due to its taste and richness in cellulose and protein. The edible parts of lettuce contain 94% water, 1.8% protein, 2.9% carbohydrate, 300-1500 IU vitamin A, 0.09 mg of thiamine, 10 mg of minerals, 50 mg of calcium, and 2.0 mg of iron (Giro, 2017).

Shatilov *et al.* (2019) stated that almost 21 million tons of lettuce are produced per year worldwide, mainly under temperate climatic conditions. The world's leading lettuce producing countries (100 top producers), only 14 are in Africa (Noumedem *et al.*, 2017). In 2014, Tunisia produced approximately 75,000 tons, and in 2019, production increased by 15.3% compared to 2018. Tunisia lettuce production increased as well as exports which grew by 9.2% between 2017 and 2019 production seasons. Lettuce is one of the vegetables that attract many farmers in South Africa due to its high demand for consumption as raw salad or after blending with other vegetables (MM, M. & Du Plooy, 2008). Additionally, it is well-known for its delicate, crispy texture, slightly bitter taste, milky juice, and freshness, which make it a popular salad and dietary dish. In Gambia, lettuce is mostly produced by small-scale growers, who apply 15N:15P:15K at a rate of 200 kg/ha plus selected organic fertilisers, except biochar (WACOMP, 2023). In Kenya, lettuce is grown using 12N:12P:12K at a rate of 454-908 g per 30 m^2 of soil, with suitable soil pH ranging from 6.0 to 6.8 (Starkeayres, 2014). The use of biochar is still not a standard additive.

Vegetable production area in Kenya has increased from 164,478 to 177,022 ha by 2023, reflecting 7% increase, while volume produced decreased from 3,209,165 in 2022 to 2,886,971 MT in 2023, reflecting 10% decrease (Table 3) (AFA-Horticultural Crops Directorate, 2024). There is therefore a need to try new technologies to reverse the trend and boost production.

Table 3: Summary of vegetable production in Kenya, 2022/23

Crop	Area (hectare)		Volume (metric tons)		Value (KES) million		% of total
	2022	2023	2022	2023	2022	2023	value (2023)
Tomato	28,331	30,679	616,617	536,821	22,521.70	23,485.39	29.5
Carrot	5,682	4,771	93,965	91,026	1,759.15	2,188.93	2.8
Lettuce	-	23	-	199	-	-	0.0
Cabbage	34,848	29,695	1,382,066	1,012,822	15,857.19	15,556,68	19.6
Kales	38,586	44,509	609,272	733,503	13,398.21	15,057.00	19.0

Source: AFA-Horticultural Crops Directorate, (2023)

The export of vegetables increased from 61,819 in 2022 to 147,693 MT in 2023. The increase in vegetable production earned 23.5 million Kenyan Shilling (KSh) in 2022 and 41.2 million KSh in 2023, reflecting a significant increase in value of 17.7 million KSh (Table 4). However, the contribution of lettuce to the export volume and earnings remains very low, and hence the need to try new technologies (AFA-Horticultural Crops Directorate, 2023).

Table 4: Summary of vegetable exports by category, 2023

Vegetable	Volumes (MT)	Value (million KSh)	% of total value
Tomato	23	5.26	0.0
Carrot	101	8.42	0.0
Lettuce	2	0.450	0.0
Chilli	1,347	423	0.8
Onion	1,242	83	0.2

Source: AFA-Horticultural Crops Directorate, (2023)

2.3. Soil Degradation

This is a process by which production land loses its natural state through erosion, either by wind or runoff, as well as reduction/decline in the quality of soil nutrients and use of non-recommended production practices (Tully *et al*., 2015). Soil degradation is a major global challenge in the least developing countries, where large proportions of the population gain their livelihoods directly from the soil (Tully *et al*., 2015). In Sub-Saharan Africa, it results in a decline in crop productivity, which has been linked to hunger and poverty. Sanchez *et al.* (2003) reported that almost 40% of soils in SSA are limited in nutrient reserves (<10% weatherable minerals), 25% are affected with aluminum toxicity, and 18% have a high leaching potential (low buffering capacity). Tully *et al*. (2015) and Zingore *et al*. (2007) stated that farm management practices play a crucial role in soil degradation and may vary greatly between production seasons.

Synthetic fertilisers have played a significant role in increasing crop production since the "green revolution" (Liu *et al*., 2010). However, they are not a sustainable solution for the maintenance of crop yields (Vanlauwe *et al*., 2010). Long-term overuse of synthetic fertilisers may accelerate acidification, thereby affecting soil biota, biogeochemical processes, environment, and decreasing crop yield (Pietri & Brooks, 2008). Due to the easy and quick absorption of inorganic fertilisers, in the long-run they degrade the soil structure and cause poor soil fertility. Organic fertilisers such as compost and biochar could be useful materials to sustainably maintain or increase soil organic matter, thereby preserving and improving soil fertility and crop yields.

2.4. Overview of Biochar Soil Amendment

Biochar has been in existence for almost 200 years as a soil improvement material and has a mean residence time estimated at 3000 years, owing to its stable nature and release of nutrients at a low rate within the soil (Kavitha *et al*., 2018). Biochar is a carbon-rich material generated from various raw materials such as rice husk, straw, small tree branches, barks, and groundnut shells through pyrolysis (Sohi *et al*., 2010; Sohi *et al.*, 2009). It is a resilient type of organic material produced under controlled conditions at over 250°C, and has been shown to increase crop yield and minimizes emissions from agricultural products (Hossain *et al*., 2019).

In recent years, biochar has become an important amendment with capacity to maintain soil physical characteristics such as porosity, water holding capacity, bulk density, and aggregation, as well as chemical characteristics, heavy metal adsorption capacity, pH improvement, and cation exchange capacity (Tables 5 and 6), thereby optimizing crop yield (Zheng *et al.,* 2011). Soil porosity could be lowered by the micro- and macro-pores in the structure of biochar. Consequently, biochar improves the availability of water in the soil (Novak *et al*., 2012). Biochar can increase the porosity of the soil as well as the capacity of soil to hold or retain water (Herath *et al*., 2013). Therefore, adding biochar to the soil increases soil moisture content up to 15% compared to soil without biochar.

Biochar also reduces soil bulk density. Atkinson (2014) stated that the high porosity nature of biochar and its low bulk density (~0.3 Mgm-3) have the potential to decrease soil bulkiness. Soil aggregation refers to a group of soil particles that are anchored or bound to each other. It is mostly influenced by microbial load, organic matter, soil type, and the presence of exchangeable cations (Verheijen *et al*., 2010). It is influenced by the type of micro-organisms and the kind of microbial synthesis in the soil (Ding *et al*., 2016).

Table 5: Properties before the experiment

Treatment	Nitrogen (mg/kg)	Potassium (mg/kg)	Magnesium (mg/kg)	Cation Exchange Capacity (meg/100 g)	pH
Control	19	206	345	16.3	5.8
Biochar	39	326	274	15.4	5.7
Fertiliser	34	172	527	21.1	6.0

Source: Zheng *et al*. (2011)

Table 6: Properties after the experiment

Treatment	Nitrogen (mg/kg)	Potassium (mg/kg)	Magnesium (mg/kg)	Cation Exchange Capacity (meg/100 g)	pH
Control	21	198	310	15.2	5.4
Biochar	12	259	318	16.1	6.1
Fertiliser	58	175	456	17.7	5.8

Source: Zheng *et al*. (2011)

Biochar is said to be very efficient in the removal of heavy metals from aqueous environments (Regmi *et al.,* 2012). Ameloot *et al.* (2013) reported that biochar can absorb heavy metals such as copper, lead, mercury, and cadmium, as well as other harmful organic pollutants from aqueous environments. Biochar improves the cation exchange capacity in the soil. At low pH levels within the soil, the functional groups present in biochar are positively charged ions. Kołodyńska *et al.* (2012) stated that the temperature at which pyrolysis is undertaken influences the structural and elemental properties. Regarding pH improvement, the application of biochar has a great possibility of substituting liming materials (Agusalim *et al*., 2010; Zheng *et al*., 2010).

Biochar is also used in sequestration of carbon, thereby mitigating its effects in the ozone layer (Ennis *et al*., 2012; Malghani *et al*., 2013; Sheikh *et al*., 2014). The knowledge acquired in the production of biochar by farmers is often incorporated into crop production systems. Some developing countries such as Bangladesh concentrate on the agronomic and environmental impact of biochar utilization rather than focusing on greenhouse gas mitigation (Hossain *et al.*, 2019).

Biochar serves as a promoter of crop plant growth and development (Schulz *at el*., 2013). It has potential for enhancing soil quality and immobile elements that are re-mobilized for crop plant utilization. The various sources of biochar raw material are considered during crop production. Similarly, the amount of biochar utilized depends on different soil types, whereby acidic soil (13%), neutral pH (13%), coarse soil (10%), and medium texture (13%) is recommended (Hossain *et al.*, 2019). Ultisol requires a high rate (4%) of biochar, produced at a very high temperature (800°C). In this regard, application of biochar on sandy Ultisol soil reduced the biomass of corn/maize, but it had the opposite effect in clayey Oxisol soil (Hossain *et al.*, 2019). Furthermore, chicken litter-biochar exhibited the most notable effect of about 28%, compared with other raw materials like gasified wood and biosolids (Hossain *et al.*, 2019). Additionally, application of biochar reduced rice grain yield by 24.7% in spring and 17.9% in summer, but it had the opposite effect on vegetable crops (Hossain *et al.*, 2019). The impact of biochar in vegetable crops is different on vegetative growth, yield, and quality of fruits. Biochar improved soil quality and promoted the growth and development of tomato plants, but it had no positive effects on the yield and quality of tomato fruits (Vaccari *et al*., 2015).

Arising from the fact that biochar utilization enhances crop productivity through soil improvement, many researchers, policymakers, and vegetable farmers worldwide are considering it, leading to the attraction of many researchers in recent years (Kamara *et al*., 2015). Consequently, farm residues are transformed into biochar and incorporated into the soil to make it more sustainable and environment-friendly (Lehmann *et al*., 2011; Singh *et al*., 2010). Soil management using biochar is becoming interesting; many research studies have reported negative effects, several research gaps, as well as uncertainties in crop production. Therefore, more research is needed, especially on the porous nature of soil and other long-term effects (Ding *et al*., 2016). Zheng *et al*. (2010) also stated that there is a need for further research on the long-term effects of biochar as a soil amendment material for improvement of soil health and crop yield.

2.5. Organic Fertiliser Soil Amendments

These are forms of manure that are used in the production of vegetables, cereals, and other crops. The organic fertilisers used in soil amendment are obtained from diverse biomasses, including compost, wood chips, biochar, animal feaces, hay, husk, and geotextiles (Al-Tawaha *et al*., 2024; Qaisi *et al*., 2023; Singh *et al*., 2024). Both subsistence and commercial farming enterprises rely on organic fertilisers for enhancing crop production (Eliot, 2005). Organic fertilisers contain basic nutrients that are beneficial in improving crop productivity. Some of the well-known compounds in organic fertilisers are amino acids, organic matter, and minerals (Table 8). Organic fertilisers accelerate growth and development of crops, as well as improve soil structure, texture, aeration and microbes (Al-Bayati, 2009). Cera (2022) stated that organic fertilisers enhance crop production as well as ability to supply basic essential nutrients for plants growth, development, yields, as well as physical, chemical and pH neutralization (Table 7).

Table 7: NPK content in organic fertilisers

Organic fertiliser	Nitrogen content (N) %	Phosphorous content (P_2O_5) %	Potassium content (K_2O) %
Compost	2.0	0.5 – 1	2.0
Poultry manure	3.03	2.63	1.4
Farmyard manure	0.5	0.2	0.5

Source: Cera, (2022)

Essential elements in organic fertilisers not only benefit agriculture and the environment but also help reduce the risk of chemical contamination of micro- and macro-organisms, as well as surface and groundwater bodies, which then increases their utilization in agricultural production systems (Al-Chalabi *et al*., 2023). Since 1990, organic fertilisers have improved about 20% of the physical properties of the soil and crop plant metabolic processes (Al-Chalabi *et al*., 2023).

Table 8: Biochemical analysis of soil, biochar, compost, and poultry manure

Biochemical analysis	Soil	Biochar	Compost	Chicken manure
N (mg/kg)	0.072	1.393	0.821	5.685
P (mg/kg)	1.42	620.82	568	1644.65
K (mg/kg)	54.95	132.9	167.65	744.45
Mg (mg/kg)	28.95	137.1	127	685.95
Ca (mg/kg)	1512.76	725.9	82.82	3968.72
Na (mg/kg)	419.65	108.32	125.95	820.62
Organic Matter	3.422	-	41.507	11.853
Carbon : Nitrogen	27,63	39.1	29.39	1.21

Source: Alomari *et al.* (2024)

An experiment conducted by Islam *et al*. (2012) stated that organic fertiliser has positive effects on the growth, development, and yield of lettuce plants compared with synthetic/ chemical fertilisers. Another experiment was conducted on lettuce with different levels of organic fertilisers (6.5, 13, and 26 ton/ha) and concluded that 13 ton/ha increased leaf diameter and overall crop marketable weight (Al-Chalabi *et al*., 2023).

Under-developed countries experience an increase in the price of synthetic fertiliser, which hinders subsistence farmers from purchasing the maximum quantity for crop production (Bosco Bua *et al.*, 2017). As a result, the use of different fertiliser management approaches is necessary for the optimization of crop production. Soil amendment using organic materials regenerates nutritional characteristics, which many countries see as an important approach (Mohd *at el*., 2002). Organic fertilisers (Table 8) are among the most vital alternatives for smallholder farmers because they are affordable and improve the physical, chemical, and biological properties of the soil (Ahmed *et al*., 2013; Islam *et al*., 2017). Furthermore, organic fertilisers enhance soil health, which gives rise to increase in food production, overall income, as well as the health and livelihood of farmers (Islam *et al*., 2017; Piash *et al.*, 2019).

Organic fertilisers supply many nutrients and have significant effects on soil amendment (Al-Taey *et al*., 2018). The availability of organic matter in organic fertilisers has positive effects on soil moisture retention, nutrition, and soil physical properties (Al-Taey *et al*., 2022). Utilization of organic fertilisers is an essential component of sustainable agricultural practices (Masarirambi *et al*., 2012). However, the persistent nature of organic fertilisers is influenced by temperature, drainage, rainfall, drought, and floods (Masarirambi *et al*., 2012). Examples of organic fertilisers include poultry manure, compost manure, and farmyard manure (Table 8).

2.5.1. Poultry manure

Animal manures have been used for plant production effectively for centuries. The use of organic fertiliser such as poultry manure improves the soil organic matter content and other essential nutrients (Khan *et al*., 2023; Wanikar *et al*., 2024). Poultry manure has long been recognized as natural fertiliser, because of its high nitrogen content (Table 8) (Alomari *et al*., 2024). Poultry manure comprises of 3.5% N, 1.5 – 3.5% P; 1.5 – 3.0% K, and micronutrients (Mohammed *et al*., 2010). The utilization of poultry manure is an integral part of sustainable agricultural production (Masarirambi *et al*., 2012). The economics of using poultry manure varies considerably based on raw material constituents, which normally could be bedding litter, sawdust, wood shavings, grass cuttings, banana leaves, or groundnut shells.

Poultry manure is an excellent source of nitrogen, phosphorus, potassium, sulfur and a pH of 6.5 to 8.0 (Anonymous, 2008). This approach facilitates reintegration of main substances, such as organic matter and other nutrients, back into the soil to regain its health. It also improves soil structure, nutrient retention, aeration, water-holding capacity and infiltration (Deksissa *et al*., 2008). Garg and Bahla (2008) reported that poultry manure contains higher phosphorus, which is eventually supplied to plants, compared to other organic fertilisers. John *et al*. (2004) also reported that poultry manure contains macronutrients that are associated with high photosynthetic activities in plants, as well as root and vegetative growth. Treated poultry waste, such as litter and beddings, have the potential to amend the soil for sustainable farming operations.

2.5.2. Compost manure

The world population as well as food consumption are rapidly increasing, while climate change is affecting soil nutrients through depletion caused by run-off, floods, droughts, and excessive use of synthetic fertilisers. Based on the effects of climate change, soil amendment is required to sustain maximum crop growth and yield through the application of organic fertilisers rather than synthetic fertilisers (Alomari *et al*., 2024). Ceesay *et al*. (2017) stated that the recommended requirement of compost is 5 – 10 kg per 5 m² bed, which is equivalent to 20 ton/ha. Compost is an important soil amendment material that helps to regenerate soil nutrients and maximize crop production. Furthermore, compost provides abundant active microbes that influence the metabolic activities of the microbial community (Zhang *et al*., 2020). This strategy makes it possible to reduce the rate of synthetic fertiliser application to the soil, thus decreasing the risks of soil degradation and nutrient leaching, while maintaining soil quality (García-López *et al.,* 2023). Compost contains nutrients that are released slowly into the soil and from where they can be absorbed after mineralization. Compost is more productive than synthetic fertiliser due to its long-term provision of nutrients within the soil. It also improves soil texture, structure, water-holding capacity, aeration, crop growth, and yield (Escobar *et al*., 2007). A comparison of compost use versus other organic fertilisers, especially charged biochar application, in lettuce production has not been done; thus, further research is required.

2.5.3. Farmyard manure

Farmyard manure (FYM) is produced entirely from farm materials such as animal dung and urine, alongside litter-beddings and leftover materials from roughages or fodder fed to animals such as cattle, sheep, and goats. Farmyard manure is one of the organic fertilisers that is vital in soil amendment approaches; it not only improves soil health but also has the potential to increase the population of beneficial soil micro-organisms within the rhizosphere (Funda *et al*., 2011; Shaheen *et al*., 2007). Animal by-products have been used for many years as sources of farmyard manure, which serves as a good nutrition for plant growth and development. Masood *et al*. (2014) reported that short-term application of higher FYM levels such as 10 – 20 ton/hectare improves soil properties, including nutrient content, cation exchange capacity, biological aspects, soil-available water capacity, as well as availability and use of water by plants (Blanco-Canqui *et al*., 2015; Zhang *et al*., 2020). It is easy to acquire, which makes it preferable to farmers and producers. The risks of utilizing synthetic fertiliser and increasing farmers' awareness of environmental and health issues have increased the demand for organically produced vegetables. Therefore, the use of FYM has been in use for many years as a safe alternative. It is an integral part of sustainable agriculture, where it improves the physical and chemical properties of the soil, as well as reduces the application of synthetic fertilisers. In addition, farmyard manure is used as a soil amendment (Cabecinha *et al*., 2010; Costa *et al*., 2008), and source of nutrients, especially nitrogen (Brito *et al*., 1999; Guerrero *et al*., 2002).

These effects notwithstanding, the weak carbon bonds of FYM reduce its retention in the soil and hence amendment should be repeated at the beginning of each production season (Erguler *et al*., 2024). Nonetheless, utilization of FYM immensely improves yield and maximizes crop production based on the stable nature of the nutrients present and persist within the soil for many years. These effects can support healthier and more efficient development of lettuce crop productivity (Erguler *et al*., 2024). Farmyard manure pH ranges from 6.85 to 7.27, which is conducive for growth of many crops. Additionally, it is well known for its effects, availability and easy acquisition compared to synthetic fertilisers. However, the right rate of FYM to use on small-scale and commercial scale for some crops is still not known (FAO, 2000).

2.6. Nutritional Quality of Lettuce

Lettuce is one of the vegetable crops that is grown for its dietary importance and health benefits. Lettuce is cultivated globally, despite being regarded as having low nutritional content, but high moisture (90%-95%) content (Kim *et al*., 2016). On the other hand, Mwadzingeni (2021) stated that lettuce is one of the most nutrient-rich vegetables with the potential to decrease malnutrition, especially in children under 5 years old. It contains biologically active compounds, vitamins, minerals, and organic substances, which make it a considerably nutritious crop (Pinto *et al*., 2014; Pinto *et al*., 2015), equivalent to other nutritious vegetables. Owing to a rapid increase in global population and limited crop production area, it is necessary for the small quantity of crops produced to have maximum nutrients that consumers will benefit from after utilization (Tirono & Mulyono, 2023).

The nutritional and market quality of lettuce relates not only to head size and appearance (Camejo *et al*., 2020; Koudela *et al*., 2008), but also to vitamin and mineral-nutrient contents (Simko, 2019), and the maintenance of nitrate and nitrite concentrations in leaves at unharmful levels (Colonna *et al*., 2016; Konstantopoulou *et al*., 2010). Moreover, leaf colour, caused by the balance of chlorophylls, anthocyanins, and carotenoids can also influence the quality of leaves as pigmentation is often associated with the presence of antioxidant compounds (Liu *et al*., 2007; Llorach *et al*., 2008; Schreiner *et al*., 2006; Zhu *et al*., 2016).

Lettuce is important in diet due to the phytonutrient content present, which is used to protect body cells from damage. Phytonutrients/phytochemicals in lettuce plants provide human bodies with various health benefits, including the provision of flavonoids, phenolic compounds, carotenoids, vitamins, and fiber (Mitra *et al*., 2021). Antioxidant compounds present in lettuce when ingested contribute to body health by controlling free radicals (Bogdanovic *et al*., 2010). In this regard, vitamin C (ascorbic acid), beta-carotene, lutein and zeaxanthin, quercetin, kaempferol, chlorogenic acid, and polyphenols are all examples of antioxidants. Consequently, consuming lettuce in diets plays an important role and balances nutrients in daily meals. Vitamins play several roles in the human immune system, including the formation of collagen, the absence of which can cause defects in bone and capillary systems such as weak bones, swelling of joints, gums, and bleeding (scurvy). Llorach *et al*. 2008 stated that various varieties of lettuce have different quantities of vitamins that the human body can absorb for metabolic processes, as well as to minimize the effects of pathogen (Tables 9 and 10).

Table 9: Vitamin content expressed in mg/100 g of different fresh lettuce varieties

Lettuce type	Plenti-Butterhead	Murai/Red	Temptation	Levistro	Kibou
Vitamin C (mg/100 g	3.85	3.50	4.99	9.60	5.25

Source: Llorach *et al.* (2008)

Table 10: Vitamin C content in mg/100 g of different fresh vegetables

Vegetable	Vitamin C
Tomato	23
Carrot	4
Potato	15

Source: Llorach *et al.* (2008)

Vitamins have antioxidants for controlling free radicals in the immune system, as well as the minerals Se and Zn (Aćamović-Djoković *et al*., 2011; Bielski *et al*., 1975; Foyer, 2005).

Mampholo *et al*. (2016) stated that popularly grown varieties (icebergs, green leaves, romaine, and red leaves) are good sources of vitamins. Organic fertilization is an approach used to increase nutrient contents in vegetables such as lettuce, kale, and cabbage (Tirono and Mulyono, 2023).

In Kenya, almost 94% of the adult population does not meet the World Health Organization's standard of consuming fruits and vegetables of 400 g daily. In 2015, a national survey conducted by the Global Alliance for Improved Nutrition (2022) in Kenya found that 50.9% consumed vegetables daily, while 15.3% consumed fruits. The average consumption of vegetables and fruits per day per week was 4.96 and 2.52, respectively. On average, a person has 1.31 (SD 1.1) servings of vegetables a day and 0.79 (SD 1.2) servings of fruits per day, while in the US, vegetables are 1.5 servings and fruits are one serving per day (Conrad *et al.*, 2017). In the past 15 years, consumption of vegetables has remained at 100 – 130 g per person per day, despite an increase in GDP of 46%. The awareness of Kenyans on the health benefits of vegetables is still low especially the green leafy vegetables which are seen as a poor man's food.

2.7. Economics of Lettuce Production

Net economic benefit (NEB) analysis in crops, often part of a broader cost-benefit analysis (CBA) or gross margin analysis (GMA), helps determine the profitability and overall value of a crop or farming practice by comparing its total benefits to its total costs. It is a systematic way of assessing whether the gains from a crop outweigh the expenses involved in its production. Key elements of a net economic benefit analysis in crops include identifying costs and benefits. The net economic benefit is found by subtracting the total costs from the total benefits; if the result is positive, the crop is considered profitable, while if negative, it indicates a loss. In essence, a net benefit analysis helps farmers make informed decisions about crops to grow, farming practices to adopt, and allocation of resources effectively to maximize profitability and sustainability.

Lettuce is a leafy green vegetable that is consumed largely in the US. It serves as a staple ingredient in salads, sandwiches and numerous prepared foods. Based on research done in 2022, lettuce consumed accounted for almost 20% of the $21.8 billion generated from vegetable and melon sales (USDA – NASS, 2023). The major leafy varieties such as iceberg contributed $1.33 billion, romaine $1.54 billion, and butter head $1.25 billion. Nearly 85% of the total lettuce consumed in the US is produced domestically, with California and Arizona contributing more than 90% of the national output (USDA - NASS, 2023). In 2015, the estimated per capita consumption of lettuce in the US was approximately 11.7 kg of which headed variety (iceberg) constituted about 6 kg, representing 51% of total lettuce consumed (USDA-ERS, 2016).

Production of lettuce is increasing and becoming a profitable venture in the vegetable industry in Kenya. This sector is driven by the high demand by urban dwellers, short growth cycle, and nutritional benefits. Cultivation of lettuce in Kenya is practiced in both open fields and greenhouse; most of the common cultivated varieties are iceberg, romaine, and butter head/loose leaf (KALRO, 2021). Lettuce producers such as smallholders and peri-urban farmers do so due to its high returns/output and consistent market demand from restaurants, hotels, and super-markets (SNV, 2019). In Kenya, single-headed iceberg sells for 70 to 100 Kenyan shilling in major towns such as Nakuru, Eldoret, and Nairobi (Muthoni, 2022). Based on good and favourable agro-climatic conditions, as well as good agronomic practices farmers can earn average profits, ranging from 100,000 to 150,000 Kenyan shilling per acre (KALRO, 2021; SNV, 2019).

In the Gambia, the vegetable marketing sector faces numerous structural and systemic operational challenges that reduce the NEB for smallholder farmers. These include inadequate transportation networks, inefficient market infrastructure, poor market information systems, and an undeveloped agro-processing industry, all of which have negatively impacted the distribution and profitability of vegetable produce (FAO, 2020; Fatty *et al*., 2021). Moreover, smallholder vegetable farmers often lack timely access to essential market information such as price trends, consumer demand, and optimal selling period, resulting in sub-optional decision-making and reduced profitability (Fatty *et al*., 2021; Onyango *et al.*, 2023). Consequently, despite increasing production, the inability to access high value markets and minimize transaction costs significantly undermines the net economic benefit of vegetables produced in the Gambia (World Bank, 2021).

Profitability of vegetable production system is largely constrained by the high cost of essential inputs such as seeds, fertilisers, pesticides, irrigation, hired labour, and transportation logistics. These inputs constitute the bulk of variable costs that directly influence gross margins and have a significant effect on production efficacy, yield, and economic returns (Muthini *et al*., 2020; Ogunniyi *et al*., 2012; Wainaina *et al*., 2016). Sheahan and Barret (2017) stated that gross margin analysis is widely employed in farm enterprise to determine financing viability by subtracting total variable costs from gross revenue. Among smallholder farmers across Sub-Saharan Africa, the cost of agricultural inputs is determined by several factors such as local or imported planting materials, organic or synthetic fertilisers, area planted, distance from and to the farm/market, skills and knowledge needed to effectively turn these inputs into meaningful productive crop outputs (produce) (Kassie *et al*., 2025; Muthini *et al*., 2020; Wainaina *et al*., 2016). These inputs significantly influence the affordability, accessibility, and profitability of vegetable production, especially among smallholder farmers in Sub-Saharan Africa.

Organic fertilisers originate from natural materials, whereas synthetic fertilisers are mined or processed in industries. Consequently, organic fertilisers tend to be cheaper than industrial synthetic fertilisers, as illustrated by Ksh 4,000 to 6,000 used to purchase 50 kg of synthetic fertiliser (AFA, 2023), while organic fertiliser cost ranges from Ksh 500 to 200 per 50 kg (KALRO, 2021). Smallholders do not prepare their own organic fertilisers and often rely on external sources such as agro-dealers, farmer cooperatives, commercial waste recyclers to acquire them (Kassie *et al*., 2025; Wainaina *et al*., 2016).

During crop production, it is prudent to consider the source of inputs, distance to be travelled, type of labour to use, whether skilled or non-skilled, among others. Utilization of synthetic fertilisers is more expensive than utilization of organic fertilisers in crop production (AFA, 2023; KALRO, 2021). More time and skilled labour is necessary when applying amendments to soil before planting crops. The labour costs for skilled and unskilled workers are significantly different. In Kenya, unskilled farm labour costs Ksh 300 to 500, while skilled farm labour costs Ksh 800 to 1200 (Onyango *et al.*, 2023). More time and skills are necessary in obtaining ratios, incorporating in soil, composting and other practices that require precision. This is contrary to use of non-skilled labour in growing crops on land without amendments. In this regard, engagement of more time and skilled labour is more expensive than engagement of less time and non-skilled labour (Onyango *et al.*, 2023).

Literature available on NEB of vegetable crop production using organic fertilisers in Gambia and Kenya is scanty. Consequently, the net economic benefit of charged biochar, poultry manure, compost, and farmyard manure on lettuce production in a diverse climate and production schemes needs further research.

CHAPTER THREE
MATERIALS AND METHODS

3.1. Research Site

The research was conducted in Field-3 located at Egerton University, Njoro, Kenya. The field lies at latitude 0’23’S, longitude 35’35’E, and 2238 m above sea level (Jaetzold *et al*., 2006). The average minimum and maximum temperatures at the site range from 16 – 22ºC and 5 – 8ºC, respectively, while the total annual rainfall ranges from 1180 – 1400 mm (Jaetzold *et al*., 2012). Mollic Andosols predominantly occupy the experimental site, while the soil is well-drained and friable, with moderate fertility, low level of phosphorus (0.14%), and an acidic pH, ranging from 5.0 to 6.0 (Jaetzold *et al*., 2012).

3.2. Experimental Design, Treatments, and Layout

The experiment was set up in a Randomized Complete Block Design (RCBD) with six treatments and three replications (Figure 1). Each treatment was set up in a 1.5 m × 2 m bed. The plant inter- and intra-spacing was 30 cm × 30 cm. The spacing between replications and beds was 1 m and 50 cm, respectively. The treatments (T) were: control (plain soil), positive control (farmer’s practice of NPK + urea), charged biochar, poultry manure, compost, and farmyard manure. The organic fertilisers (Table 11) were mixed into respective beds before transplanting the lettuce seedlings to the beds. The experiment was conducted in two seasons, with season 1 running from October 2024-January 2025, characterized with low rainfall, and season 2 running from February to May 2025, characterized with high rainfall.

Table 11: Quantity of material added per treatment

SN	Treatment	Quantity per bed of 3 m^2 (kg)	Quantity per hectare
T1	Farmyard manure	6.00	20 tons
T2	Negative control	0.00	0 tons
T3	Charged biochar	6.00	20 tons
T4	Poultry manure	6.00	20 tons
T5	Compost	6.00	20 tons
T6	Positive control	0.06 NPK + 0.03 urea	200 kg NPK + 100 kg urea

Source: Ceesay *et al*. (2017); Dani *et al*. (2021).

The charged biochar, compost, farmyard manure, poultry manure was obtained from Safi Organic Limited, Griincom Organic Limited, Egerton University Tatton Farm, and Petter Kirui Poultry Farm at Njoro, Kenya (0º21’27.7” S 35º57’49.6” E), respectively.

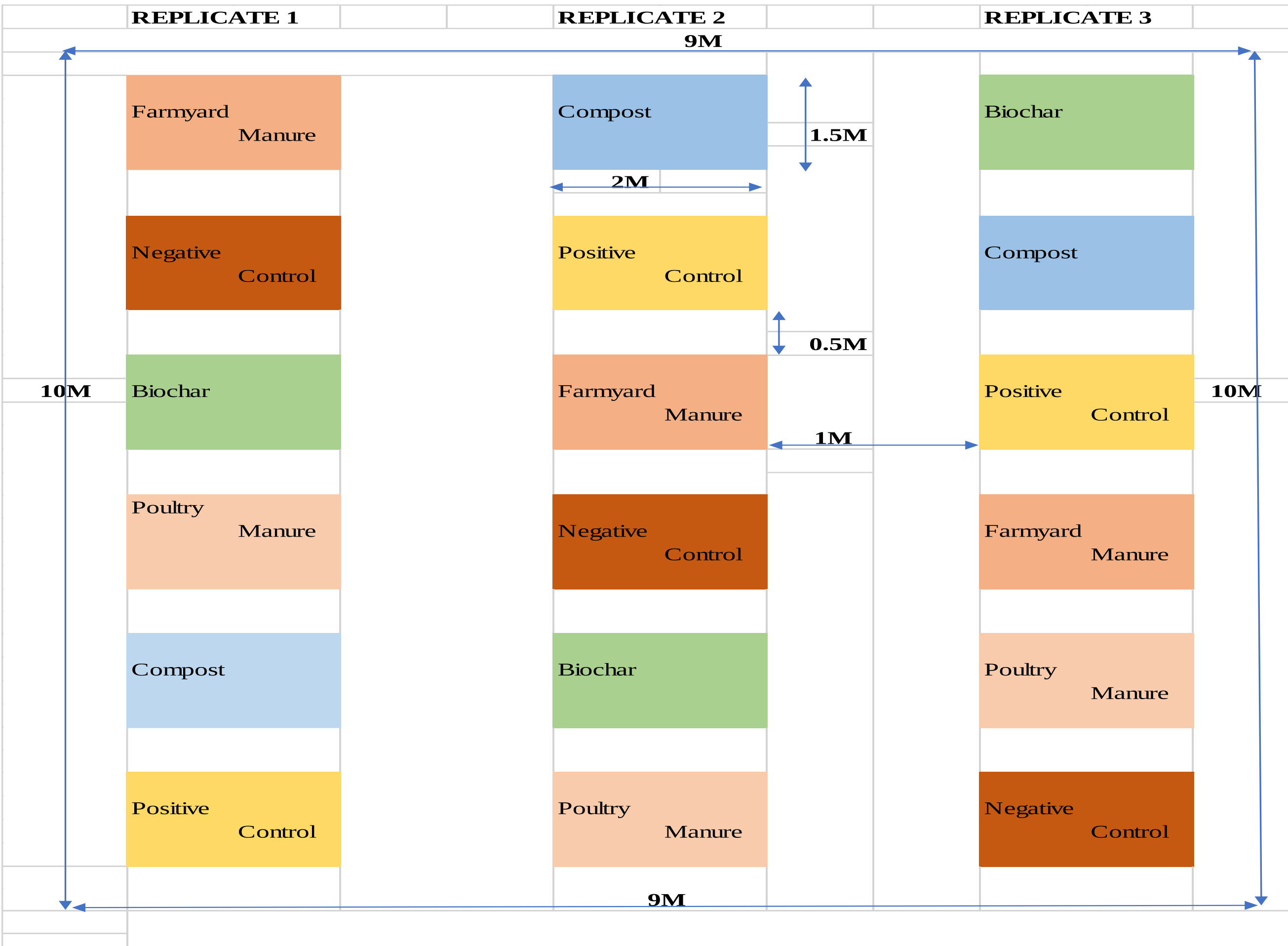

Figure 1: Experimental layout

3.3. Lettuce Establishment and Maintenance

Iceberg lettuce variety used in this research was purchased from Safari Seeds Limited in Kenya. This variety is adaptable to different climatic conditions, has a low bolting ability and crispier texture (Gumisiriza, 2023).

3.3.1. Seedling nursery establishment

The Seedling nursery bed preparation was done one week before seed sowing. The site was tilled with a hoe to a fine tilth and levelled. A sunken bed was prepared and irrigated with a hose pipe on a daily basis. The day before planting, soil was tilled to loosen the soil particles and then flattened to avoid burying seeds too deeply into the soil, which may cause poor germination. Furrow lines were made across the bed at 10 cm apart, seeds dropped gently into them and covered lightly with soil. After sowing, irrigation and shade were applied immediately. After germination in 5 – 7 days post-sowing, seed beds were weeded and weeding continued when necessary to avoid seedlings and weeds competing for nutrients, water and light. Subsequently, permanent beds were prepared at a different site for transplanting in seedlings.

3.3.2. Land preparation

The experimental site was ploughed with a hoe and leveled to a fine tilth, after which permanent beds were demarcated using a tape measure and pegs at a spacing of 1.5 m by 2 m. The requisite beds were prepared well and experimental materials (charged biochar, poultry manure, compost, farmyard manure, and NPK plus urea) added per bed as per treatments. The experimental materials were thoroughly incorporated into each assigned bed before transplanting lettuce seedlings into the bed. During transplanting, seedlings were carefully uprooted and transplanted when five-weeks-old after sowing.

Irrigation was done immediately after transplanting using a hose pipe, followed by twice daily watering in the morning and evening to maintain moist and healthy plant growth throughout the growing seasons. Weeding commenced two weeks after transplanting and was repeated on a weekly basis for eight weeks to avoid competition for nutrients, water, and sunlight.

3.4. Data Collection

Data values were collected on soil, organic fertilisers, lettuce growth, yield, and tissue for the determination of different effects as shown in the following sections.

3.4.1. Measurement of soil and organic fertiliser properties

Soil samples were collected randomly using the zigzag (Z) method. Samples were collected from seven spot to represent the whole experimental research field in terms of nutrient and other parameters present before permanent beds were demarcated. The soil was collected with an auger from 0 to 20 cm depth. The collected samples were mixed and composite sample taken to the laboratory. The composite samples were air-dried in the soil laboratory at room temperature and thereafter a 2-mm-sieve was used to sieve and remove foreign materials. Composite samples were also collected from charged biochar and organic fertilisers (compost, farmyard manure, and poultry manure) that were used in the research before application to the seedling beds. The parameters measured were pH, organic carbon, cation exchange capacity (CEC - testing salinity), organic manure, and mineral nutrients (nitrogen, phosphorus, potassium, magnesium, and calcium).

The electrometric and ammonium acetate procedures were used in the determination of pH and CEC, respectively, in soil and organic fertilisers (Gillman and Sumpter, 1986). The total nitrogen in both soils, charged biochar, and organic fertilisers was measured using Kjeldahl method (Hinga *et al.*, 1980). Standard methods and procedures were used to analyze phosphorous, potassium, calcium, and magnesium in the soil, charged biochar, and organic fertilisers (Okalebo *et al*., 2002). After harvest, soil samples were collected from experimental plots to analysis the nutrients and other parameters, as mentioned above. The N, P, K, Mg, Ca, OC, pH, CEC, OM, and C:N of soil, charged biochar, and organic fertilisers, as well as N, P, K, Mg, and Ca contents in lettuce leaf tissue were measured using different standard procedures and methods described in the following sections (Table 12).

Table 12: Summary of methods and procedure used in measurements

Parameter	Method and procedure
Ph	pH meter (Okalebo *et al*., 2002)
Nitrogen (N)	Kjeldahl (Bremner 1960)
Phosphorous, K, Mg, & Ca	Mehlich (Hinga *et al*., 1980)
Organic carbon (OC)	Walkley black (Matus *et al*., 2009)
Cation Exchange Capacity (CEC)	Ammonium acetate (Gillman and Sumpter, 1986)
Leaf diameter	Measuring ruler (cm)
Plant height	Measuring ruler (cm)
Number of leaves	Physical counting
Biomass	Weighing scale (kg)
Vitamin C	Redox titration (Reische *et al*., 2008)

(a) The electrometric method used to test pH involved a ratio of soil and water of 1:2.5. Prior to measuring the pH, buffer 4 and 7 were used to calibrate the electronic pH meter (Okalebo *et al*., 2002). The same procedure was also used to determine the pH of organic fertilisers. Sample weight of 20 g of air-dried soil or organic fertilisers was taken and stirred in distilled water in 50 ml plastic bottles. Electronic/mechanical shaker was used to mix the contents for 30 minutes and then the pH meter was measured with a pH meter.

(b) Kjeldahl's method was used to measure nitrogen (total N) (Bremner *et al*., 1960) entailed measuring a sample of 0.3 g, digesting for two hours and then cooling for 30 minutes. Distillation followed digestion and after which readings were recoded. Equation used in calculation of N was as follows:

$$\text{Total nitrogen} = \frac{(\text{Uv - Ubv}) * \text{HCl acid concentration (* dilution factor *100}}{1000 * \text{sample weight} * \text{aliqout}} \quad \text{........Equation 1}$$

Where Uv = volume used; Ubv = volume of blank used.

(c) Mehlich's III method (Hinga *et al.*, 1980) was used to extract P from samples weighing 2.5 g of air-dried soil, charged biochar, compost, farmyard, and poultry manures. Each sample was put in 50 ml plastic bottle and mixed with a scoop of activated charcoal and 25 ml of Mehlich III extracting solution. An electronic shaker was then used to mix the mixture for 30 minutes. Filtration was done through a funnel with size 2.5 µm Whatman paper. Two (2) ml of the filtrate was pipetted into 50 ml volumetric flask. Colouring reagent (10 ml) was also added, followed by distilled water to the mark of the volumetric flask. The solution in the volumetric flask was left to stand for one hour for full development of the colour (blue). The absorbance of the solution was measured using a UV-VIS spectrophotometer at a wavelength of 880 nm. Phosphorous in the solution was obtained from the standard curve. Equation used in P determination was as follows:

$$\text{Available P (mg/kg)} = \frac{\text{X} * (\text{Vex}/1000) * \text{dilution factor}}{\text{Sample weight (g)} * 1000} \quad \text{..................................Equation 2}$$

Where X = calibration curve value; Vex (ml) = volume extracted

(d) The same procedure as shown above (c), was used to determine the K, Mg, and Ca with the use of an atomic absorption spectrophotometer (AAS) at different wavelength of 766.5nm, 285.2nm, and 422.7nm, respectively. The concentration of K, Mg, and Ca in the solution was obtained from the standard curve. The equation used in determination of K, Mg, and Ca is shown below:

$$\text{K, Mg, and Ca (mg/kg)} = \frac{\text{X (calibration curve value)} * \text{volume extracted} * 1000}{\text{Sample weight (g)} * 1000} \quad \text{.......Equation 3}$$

(e) Black and Walkley (Matus *et al*., 2009) wet oxidation method was used to measure organic carbon. A sample weighing 0.3 g of soil or organic fertiliser was put in 500 ml conical flask followed by adding 10 ml of 1 N potassium dichromate ($K_2Cr_2O_7$). Additionally, 20 ml of concentrated sulfuric (H_2SO_4) was added, swirled gently in a fume-hood and allowed to settle for 30 minutes. Thereafter, 200 ml of distilled water was added to dilute the sample. Further, 10 ml of orthophosphoric acid and 5 drops of indicator (diphenylamine) were added. Organic Carbon was obtained as (Potassium dichromate * (Blank Titrated – Sample Titrated) ÷ Blank Titrated) * (0.003 ÷ Sample Weight) * 100.

Thus, O.C (%) = {(10(BT – ST))/BT * (0.003/SW)} * 100 ……………………….……..Equation 4

Where; BT = Blank Titrated; ST = Sample titrated; SW = Sample Weight

(f) Ammonium acetate procedure was used to measure cation exchange capacity (CEC) (Gillman and Sumpter, 1986). A sample weighing 5 g was used in the determination of CEC of soil and organic fertilisers. Each sample was put in a conical flask followed by adding 33 ml of ammonium acetate and filtered. The sample was then washed with 3 portions of 25 ml ethanol. Finally, the sample was washed with 25 ml acidified potassium chloride into 100 ml volumetric flack. An aliquot was distilled and titrated, then the reading was recorded for the determination of CEC of the sample.

Thus, CEC = {(Vused * Conc. acid * Vex) / SW} * 100 …………………………….…..Equation 5

Where CEC = Cation Exchange Capacity; Vused = Volume-used (titrated); Conc. acid = Concentration of acid used (N HCl); Vex. = Volume extracted; SW = Sample Weight used

3.4.2. Measurement of growth and yield components

Growth is an irreversible increase in size of plants and their parts, including leaf diameter, height, number of leaves, head diameter, among others. The standard procedures were used to collect data on the growth and yield components of lettuce, with the main focus being leaf diameter, plant height, number of leaves, head diameter, and plant biomass (fresh and dry weights) of three randomly sampled plants per treatment. The measurements were taken at weekly intervals, starting at 14 days post-transplant (DPT) and ending at 66 DPT. The measuring was stopped when there was no further major change in the assessed component.

(a) Leaf diameter

The leaf diameter of three randomly selected plants per treatment was measured with a ruler and recorded in cm on a weekly basis at 14, 21, 28 and 35 DPT. The measuring of leaf diameter was stopped once there was no further major increase in leaf diameter. The leaf diameter readings were recorded in cm. Subsequently, the average diameter per plant was calculated.

(b) Plant height

The height of the three randomly selected plants per treatment was measured bi-weekly with a 30-cm ruler from the base to the tip of the tallest leaf at 14, 21, 28 and 35 DPT. The measuring was stopped once there was no further major increase in height. The plant height readings were recorded in cm. Subsequently, the average height per plant was calculated.

(c) Number of leaves

The leaves were counted on three randomly selected plants per treatment. This was done physically by counting and recording the number of leaves on the sampled plants at 14, 21, 28 and 35 DPT. Subsequently, the average number of leaves per plant was calculated.

(d) Lettuce head diameter

The head diameter of three randomly selected plants was measured with a ruler and recorded in cm on a weekly basis at 44, 51, and 58 DPT. Subsequently, the average head diameter per plant was calculated.

(e) Yield (fresh and dry weights)

This is the quantity of lettuce harvested per treatment. Yield was expressed in g/plant (then converted to tons per hectare). Yield was determined by harvesting and weighing the total biomass of three randomly selected lettuce plants per treatment. Biomass was collected once, at 66 days post-transplanting, on whole harvested lettuce plants. The fresh weight of each plant was weighed and recorded in g per plant to determine the yield of lettuce. The sampled fresh lettuce plant was split open for easy drying, after which it was oven-dried at 65°C for 7 days until a constant (weighing scale) weight was achieved.

3.4.3. Nutritional quality

The three randomly selected plants per treatment were used to assess nutritional quality of lettuce leaf tissues, including vitamin C concentration and nutrients uptake. From each sampled plant, second and fourth leaves were gently cut-off with a clean knife and analyzed for vitamin C content and mineral nutrients (N, P, K, Ca, and Mg) to determine nutrient absorbed after production. Therefore, the vitamin C content and mineral nutrients determination and procedures are quoted in Table 12.

Determination of vitamin C used modified redox titration method (Reische *et al*., 2008), whereby 2 g of potassium iodide and 1.3 g of iodine were used to prepare a titrant that was added to 5 g of lettuce tissue sample in a conical flask, into which 50 ml of distilled water was added and left to stand for one hour. Thereafter, the liquid was extracted using a Muslin cloth as a sieve, then 50 ml of distilled water, as well as starch indicator were added in the sieved solution. The sample was titrated and the reading recorded to determine vitamin C.

Vitamin C = (C*V*M / SW) * 100 …………………………………………..Equation 6

Where C= concentration; V= volume titrated; M= I_2 molecular mass; SW= sample weight

Vitamin C concentration = Mass of vitamin C (mg) / Vol titrated (mL)

Where Moles I_2 = I_2 concentration used (0.005 mol/L) * Volume of I_2 used (titrated)

Moles of I_2 = Moles of Vitamin C

Mass of vitamin C = Moles of vitamin c (mol) * molar mass I_2 (176.12 g/mol) * 1000

3.4.4. Net economic benefit calculation

A simplified net economic benefit (NEB) analysis was performed in this study. The net economic benefit was calculated using the data recorded for the costs of all inputs (charged biochar, compost, farmyard manure, poultry manure, NPK, urea, labour used in the production) and the income (revenue) generated from selling the lettuce produce. The costs of land, machinery, water and other inputs that were held constant and provided freely were not included as they were beyond the scope of this study. The NEB was represented by income (output) minus input costs. The revenue (income) equals (total fresh weight of lettuce heads per bed/fresh weight of one lettuce head) x price per one lettuce head. The NEB was recorded in Kenyan shillings.

(a) Input expenditure

The cost of experimental inputs per treatment per season are shown in Table 13. The cost of lettuce seeds (Ksh 22.23), as well as NPK and Urea (Ksh 16.50) were set by the Agrovet shop where they were purchased. The price of charged biochar (Ksh 360), compost and transportation (Ksh 240, respectively), poultry manure and transportation (Ksh 156, respectively), farmyard manure and transportation (Ksh 90, respectively), were set by the various sellers who provided the materials. These costs were derived from bulk costs as: seeds 400/18 treatments (=22.23), NPK (200/kg)*0.06 kg (=12) + urea (150/kg)*0.03 kg (=4.5), charged biochar (3,000/50 kg)*6 kg (=360), compost (2,000/50 kg)*6 kg (=240), poultry manure (1,300/50 kg)* 6 kg (= 156), and farmyard manure (750/50 kg) * 6 kg (=90) (Table 13).

The cost of labour was obtained from people searching for short-term labour within the experimental research farm at Egerton University and paid for as Ksh 500 per 8 hours person. Activities that labour was utilized on were five and included: land preparation (Ksh 300 per 4 hours), mixing amendments into the soil (Ksh 250per 4 hours), transplanting lettuce (Ksh 250 per 4 hours), weeding (Ksh 270 x 3 times of 4 hours), and harvesting (Ksh 250 per 4 hours). Therefore, total labour cost equaled Ksh 1,860 for the 18 treatments. Thus, the labour cost per treatment equaled Ksh 103.3.

Table 13: Costs of experimentation inputs

Input	Unit cost (Ksh)/treatment/season	Total cost (Ksh)
Seed	22.23	400/seasons
Charged biochar	360	3,000/50 kg
Compost	240	2,000/50 kg
Poultry manure	156	1,300/50 kg
Farmyard manure	90	750/50 kg
NPK + Urea	16.50	200/1 kg + 150/1kg
Labour	103.30	103.30/3 m^2

The cost of inputs (COI) for lettuce production for each treatment was arrived at based on the inputs for each treatment in an area of 2 m x 1.5 m (3 m^2) as shown in Table 14. Essentially, the cost of seeds and labour was constant across treatments. What varied was cost of nutrient sources as shown in Table 14. Subsequently, the total cost of inputs (COI) for each treatment was arrived at by totaling the cost of individual inputs for each treatment as shown in Table 14.

Table 14: Costs of inputs for lettuce production per treatment per season

Trt	Treatment name	Costing formula per 3 m^2	Costing values	Total cost/ treatment
1	Farmyard manure	FYM+S+L	90+22.23+103.3	215.6
2	Negative control (Soil)	N+S+L	0+22.23+103.3	125.6
3	Charged biochar	B+S+L	360+22.23+103.3	485.6
4	Poultry manure	PM+S+L	156+22.23+103.3	281.6
5	Compost	C+S+L	240+22.23+103.3	365.6
6	Positive control (NPK+Urea)	NPK+Urea+S+L	16.5+22.23+103.3	142.1

*FYM = Farmyard manure, S = Seeds, L = Labour, N = Nil/Zero, B = Charged Biochar, PM = Poultry manure, C = Compost

(b) Output (income)

The sale price for lettuce per head (KSh 25) was obtained from Nakuru market. The lettuce heads sampled were weighed, recorded and their average fresh weight of lettuce (AFWTL) calculated. The total fresh weight (TFWTL) of heads per treatment (30) was calculated by multiplying the AFWTL for each treatment by the 30 heads per treatment.

Thus, total FWTL (g/bed) = AFWTL x Yield (30 heads) ……………………..……… Equation 7

Thereafter, the total income of lettuce (IOL) for each treatment was calculated as: (total fresh weigh of lettuce/average fresh weight of lettuce) * price of AFWTL. In this regard, the sale price of KSh 25 per head of lettuce (average fresh weight of lettuce) was obtained from Nakuru farmers' market in Kenya.

Thus, IOL = (TFWTL/AFWTL) x Ksh. 25 ………………………………..………Equation 8

The NEB was calculated as income of lettuce (IOL) minus cost of inputs (COI).

Thus, NEB = IOL – COI ……………………………………………………………… Equation 9

3.5. Data Analysis and Statistical Model

Each set of data measured per variable was subjected to analysis of variance (ANOVA) using JMP Pro Version 17 program. The Tukey's test was conducted to separate means at α = 0.05 (Brunner *et al.*, 2018). The data fitted model:

$\mathbf{Y}_{\boldsymbol{ijk}} = \mu + \mathbf{b}_{\boldsymbol{i}} + \mathbf{t}_{\boldsymbol{ij}} + \varepsilon_{\boldsymbol{ijk}}$	……………………..……..…Equation 10

where: Y_{ijk} = Total observation;

μ = Overall mean;

b_i = Effect of block; i = 1, 2, 3;

t_{ij} = Effect of treatments; j = 1, 2, 3, 4, 5, 6; and

ε_{ijk} = Error term

CHAPTER FOUR

RESULTS

4.1. Effects of Charged Biochar and Organic Fertilisers on Soil Properties

In season 1, the laboratory analysis results showed a variation of nutrients and other properties such as pH and cation exchange capacity (CEC) before and after lettuce production (Table 15). The soil sample had a slight neutral pH of 7.15, low total nitrogen (0.15%), phosphorus (67.4 ppm), and organic carbon (1.26%). The CEC was relatively low (4.29 meq/100g), showing poor fertility of the soil. The C: N ratio of 8.40 was within the moderate range. Poultry manure and farmyard manure showed significantly higher organic matter (27.03% and 12.83%), phosphorus (994.8 and 909.2 ppm), and nitrogen content (1.47% and 2.83%), respectively. Poultry manure had the highest CEC (69.43 meq/100g), suggesting that it had a potential to improve and maintain soil fertility (Table 15).

In season 1 post-production, there was an increase in CEC compared to the pre-treatment level, with the highest CEC content observed in the charged biochar treated bed (24 meq/100g) (Table 15). Soil organic matter increased in all treated beds, with farmyard manure showing the highest value (4.24%). The nutrient levels, particularly phosphorus and potassium, were also enhanced (Table 15). The charged biochar treated soil had the highest phosphorus concentration (169 $mgkg^{-1}$), followed by compost (134 $mgkg^{-1}$) and poultry manure (129 $mgkg^{-1}$). Notably, poultry manure and compost also increased the pH of the soil to near-neutral (Table 15).

The laboratory analysis conducted for season 2 showed a visual variation in the physicochemical properties across the different treatments after lettuce production (Table 15). Nonetheless, the pre-plant baseline data was similar to that observed in season 1, indicating similar soil conditions across both production sites. As in season1, the post-harvest soil assessments demonstrated visible changes in soil properties in season 2. The highest pH was observed in the positive control bed and the negative control had the lowest pH. All organically amended beds, including charged biochar, compost, and poultry manure, maintained a moderately acidic (pH 6.2), with the exception of farmyard manure with slightly lower pH (6.1). The nitrogen content was higher for positive control (0.35%), while compost (0.26%) had the lowest content (Table 15).

Table 15: Physicochemical characteristics of experimental materials (Seasons 1 & 2)

Material (Nutrient source)	N (%)B	NA	ND	P (mgkg^{-1})B	PA	PD	K (mgkg^{-1})B	KA	KD	Mg (mgkg^{-1})B	MgA	MgD	Ca (mgkg^{-1})B	CaA	CaD
Season 1															
Charged biochar	0.70^{a}	0.19^{ab}	-0.51	777^{a}	169^{b}	-608	0.26^{a}	42.1^{a}	41.8	0.04^{a}	169^{b}	169	0.01^{a}	799^{a}	799
Compost	0.65^{a}	0.17^{b}	-0.48	485^{a}	134^{b}	-351	0.04^{a}	45.1^{a}	45.1	0.04^{a}	197^{b}	197	0.01^{a}	802^{a}	802
Farmyard manure	2.83^{a}	0.17^{b}	-2.66	909^{a}	120^{b}	-789	0.30^{a}	2.0^{b}	1.73	0.05^{a}	193^{b}	193	0.01^{a}	168^{b}	168
-ve control (Soil)	0.15^{a}	0.19^{ab}	0.04	67^{a}	91^{b}	23.2	0.26^{a}	45.0^{a}	44.7	0.05^{a}	190^{b}	190	0.01^{a}	803^{a}	803
+ve control (NPK+urea)		0.22^{a}	NA		102^{b}	NA		46.8^{a}	NA		200^{b}	NA		794^{a}	NA
Poultry manure	1.47^{a}	0.19^{ab}	-1.28	995^{a}	129^{b}	-866	0.05^{a}	39.8^{a}	39.8	0.05^{a}	196^{b}	196	0.01^{a}	803^{a}	803
Season 2															
Charged biochar	0.70^{a}	0.33^{b}	-0.37	777	31^{b}	-746	0.26^{a}	43.7^{b}	43.5	0.04^{a}	48^{b}	48	0.01^{a}	551	551
Compost	0.65^{a}	0.26^{b}	-0.39	485	28^{b}	-456	0.04^{a}	27.8^{b}	27.8	0.04^{a}	72^{a}	75	0.01^{a}	556	556
Farmyard manure	2.83^{a}	0.31^{b}	-2.52	909	38^{b}	-871	0.30^{a}	36.7^{b}	36.4	0.05^{a}	35^{b}	35	0.01^{a}	548	548
-ve control (Soil)	0.13^{a}	0.30^{b}	0.17	67.6	23^{b}	-44.6	0.24^{a}	30.3^{b}	30.1	0.05^{a}	74^{a}	74	0.03^{a}	481	481
+ve control (NPK+urea)		0.35^{b}	NA		26^{b}	NA		35.6^{b}	NA		65^{a}	NA		570	NA
Poultry manure	1.47^{a}	0.33^{b}	-1.14	995	53^{b}	-942	0.05^{a}	45.5^{b}	45.4	0.05^{a}	18^{b}	18	0.01^{a}	561	561

Table 15: (Continued)

Material (Nutrient source)	pHB	pHA	phD	OC (%)B	OCA	OCD	CEC (meq/100g)B	CECA	CECD	OM (%)	OMA	OMD	C: N B	C:NA	C:ND
Season 1															
Charged biochar	6.86^{a}	6.3^{b}	-0.58	3.27^{a}	2.29^{b}	-0.98	22.0^{a}	24.0^{b}	2.0	5.64^{a}	3.95^{b}	-1.69	4.67^{a}	12.1^{b}	7.38
Compost	8.27^{a}	6.3^{b}	-1.97	3.97^{a}	2.43^{b}	-1.54	13.1^{a}	19.3^{b}	6.2	6.84^{a}	4.15^{b}	-2.69	20.20^{a}	14.3^{b}	-5.93
Farmyard manure	7.54^{a}	6.5^{b}	-1.05	7.44^{a}	2.46^{b}	-4.98	31.7^{a}	20.0^{b}	-11.7	12.8^{a}	4.24^{b}	-8.59	2.63^{a}	14.1^{b}	11.50
-ve control (Soil)	7.15^{a}	6.3^{b}	-0.81	1.26^{a}	2.10^{b}	0.84	4.3^{a}	20.0^{b}	15.7	0.82^{a}	3.62^{b}	1.45	8.40^{a}	11.1^{b}	2.65
+ve control (NPK+urea)		6.1^{b}	NA		2.33^{b}	NA		20.0^{b}	NA		4.02^{b}	NA		10.6^{b}	NA
Poultry manure	8.98^{a}	6.4^{b}	-2.58	15.70^{a}	2.28^{b}	-13.4	69.4^{a}	22.7^{b}	-46.8	27.0^{a}	3.93^{b}	-23.1	10.70^{a}	12.0^{b}	1.33
Season 2															
Charged biochar	6.86^{a}	6.2^{b}	-0.66	3.27^{a}	2.83^{b}	-0.44	22.0^{a}	29.2^{b}	7.20	5.64^{a}	4.88^{b}	-0.76	4.67^{a}	8.58^{b}	3.91
Compost	8.27^{a}	6.2^{b}	-2.07	3.97^{a}	3.32^{b}	-0.65	13.1^{a}	30.7^{b}	17.53	6.84^{a}	5.72^{b}	-1.12	20.22^{a}	12.77^{b}	-7.45
Farmyard manure	7.54^{a}	6.1^{b}	-1.44	7.44^{a}	2.93^{b}	-4.51	31.7^{a}	32.7^{b}	0.96	2.17^{a}	5.05^{b}	2.88	2.63^{a}	9.45^{b}	6.82
-ve control (Soil)	7.13^{a}	6.0^{b}	-1.13	1.21^{a}	2.87^{b}	1.66	4.12^{a}	29.3^{b}	25.18	2.09^{a}	4.95^{b}	2.86	9.30^{a}	9.57^{b}	0.27
+ve control (NPK+urea)		6.3^{b}	NA		3.03^{b}	NA		28.7^{b}	NA		5.22^{b}	NA		8.66^{b}	NA
Poultry manure	8.98^{a}	6.2^{b}	-2.78	15.6^{a}	3.32^{b}	-12.28	69.4^{a}	30.7^{b}	-38.76	27.00^{a}	5.72^{b}	-21.28	10.67^{a}	10.06^{b}	-0.61

Key: B = Pre-production content, A = Post-production content, D = Difference (A-B), NA = Not applicable, -ve = Negative, +ve = Positive. *Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$ by Tukey's t-test.

Available phosphorus concentration varied significantly across treatments, ranging from a low of 23.05 $mgkg^{-1}$ in the negative control to a high of 52.46 $mgkg^{-1}$ in poultry manure treated bed. The concentration of potassium was higher in poultry manure (45.49 $mgkg^{-1}$), followed by charged biochar (43.72 $mgkg^{-1}$), while the least was observed in compost (27.79 $mgkg^{-1}$) treated bed. Negative control (74.16 $mgkg^{-1}$) had the highest magnesium concentration, while poultry manure (18.06 $mgkg^{-1}$) had the lowest concentration. Calcium was high in positive control (569.77 $mgkg^{-1}$), while negative control (481.14 $mgkg^{-1}$) had the lowest concentration (Table 15). The soil organic carbon was highest in compost and poultry manure with the same concentration of 3.32%, while charged biochar had the lowest of 2.83%. Farmyard manure had the highest CEC (32.67 meq/100g), while positive control had the lowest CEC (28.67 meq/100g). The soil organic matter was higher in poultry manure and compost with the same quantity (5.72%), while charged biochar (4.88%) had the lowest. Carbon to nitrogen ratio was higher in poultry manure (10.06), while the lowest observed was from charged biochar (8.58) treated beds (Table 15).

4.2. Effect of Charged Biochar and Organic Fertilisers on Lettuce Growth and Yield

4.2.1. Growth Components

4.2.1.1. Leaf diameter

The results showed that charged biochar and organic fertilisers significantly influenced the leaf diameter of lettuce, indicating that the crop responded differently to various treatments. There were no statistically significant differences observed among treatments at 14 DPT in either season (season 1 P = 0.401; season 2 P = 0.328). From 21 DPT onwards, significant variation resulted. In season 1, a statistically significant increase in leaf diameter was observed between the positive control and negative control at 21 DPT (7.3 cm and 4.9 cm; P = 0.054) and at 35 DPT (15.5 cm and 10.1 cm; P = 0.0227). However, no significant differences were observed among the positive control and other organic treatments, namely: compost (6.5 cm; 14.2 cm), farmyard manure (6.2 cm; 14.1 cm), and charged biochar (6.7 cm; 13.1 cm) at 21 and 35 DPT (Table 16).

Similar results were obtained in season 2, which showed significant differences at 21, 28, and 35 DPT (P = 0.026, 0.023, and 0.041, respectively). At 21 DPT, charged biochar (5.6 cm) showed significantly larger leaf diameter than the negative control (4.0 cm), while the other organic treatments of farmyard manure (5.1 cm), compost (5.0 cm), poultry manure (4.6 cm) did not differ significantly from the negative control.

Table 16: Lettuce leaf diameter in seasons 1 and 2

Treatment (Nutrient Source)	Season 1 (DPT)				Season 2 (DPT)			
	14	21	28	35	14	21	28	35
Farmyard manure	4.067^{a}	6.150^{ab}	10.533^{a}	14.057^{ab}	3.337^{a}	5.107^{ab}	7.113^{ab}	10.567^{ab}
Negative control	3.047^{a}	4.940^{b}	7.223^{b}	10.137^{b}	3.187^{a}	3.990^{b}	5.097^{b}	7.933^{b}
Charged biochar	3.703^{a}	6.657^{ab}	9.443^{ab}	13.110^{ab}	3.253^{a}	5.633^{a}	6.873^{ab}	9.847^{ab}
Poultry manure	3.517^{a}	6.150^{ab}	8.880^{ab}	11.770^{ab}	2.910^{a}	4.557^{ab}	6.873^{ab}	10.890^{a}
Compost	3.893^{a}	6.507^{ab}	10.313^{a}	14.220^{ab}	3.523^{a}	4.957^{ab}	7.757a	9.907^{ab}
Positive control	3.807^{a}	7.320^{a}	11.0367^{a}	15.537^{a}	3.263^{a}	4.527^{ab}	6.463^{ab}	9.150^{ab}
P value	0.401	0.054	0.0150*	0.0227*	0.328	0.026*	0.023*	0.041*
S.E. value	0.322	0.469	0.692	1.006	0.179	0.288	0.023	0.041
CV %	15.703	16.015	17.213	17.740	9.906	14.128	17.025	14.326

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$ by Tukey's t-test

At 28 DPT, compost (7.8 cm) significantly out-performed the negative control (5.1 cm; $P = 0.023$), while other treatments showed intermediate similar values. At 35 DPT, poultry manure had significantly larger leaf diameter (10.9 cm) than the negative control (7.9 cm; $P = 0.041$). However, farmyard manure (10.6 cm), charged biochar (9.8 cm), compost (9.9 cm), and the positive control (9.2 cm) did not show any statistically significant differences (Table 16).

4.2.1.2. Plant height

The results showed progressive increase of lettuce plant height for all treatments during the production seasons (Table 17). At 14 DPT, there were statistically significant differences ($P = 0.0142$) in plant height among the treatments in season 1, while in season 2, there was no statistically significant difference ($P = 0.062$) observed at 14 DPT.

There was an increasing effect on plant height from 21 DPT to 35 DPT as indicated by 21 DPT ($P = 0.0455$ and 0.008), 28 DPT ($P = 0.0285$ and 0.016), and 35 DPT ($P = 0.0017$ and 0.004) in seasons 1 and 2, respectively. At 14 DPT in season 1, there was a significant difference among negative control (10.6 cm) and other treatments, while charged biochar (13.8 cm), FYM (13.3 cm), positive control (13.8 cm) had similar effects. At 35 DPT, poultry manure was significantly different (17.3 cm) from compost (13.8 cm) and negative control (12.9 cm) in season 2, while in season 1 positive control was significantly different from all treatments, except charged biochar (Table 17).

Table 17: Lettuce plant height in seasons 1 and 2

Treatment	Season 1 (DPT)				Season 2 (DPT)			
(Nutrient Source)	14 DPT	21 DPT	28 DPT	35 DPT	14 DPT	21 DPT	28 DPT	35 DPT
Farmyard manure	13.3^{a}	16.6^{ab}	19.1^{ab}	21.4^{bc}	8.857^{a}	10.987^{a}	12.690^{a}	16.223^{ab}
Negative control	10.6^{b}	13.3^{b}	16.2^{b}	14.4^{c}	7.323^{a}	9.323^{b}	10.853^{b}	12.873^{c}
Charged biochar	13.8^{a}	17.3^{a}	20.7^{a}	22.7^{ab}	9.167^{a}	10.690^{a}	12.333^{ab}	16.967^{ab}
Poultry manure	13.4^{a}	16.2^{ab}	18.5^{ab}	20.7^{bc}	8.633^{a}	10.367^{ab}	13.143^{a}	17.323^{a}
Compost	13.2^{ab}	16.3^{ab}	18.9^{ab}	21.1^{bc}	8.223^{a}	10.367^{ab}	11.890^{ab}	13.767^{bc}
Positive control	13.8^{a}	17.3^{a}	20.0^{a}	25.1^{a}	8.633^{a}	10.177^{ab}	11.913^{ab}	15.143^{abc}
P value	0.0142*	0.0455*	0.0285*	0.0017*	0.062	0.008*	0.016*	0.004*
SE	0.626	0.883	1.049	1.152	0.522	0.254	0.483	0.644
CV %	11.08	11.701	11.154	12.401	11.452	6.272	8.421	12.492

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$ by Tukey's t-test

4.2.1.3. Number of leaves

Results showed an increasing number of leaves in all experimental treatments following lettuce seedling transplanting, establishment and subsequent growth in the permanent beds. At 14 DPT during early stages of growth of lettuce plants, there were no significant differences (P = 0.23) in the number of leaves among the treatments in season 1, after which statistically significant differences were observed gradually from 21 DPT to 35 DPT. Observation at 35 DPT, showed a significant difference in the number of leaves among poultry manure (15) and negative control (11). However, there were no significant differences in the number of leaves among other treatments, namely: farmyard manure, charged biochar, compost, and positive control which had 13, 14, 13, and 14 leaves, respectively in season 1.

Similarly, in season 2 at 14 DPT of growth of lettuce plants, there were no significant differences (P = 0.465) in the number of leaves among the treatments, after which statistically significant differences were observed from 21 DPT to 35 DPT. In season 2, there were significant differences in the number of leaves from 21 to 35 DPT. At 35 DPT of lettuce plants, there were no differences in the number of leaves among the positive control (11), charged biochar (11), as well as farmyard manure (11). However, the number of leaves of these three treatments was significantly different from those of the negative control (9) ones (Table 18).

Table 18: Lettuce number of leaves in seasons 1 and 2

Treatment	Season 1 (DPT)				Season 2 (DPT)			
(Nutrient source)	14	21	28	35	14	21	28	35
Farmyard manure	3.7ª	6.0ªᵇ	8.3ᵇ	13.0ªᵇ	3.0ª	5.3ªᵇ	7.7ªᵇ	10.7ªᵇᶜ
Negative control	3.7ª	5.0ᵇ	9.0ªᵇ	11.0ᵇ	3.0ª	4.7ªᵇ	7.0ᵇ	9.0ᵈ
Charged biochar	3.7ª	6.3ªᵇ	9.3ªᵇ	14.3ªᵇ	3.0ª	5.7ªᵇ	8.0ªᵇ	11.0ªᵇ
Poultry manure	4.3ª	6.7a	11.7ª	15.0ª	3.0ª	4.7ªᵇ	7.3ᵇ	10.0ᵇᶜᵈ
Compost	3.3ª	6.3ªᵇ	9.0ªᵇ	13.0ªᵇ	2,7ª	4.3ᵇ	7.0ᵇ	9.7ᶜᵈ
Positive control	4.3ª	7.3ª	10.7ªᵇ	14.3ªᵇ	3.0ª	6.0ª	8.7ª	11.3ª
P value	0.230	0.0047	0.0349	0.0316	0.465	0.015	0.006	0.0002
SE	0.333	0.272	0.593	0.694	0.136	0.304	0.236	0.236
CV %	16.1	13.2	15.1	12.6	8.0	14.8	9.2	8.7

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$ by Tukey's test.

4.2.1.4. Head diameter

The results showed a statistically significant increase and consistency in head size development from 44 DPT to 58 DPT in both seasons ($P = 0.003$ for season 1 and 0.011 for season 2). At 44 DPT of season 1, there was a significant difference among negative control (12.7 cm) and all other treatments, as shown by positive control (19.1 cm), poultry manure (17.8 cm), charged biochar (17.3 cm), farmyard manure (17.2 cm), and compost (16.6 cm).

Similar trends were observed in lettuce head diameters at 51 DPT and 58 DPT (Table 19). However, in season 2 there were no significant differences at 44 DPT among negative control (15.3 cm), positive control (17.5cm) and compost (17.5cm), but results showed significant difference between charged biochar (19.7 cm), farmyard manure (19.5 cm), as well as poultry manure (19.1 cm) and negative control (15.3 cm). Similarly, at 51 DPT, charged biochar (21.7 cm), farmyard manure (21.3 cm), and poultry manure (20.9 cm) were significantly different from negative control (17.1 cm). The results at 58 DPT indicated the same trend, whereby charged biochar (23.1 cm), poultry manure (22.55 cm) and farmyard manure (22.4 cm) were significantly different from negative control (19.0 cm) in head diameter (Table 19). Additionally, compost and positive control head diameters were not significantly different from 44 DPT to 58 DPT.

Table 19: Lettuce head diameter in seasons 1 and 2

Treatment	Season 1			Season 2		
(Nutrient Source)	44 DTP	51 DPT	58 DPT	44 DPT	51 DPT	58 DPT
Farmyard manure	17.2^{a}	19.1^{a}	21.2^{ab}	19.5^{a}	21.3^{a}	22.4^{a}
Negative control	12.7^{b}	14.7^{b}	16.8^{b}	15.3^{b}	17.1^{b}	18.9^{b}
Charged biochar	17.3^{a}	19.7^{a}	22.3^{a}	19.7^{a}	21.7^{a}	23.1^{a}
Poultry manure	17.8^{a}	19.8^{a}	22.3^{a}	19.1^{a}	20.9^{a}	22.6^{a}
Compost	16.6^{a}	19.3^{a}	21.8^{a}	17.5^{ab}	19.3^{ab}	21.3^{ab}
Positive control	19.1^{a}	21.0^{a}	22.9^{a}	17.5^{ab}	19.4^{ab}	21.4^{ab}
P value	0.003*	0.006*	0.012*	0.011*	0.005*	0.011*
SE value	0.747	0.847	0.948	0.803	0.758	0.657
CV %	13.745	12.642	11.830	10.867	9.817	7.767

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$ by Tukey's t-test.

4.2.2. Yield Components

4.2.2.1. Fresh weight

The ANOVA showed a statistically significant difference in fresh weight yields (g/plant) among treatments in both seasons. In season 1, there was a significant (P = 0.0098) difference between positive control (774.3 g) and poultry manure (694.0 g) when compared to negative control (411.0 g). However, there were no significant differences among treatments, except with negative control. In season 2, a significant (P = 0.0186) difference between poultry manure (773.3 g) compared to compost (408.9 g) and negative control (322.2 g) was observed. However, there were no significant differences among positive control (595.7g), charged biochar (543.9 g), and farmyard manure (479.8 g) with regard to their fresh weight yields (Table 20).

The yield translation of the results for the two seasons showed that in season 1, poultry manure and positive control resulted in the highest fresh biomass yield of 2.3 ton/ha and 2.6 ton/ha, respectively. These were significantly higher than the negative control yield (1.4 ton/ha). Charged biochar and compost produced intermediate yields of 2.0 ton/ha and 2.2 ton/ha, while farmyard manure yielded 2.1 ton/ha. In season 2, similar trends were observed. Poultry manure had the highest yield (2.6 ton/ha), followed by the positive control (2.0 ton/ha) and charged biochar (1.8 ton/ha). Compost and the negative control yielded the lowest 1.4 ton/ha and 1.1 ton/ha, respectively (Table 20).

Table 20: Lettuce fresh weight at 66 DPT in seasons 1 and 2

Treatment (Nutrient source)	Season 1 (g/plant)	ton/ha	Season 2 (g/plant)	ton/ha
Farmyard manure	622.00^{ab}	2.1	479.78^{ab}	1.6
Negative control	411.00^{b}	1.4	322.22^{b}	1.1
Charged biochar	591.33^{ab}	2.0	543.89^{ab}	1.8
Poultry manure	694.00^{a}	2.3	773.33^{a}	2.6
Compost	645.67^{ab}	2.2	408.89^{b}	1.4
Positive control	774.33^{a}	2.6	595.67^{ab}	2.0
P value	0.0098*	-	0.0186*	-
SE value	50.70		69.60	
CV %	21.876		34.398	

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$ by Tukey's t-test

4.2.2.2. Dry weight

The results showed statistically significant differences among treatments based on dry weight (Figure 2). Application of different organic amendments significantly influenced the dry biomass of lettuce in the two production seasons (season 1 $P = 0.012$ and season 2 $P = 0.017$). The highest dry biomass in season 1 was observed for the positive control (44 g), followed by poultry manure (39.33 g), while the least was for negative control (32.67 g).

In season 2, poultry manure (47.33 g) showed the highest dry biomass, although it was not significantly different from farmyard manure (29.3 g), charged biochar (33 g), and positive control (36.7 g), but it was significantly different from compost (25 g) and negative control (19.67 g). Farmyard manure and charged biochar yielded moderate dry biomass in both production seasons, although the yields were not statistically significantly different from those of compost and negative control (Figure 2). Poultry manure showed consistently highest biomass, while negative control showed consistently lowest biomass across the two production seasons.

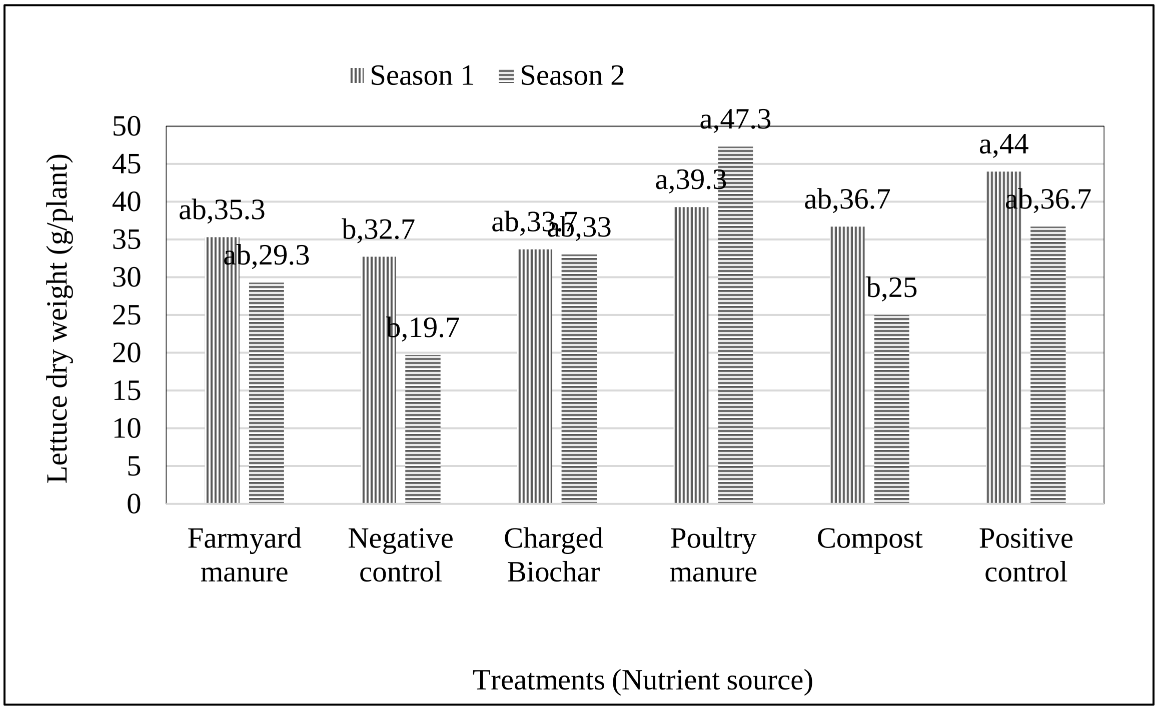

Figure 2: Graph of lettuce dry weight (g/plant) versus treatments

Season 1 $P = 0.012$ and season 2 $P = 0.017$. Means with the same letter(s) within a season are not significantly different at $P \leq 0.05$ by Tukey's t-test.

4.3. Effect of Charged Biochar and Organic Fertilisers on Quality and Mineral Nutrients

4.3.1. Vitamin C

Results showed statistically significant differences ($P = 0.0006$*; $P = 0.048$*) among the vitamin C content in both production seasons. The vitamin composition among treatments in season 1 showed that there was statistically significant variation between poultry manure (3.2 mg/100g) and the rest of the treatments. Farmyard manure, charged biochar, compost, positive and negative controls had 2.0, 2.5, 2.0, 2.0, and 2.3 mg/100g, respectively (Figure 3).

In season 2, farmyard manure (1.4 mg/100g) showed the highest statistically significant difference with poultry manure (1.0 mg/100g). However, there were no statistically significant differences among farmyard manure and other treatments, whose contents were: compost (1.2), charged biochar (1.2), positive (1.1) and negative control (1.1) mg/100g (figure 3). Similarly, there was no significant difference between poultry manure and charged biochar, compost, positive and negative control (Figure 3).

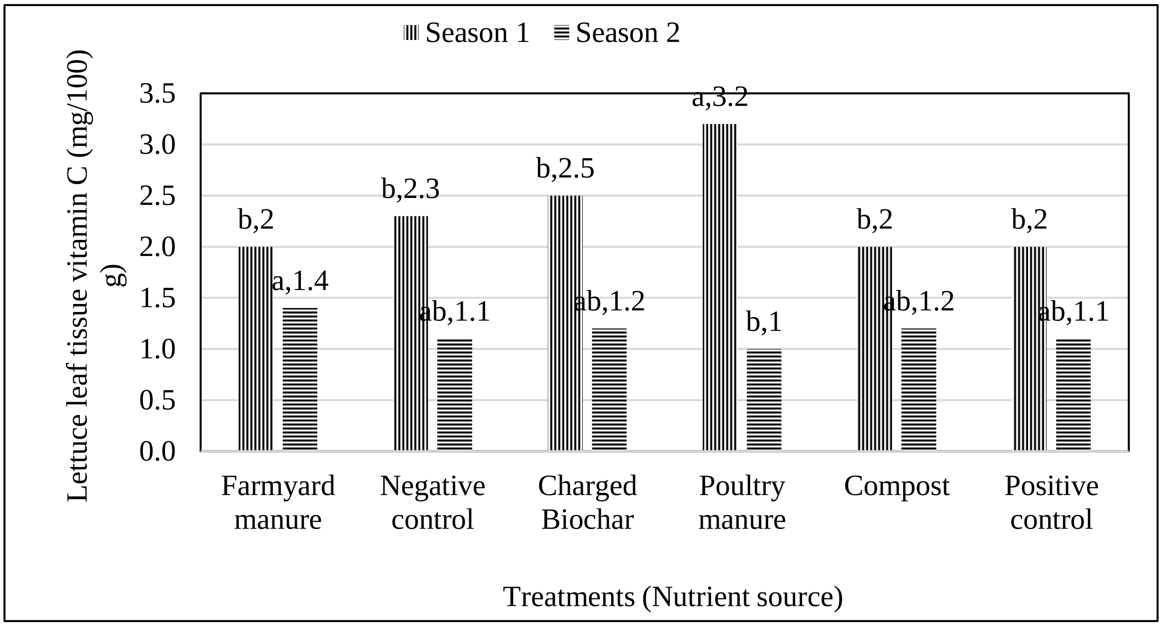

Figure 3: Graph of vitamin C (mg/100 g) versus treatments

Season 1 P = 0.0006 and season 2 P = 0.048. Means with the same letter(s) within a season are not significantly different at $P \leq 0.05$ by Tukey's t-test.

4.3.2. Mineral nutrients

This study focused on post-harvest analysis of five macro-nutrients (N, P, K, Mg and Ca) in mature lettuce leaf tissue aged 66 DPT due to financial reasons. The ANOVA outputs showed that there were no statistically significant differences among nutrient contents in lettuce leaf tissue in all treatments in both growing seasons (Table 21). However, numerically there were variations observed among the treatments in both production seasons (Table 21).

In season 1, N concentration ranged from 2.92% in the negative control to 3.72% in the compost treated bed. Farmyard manure, charged biochar, and compost tended to enhance N accumulation compared to the control. The P levels were highest in the positive control (5.11 $mgkg^{-1}$) and compost (4.99 $mgkg^{-1}$), while the other treatments showed similar values. Potassium showed greater variability, ranging from 3.35 $mgkg^{-1}$(negative control) to 3.94 $mgkg^{-1}$ (farmyard manure). Magnesium and calcium levels showed similar contents. All the treatments had the same values of 3.22 $mgkg^{-1}$ for magnesium, except negative control which had 3.21 $mgkg^{-1}$. Calcium showed little difference, with charged biochar having slightly higher (0.28 mgkg^{-1}) content, while the least value was observed for farmyard manure and negative control that had the same values of 0.23 mgkg^{-1} (Table 21).

Table 21: Mineral nutrients in lettuce leaf tissue in seasons 1 and 2

	Season 1					Season 2				
Treatment (Nutrient source)	N (%)	P (mgkg^{-1})	K (mgkg^{-1})	Mg (mgkg^{-1})	Ca (mgkg^{-1})	N (%)	P (mg kg^{-1})	K (mg kg^{-1})	Mg (mgkg^{-1})	Ca (mg kg^{-1})
Farmyard manure	3.40^{a}	4.85^{b}	3.94^{c}	0.22^{d}	0.23^{e}	2.96^{a}	0.30^{b}	3.86^{c}	0.21^{d}	0.21^{e}
Negative control	2.92^{a}	4.34^{b}	3.35^{c}	0.21^{d}	0.23^{e}	2.48^{a}	0.42^{b}	3.28^{c}	0.23^{d}	0.25^{e}
Charged biochar	3.59^{a}	4.03^{b}	3.67^{c}	0.22^{d}	0.28^{e}	2.73^{a}	0.42^{b}	3.86^{c}	0.22^{d}	0.28^{e}
Poultry manure	3.20^{a}	4.54^{b}	3.70^{c}	0.22^{d}	0.25^{e}	2.69^{a}	0.38^{b}	3.58^{c}	0.23^{d}	0.23^{e}
Compost	3.72^{a}	4.99^{b}	3.63^{c}	0.22^{d}	0.26^{e}	2.71^{a}	0.40^{b}	3.47^{c}	0.21^{d}	0.25^{e}
Positive control	3.24^{a}	5.11^{b}	3.69^{c}	0.22^{d}	0.24^{e}	2.44^{a}	0.38^{b}	3.61^{c}	0.22^{d}	0.23^{e}
S E	0.36	0.59	0.29	0.008	0.02	0.46	0.43	0.23	0.008	0.02
P – value	0.52	0.61	0.84	0.77	0.25	0.78	0.42	0.56	0.32	0.44
CV (%)	17.8	20.3	12.3	5.71	12.03	25.69	18.2	10.9	6.2	15.7

*Means with the same letter(s) within a column are not significantly different at $P \leq 0.05$ by Tukey's t-test

In season 2, similar trend was observed as for the first production season across all treatments. The nitrogen concentrations ranged from 2.44% to 2.95% (positive control and farmyard manure, respectively). Phosphorus ranged from 0.30 mgkg^{-1} to o.43 mgkg^{-1}, while potassium had a uniform concentration in all treatments. Charged biochar and farmyard manure had the highest value of 3.86 $mgkg^{-1}$, while negative control had the least value of 3.28 $mgkg^{-1}$. Farmyard manure and compost had the least value of magnesium, while poultry manure and negative control had a little bit higher value of 0.23 $mgkg^{-1}$ compared to the other treatments. Farmyard manure had a slightly lower value of 0.21 $mgkg^{-1}$ compared to the rest of the treatments, although a slightly higher value was observed for charged biochar treated bed (Table 21).

4.4. Effect of Charged Biochar and Selected Organic Fertilisers on Net Economic Benefit

The ANOVA revealed a highly statistically significant difference in net economic benefit among treatments in both production seasons with season 1 $P = 0.001$ and season 2 $P = 0.011$. In season 1, the highest net economic benefit was observed under the positive control (Ksh 778), followed by poultry manure (Ksh 543) and farmyard manure (Ksh 523), while charged biochar recorded the lowest benefit (Ksh 217). In season 2, poultry manure yielded the highest net economic returns of (Ksh 833) that surpassed the positive control with (Ksh 716), while the least profit (Ksh 224) was observed on compost treated beds (Figure 4).

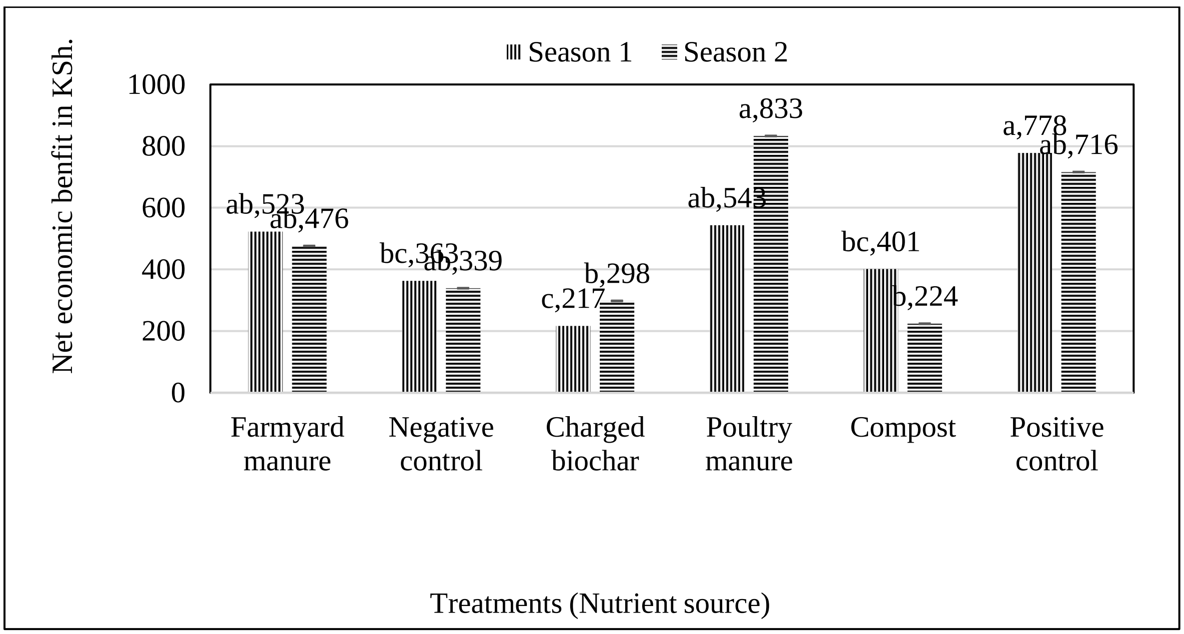

Figure 4: Graph of net economic benefit versus treatments for lettuce

Season 1 $P = 0.001$ and season 2 $P = 0.011$ in 3 m^2 production area. Means with the same letter(s) within a season are not significantly different at $P \leq 0.05$ by Tukey's test

CHAPTER FIVE
DISCUSSIONS

5.1 Effects of Treatments on Soil Properties

The soil analyzed from Field III experimental research station showed a nutrient deficiency in both two production points/areas (Table 15). This scenario was consistent with many tropical agricultural production fields, which exhibit low organic matter, nutrient levels, and nutrient holding capacity (Adekiya *et al*., 2019). The application of organic fertilisers significantly improved soil fertility, as well as enhanced lettuce productivity, which was similar to the observations made by other researches (Brady & Weil, 2016). Organic fertiliser effects are documented to be more on the improvement of soil structure, aeration, and overall health. Additionally, they may work through long-term rather than short-term impacts on crop production. These findings agree with those obtained in previous research studies by other researches (Blanco *et al.*, 2015; Sanchez *et al.*, 2023).

Among the organic fertilisers, poultry manure emerged as the most nutrient dense material, particularly in phosphorus and organic matter content that contributed substantially to soil fertility improvement (Table 15). Its high organic matter as well as C:N ratio likely facilitated rapid mineralization and nutrient release, which agreed with past research findings conducted by Ayoola and Makinde (2007), who stated that poultry manure is effective in improving soil fertility in a short period of time. Adekiya *et al.* (2020) also stated that poultry manure's efficacy improved and enhanced soil health and promoted plant growth.

Farmyard manure also presented a balanced nutrient profile with exceptionally low C:N ratio of 2.63, which then supported fast decomposition and nutrient release (Table 15). It had higher nitrogen content and was second in phosphorus content, compared to compost and charged biochar, making it a viable alternative to poultry manure for soil fertility improvement which in agreement with other research findings (Havlin *et al.*, 2014). Charged biochar was comparatively lower in nitrogen and organic matter; however, it has potential to improve soil phosphorus, CEC (determination of the salinity of soil as well as other amendment materials), as well as nutrient retention. Charged biochar has shown promising level of organic carbon as well as C:N ratio, which indicate that it may have long-term effects in improvement of soil properties and organic carbon sequestration (Lehmann & Joseph, 2015). Compost had the highest C:N ratio, which can support and improve soil nutrient retention (Zubair *et al*., 2021). Bernal *et al*. (2009) reported that compost contributes valuable humus formation and nutrient retention over time.

The initial phosphorus content was highest in experimental plots amended with poultry manure (Table 15), consistent with its enrichment potential as reported by other research findings (Eghball *et al.*, 2004; Hue & Silva, 2000). However, post-harvest results from both production seasons showed that charged biochar treated plots had the highest phosphorus compared to poultry manure. This observation showed that charged biochar has the ability to retain and enhance phosphorus absorption and reduce leaching losses (Glager *et al*., 2015; Isitekhale & Osemwota, 2010; Lehmann & Joseph, 2015; Ye *et al*., 2020). Charged biochar can also act as a slow release of P source, thereby maintaining plant available P in the rhizosphere over time (Xu *et al*., 2016).

The slight reduction of soil pH was observed across all treatments in this study (Table 15), which is a common phenomenon in organically amended soils due to microbial decomposition, nitrification, and root exudate activities (Manna *et al.,* 2005; Zaman *et al.,* 2010). Despite this occurrence, soil pH values for all treatments remained within the acceptable range (5.5 – 6.5) for optimal lettuce growth and development, and ensuring that macro- and micro-nutrients remained bio-available (Fageria, 2012; Havlin *et al.*, 2014).

The soil organic carbon and organic matter levels declined at post-production stage in all treatments (Table 15). This trend might be due to mineralization processes and microbial activity that convert organic inputs into bio-available nutrients (Agegnehu *et al*., 2016; Bationo *et al*., 2007). In addition, organic carbon may be utilized by plant roots and soil microbes or lost as CO_2 through respiration (Liang *et al.,* 2006). The observed reduction also suggests that the effective decomposition and nutrient cycling took place.

Significant increases in exchangeable potassium, magnesium, and calcium soil contents were observed in all treatments (Table 15). This increase might be as a result of cation exchange capacity of the organic soil fertilisers enhancing the soil nutrient holding capacity (Agyarko *et al.*, 2014; Biederman & Harpole, 2013; Chintala *et al.,* 2013). Organic fertilisers are known for their high buffering capacity that improves base saturation, particularly in highly weathered tropical soils (Palm *et al.*, 2001). However, total nitrogen content declined in all treatments post-harvest in this research. This reduction may be attributed to several factors, such as volatilization, leaching losses whenever it rained, and high plant demand during the peak vegetative growth and development stages, all of which have been observed and reported in various other studies (Giller & Cadisch, 1997; Murphy *et al*., 2007; Sakala *et al*., 2000).

5.2. Effects of Treatments on Lettuce Growth and Yield

5.2.1. Growth of lettuce

This study focused on four growth components of lettuce, thus: lettuce leaf diameter, plant height, number of leaves, and head diameter (Tables 16, 17, 18 and 19). Their results are discussed in the following sections.

5.2.1.1 Leaf diameter

The results showed that the effects of organic and synthetic fertilisers on lettuce became evident after the initial establishment phase (Table 16). Lack of significant differences at 14 DPT might be due to the lag phase in lettuce plant growth, as well as nutrient mineralization from organic sources, as reported in previous findings where organic amendments typically required microbial activity for nutrient mobilization (Agegnhu *et al.,* 2016; Lehmann and Joseph, 2015). From 21 DPT onwards, positive control consistently showed the largest leaf diameter, which simply meant that nutrients were available for immediate utilization. However, poultry manure and compost were similar to the positive control at 28 and 35 DPT, which agreed with previous findings of their high nutrient content and capacity to improve soil health in terms of structure and microbial activities for better plant growth (Chan *et al*., 2008; Glaser *et al.*, 2002).

In season 2, charged biochar demonstrated a significant growth promotion of lettuce leaf diameter at 21 DPT, which showed a statistically significant variation from negative control (Table 16). This was probably due to the improvement of soil nutrients, aeration, and moisture retention, as found by other researchers (Lehmann *et al*., 2011). Although charged biochar does not directly supply substantial nutrients, its synergistic effects on microbial populations contribute to mineralization that support better plant growth over time, while charged biochar provides nutrients in short terms compared with plain biochar (Bolan *et al*., 2024; Xiang *et al*., 2022; Xu *et al*., 2023).

5.2.1.2 Plant height

The results obtained showed an increase in lettuce plant height across all the treatments in both production seasons, which agreed with research findings on nutrient availability for vegetative plant growth and development (Agegnehu *et al.*, 2016; Amanullah *et al*., 2009). The observed increase in treatment differences in plant height after 28 to 35 DPT (Table 17) confirmed the cumulative effect of organic fertilisers on the dynamics of soil health enhancement and subsequent plant development. This trend reflects the gradual mineralization and sustained nutrient release from organic inputs, which improve soil nutrient availability and uptake efficiency over time (Adesemoye *et al*., 2009; Amanullah *et al*., 2009).

The results indicated that charged biochar had a strong effect on plant height in both production seasons, particularly when compared to negative control. The effects of charged biochar might have influenced soil aeration, structure, water retention and microbial activities, thereby improving nutrient use efficiency (Glaser *et al*., 2002; Lehmann and Joseph, 2015).

Poultry manure also showed beneficial effects on plant height, especially in the second production season (Table 16). This might be due to high nutrients such as N and P contents, which agree with other research findings on nutrient mineralization in poultry manure compared to compost and farmyard manure (Azeemm *et al*., 2011). However, the effect of poultry manure was less pronounced in season 2, probably due to nutrient leaching as a result of high rainfall observed during the second growing season (Palm *et al*., 2001). Similarly, season 2 showed that positive control had the highest plant height in season 1.

5.2.1.3 Number of leaves

Based on the present research findings, the number of leaves increased as plants continued to grow (Table 18). After three weeks post-transplanting, results showed that poultry manure, charged biochar, and positive control had a significant increase in number of leaves. Three weeks post-transplant is a stage of vegetative growth of lettuce plant during which nutrient availability becomes more complex (Ebrahimi *et al*., 2019). As mentioned in one of the research findings, well decomposed poultry manure is rich in readily available nutrients, especially nitrogen, which accelerate cell multiplication and leaf expansion (Oladele *et al*., 2020).

Charged biochar application is one of the amendments approaches that help to improve soil structure, aeration, nutrient retention, overall sustainable production, which were exhibited particularly in the second season; in addition, charged biochar has limited environmental impacts and mineralizes on a stable basis which agree with other research findings (Lehmann & Joseph, 2015). The positive control consistently produced the highest number of leaves, while compost had the lowest. Compost effect might be due to slow release and immobilization of nutrients, especially nitrogen within a short period of time (Hargreaves *et al*., 2008).

5.2.1.4 Lettuce head diameter

The results obtained clearly revealed that organic fertilisers used in the amendment of soil had significantly improved lettuce head development (size), particularly from the 44 to 58 DPT (Table 19). During this period, charged biochar, poultry manure, and farmyard manure performed consistently better in both growing seasons. It is possible that farmyard manure and poultry manure contributed to balancing of the soil macro- and micro-nutrient contents, which then promoted lettuce head growth. They are known to contribute to improved nutrient availability during most crucial stages of vegetative development and total biomass accumulation (Agegnehu *et al.,* 2016).

Charged biochar may have contributed to enhanced and improved plant growth through the ability to increasbiochare water retention, cation exchange capacity, mineralization of nutrients, and microbial colonization (Lehmann & Joseph, 2015). However, the delayed effectiveness of compost in the second season might have been due to slow release or mineralization of nutrients, as reported in previous research findings that the benefit of compost utilization by plants is more pronounced on a long-term basis (Hargreaves *et al*., 2008). The present research findings are similar to those of research studies done in the context of organic fertilisers for improvement of lettuce growth and yield (Ebrahimi *et al*., 2019; Oladele *et al*., 2020). However, the seasonal variation might have been due to the environmental conditions such as rain and temperature.

5.2.2. Yield of lettuce

5.2.2.1 Fresh weight

The findings showed distinct trends in lettuce fresh weight accumulation based on different inputs applied, as well as significant variations among organic fertilisers (Table 20). The yields observed in the present study were closely linked to the agronomic effectiveness of the applied inputs. Poultry manure treated beds produced the highest fresh weight yield of 2.6 ton/ha. This leading fresh weight was attributed to the immediate availability of essential nutrients, particularly nitrogen, which is critical in rapid vegetative growth of leafy vegetables such as lettuce (Palm *et al*., 2001). Garg *et al*. (2017) and Muhammad *et al.* (2019) also stated that poultry manure yielded higher compared to other organic fertilisers. Agegnehu *et al*. (2016) and Gwenzi *et al*. (2015) mentioned similar results by observing that it has high nutrient availability, immense effects on plant growth, and supports sustained plant uptake.

The negative control had the lowest fresh weight yields of 1.37 and 1.07 tons/ha in seasons 1 and 2, which may be as a result of limited nutrient availability (Table 20). The low yields of positive control in season 2 (2.0 ton/ha) compared to season 1 (2.6 ton/ha) might be due to heterogeneity of the experimental soil, climatic conditions observed during the peak period of production as well as unavailable nutrients for plant utilization. That is, too much rainfall was observed in season 2, which may have caused nutrient leaching and unavailability for lettuce uptake and growth.

The yields for charged biochar (1.97 and 1.81 ton/ha), farmyard manure (2.07 and 1.6 ton/ha), and compost (2.15 and 1.36 ton/ha) treatments were intermediate, but with no significant differences among these organic materials (Table 20). This response agreed with other research findings, which showed that organic fertilisers have the potential and ability to moderate soil nutrient sources for sustainable production processes (Li *et al*., 2021; Zhang *et al.*, 2020).

5.2.2.2 Dry biomass

The results showed that poultry manure and positive control significantly enhanced dry matter accumulation in lettuce plants (Figure 2). The poultry manure had the highest dry biomass compared to the other organic fertilisers. The positive effectiveness of poultry manure in both production seasons might be due to high mineralization during the vegetative stages which agreed with other research findings (Gachene *et al*., 2013; Mucheru-Muna *et al*., 2007; Zhao, 2014). In contrast, the low dry biomass production under compost and negative control might be due to limited or slow release of nutrients into the soil for plant uptake and use in growth.

In case of charged biochar treated beds, there was moderate effects on the dry weight of lettuce (Figure 2). However, there were no statistically significant differences between charged biochar and all other treatments in both production seasons, and this might be due to nutrient immobilization during the early application stages, which agrees with other research findings

(Lehmann & Joseph, 2015). The variations in dry weight among treatments might have been due to differential mobility of their nutrients in the soil, as well as interactions with environmental conditions that may have affected microbial activities involved in breaking-down of applied materials (Palm *et al*., 2001).

5.3. Effects of Treatments on Lettuce Quality and Mineral Nutrients

This research findings showed positive effects of organic soil amendments, particularly poultry manure, which enhanced the nutritional quality of lettuce, especially in terms of vitamin C accumulation (Figure 3, Table 21). The statistically significant differences of vitamin C concentration in lettuce tissues under poultry manure (Figure 3) was attributed to its high nutrient concentration and rapid mineralization, which improves the bioavailability of essential compounds involved in ascorbic acid biosynthesis (Lorence *et al.*, 2004). Vitamin C serves as a potent antioxidant in plant tissues and its concentration is often influenced by mineral nutrient availability, especially nitrogen and potassium, which are associated with synthesis of secondary metabolites, including vitamin C (Llorach *et al*., 2008; Smirnoff & Wheeler, 2024).

While mineral nutrient contents did not show any statistically significant variations among the treatments (Table 21), numerical differences were observed, which showed that compost and charged biochar had high values of nitrogen uptake. The present findings are consistent with several studies indicating that organic fertilisers can improve the nutritional quality and overall yield of vegetables through improved soil health (Adekiya *et al.*, 2019).

The trend of numerical differences indicated that the experimental organic fertilisers enhanced mineral nutrient accumulation in lettuce leaf tissues (Table 21). Garg *et al*. (2017) and Muhammad *et al*. (2019) reported that organic fertilisers improve nutrient content and absorption by plants, which impacts crop quality and yield. In contrast, charged biochar has been used to improve soil physical properties, as well as health, which might have long-term beneficial effects even if its effects are not noticeable immediately (Zhang *et al.*, 2020).

5.4. Effect of Treatments on Lettuce Net Economic Benefit

Findings of this study underscore the critical role of input type in determining the profitability of lettuce production (Figure 4). In season 1, the positive control produced the highest net economic benefit, which agrees with existing literature on the high responsiveness of lettuce to synthetic fertiliser that provides readily available nutrients particularly nitrogen known to be crucial in rapid vegetative growth that is sold for high income (Mugo *et al*., 2020; Palm *et al*., 2001). In season 2, poultry manure yielded higher NEB than all the other treatments, namely: positive control, farmyard manure, charged biochar, compost, and negative control (Figure 4). This might be due to the weather fluctuation during the production period. In season one had lower rainfall than season two, as indicated in Table 22 in the appendix. Lettuce is a cool season vegetable, that grown under favourable weather condition such as rainfall and temperature. This is in align with the weather data generated by KALRO, 2024 - 2025 on a monthly basis (Table 22). This indicated that poultry manure had the cumulative effect of nutrients and mineralization dynamics, that enhance lettuce growth and high yields as stated by other researchers (Agegnehu *et al*., 2016). The high yields translated into high income that surpassed the cost of inputs, hence generating highest net economic benefit (profitability). Poultry manure consistently ranked among the best treatments in both lettuce production and income generation in both production seasons (Figure 4). However, poultry manure's higher NEB in season 2 than in season 1 might be due to the availability of nutrients and absorption/mineralization ability, while in season 1 might be nutrients are unavailable for plant absorption/mineralization ability. It is rich in nitrogen and phosphorus, and has fast mineralization rate, making nutrients readily available to plants for growth, pumper harvests and profitability (Agegnehu *et al*., 2016).

In contrast, charged biochar had the lowest net economic benefit in season 1, as well as compost in season 2 (Figure 4), and this might be due to high cost of charged biochar during lettuce production, as well as its low immediate nutrient availability and immobilization potential that hinders vegetative growth, thereby translating into low yields and income (Lehmann & Joseph, 2015). Apparently, negative control out-performed charged biochar and compost in both production seasons (Figure 4); this might be due to high initial cost of charged biochar and compost used in this experiment that led to potential profits. Additionally, charged biochar and compost have slow release of mineral nutrients for utilization by plants, leading to low yields and hence low income (Nziguheba *et al*., 2010). In contrast, the negative control lacked the high input costs of charged biochar and compost (Figure 4), as well as their negative effects of lowering lettuce plant growth and yields, and by extension income, in the short-run.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

i. Charged biochar demonstrated consistent benefits across seasons by improving soil cation exchange capacity and phosphorus retention which contributed to a stable soil health condition. In addition, the initial soil conditions, characterized by low organic matter, poor nutrient availability, and limited moisture retention, were notably improved by the application of organic fertilisers.

ii. The study revealed that organic fertilisers significantly enhance lettuce growth, yield, as well as vitamin C accumulation in the edible tissue of lettuce.

iii. Economic analysis indicated that poultry manure provided the highest net economic benefit among the organic fertilisers, making it a cost-effective and sustainable alternative to synthetic fertilisers.

6.2. Recommendations

i. Poultry manure should be promoted as a primary organic material for amendment of soil and as an alternative to synthetic fertilisers in tropical lettuce production due to its high nutrient value and rapid mineralization. Agricultural policies and extension services should support the adoption of organic fertilisers, particularly poultry manure and charged biochar, through training and offering of incentives or subsidies to farmers in order to reduce heavy utilization of synthetic fertilisers. Charged biochar effects should be studied further in integrated soil fertility management programmes and to determine its long-term effects in improvement of soil structure, aeration, and nutrient retention.

ii. Further research should investigate the long-term residual effects of organic fertilisers under diverse climatic and soil conditions in enhancing productivity in terms of lettuce growth, yield, profitability, as well as micronutrients in the edible tissue.

iii. Poultry manure is recommended for lettuce production due to its high (Ksh 833/ $3m^2$) profitability. Additionally, detailed study of effects of organic fertilisers on net economic benefit of lettuce production on a large-scale is recommended.

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APPENDIX

Appendix i: Layout Showing Experimental And Guard Row Plants

		REPLICATION 1					REPLICATION 2					REPLICATION 3		
O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	X	X	X	O	O	X	X	X	O	O	X	X	X	O
O	O	O	O	O	O	O	O	O	O	O	O	O	O	O

Key: x = Experimental row lettuce; o = Guard row lettuce

Appendix ii: Analysis of variance Outputs

Soil Properties

pH

		S1				S2			
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Replication	2	0.1070	0.05351	4.28	0.045	0.02333	0.01167	0.81	0.470
Treatment	5	0.1896	0.03793	3.04	0.064	0.11333	0.02267	1.58	0.251
Error	10	0.1249	0.01249			0.14333	0.01433		
Total	17	0.4216				0.28000			

	S1		S2	
Treatment	**Fitted Mean**	**SE Mean**	**Fitted Mean**	**SE Mean**
Farmyard manure	6.4367	0.0645	6.1000	0.0691
Negative control (Soil)	6.3433	0.0645	6.0333	0.0691
Charged Biochar	6.2767	0.0645	6.2000	0.0691
Poultry manure	6.4033	0.0645	6.1667	0.0691
Compost	6.2967	0.0645	6.2333	0.0691
Positive control (NPK + urea)	6.1200	0.0645	6.2667	0.0691

CEC

		S1				S2			
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Replication	2	1.333	0.6667	0.03	0.969	39.24	19.620	1.43	0.284
Treatment	5	52.667	10.5333	0.50	0.772	31.87	6.373	0.46	0.794
Error	10	212.000	21.2000			137.13	13.713		
Total	17	266.000				208.24			

	S1		S2	
Treatment	**Fitted Mean**	**SE Mean**	**Fitted Mean**	**SE Mean**
Farmyard manure	20.00	2.66	32.67	2.14
Negative control (Soil)	20.00	2.66	29.33	2.14
Charged Biochar	24.00	2.66	29.20	2.14
Poultry manure	22.67	2.66	30.67	2.14
Compost	19.33	2.66	30.67	2.14
Positive control (NPK + urea)	20.00	2.66	28.67	2.14

Organic Carbon

		S1				S2			
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Replication	2	0.1744	0.08722	1.27	0.323	0.1452	0.07262	1.01	0.400
Treatment	5	0.2426	0.04853	0.71	0.632	0.6931	0.13862	1.92	0.178
Error	10	0.6870	0.06870			0.7219	0.07219		
Total	17	1.1040				1.5602			

	S1		S2	
Treatment	**Fitted Mean**	**SE Mean**	**Fitted Mean**	**SE Mean**
Farmyard manure	2.460	0.151	2.960	0.155
Negative control (Soil)	2.103	0.151	2.867	0.155
Charged Biochar	2.293	0.151	2.833	0.155
Poultry manure	2.280	0.151	3.317	0.155
Compost	2.430	0.151	3.317	0.155
Positive control (NPK + urea)	2.327	0.151	3.033	0.155

Nitrogen

		S1				S2			
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Replication	2	0.007078	0.003539	16.68	0.001	0.006178	0.003089	1.09	0.374
Treatment	5	0.005178	0.001036	4.88	0.016	0.016361	0.003272	1.15	0.396
Error	10	0.002122	0.000212			0.028422	0.002842		
Total	17	0.014378				0.050961			

	S1		S2	
Treatment	**Fitted Mean**	**SE Mean**	**Fitted Mean**	**SE Mean**
Farmyard manure	0.16667b	0.00841	0.3100	0.0308
Negative control (Soil)	0.19000ab	0.00841	0.3000	0.0308
Charged Biochar	0.19000ab	0.00841	0.3300	0.0308
Poultry manure	0.19333ab	0.00841	0.3267	0.0308
Compost	0.17333b	0.00841	0.2567	0.0308
Positive control (NPK + urea)	0.22000a	0.00841	0.3533	0.0308

Phosphorous

		S1				S2			
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Replication	2	1617	808.7	0.60	0.568	2923	1461.6	3.82	0.059
Treatment	5	11410	2282.0	1.69	0.225	1748	349.6	0.91	0.510
Error	10	13517	1351.7			3826	382.6		
Total	17	26544				8498			

	S1		S2	
Treatment	**Fitted Mean**	**SE Mean**	**Fitted Mean**	**SE Mean**
Farmyard manure	120.3	21.2	37.9	11.3
Negative control (Soil)	90.6	21.2	23.1	11.3
Charged Biochar	169.5	21.2	30.8	11.3
Poultry manure	128.9	21.2	52.5	11.3
Compost	133.7	21.2	28.3	11.3
Positive control (NPK + urea)	102.0	21.2	25.7	11.3

Potassium

		S1				S2			
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Replication	2	208.7	104.33	3.51	0.070	5386.5	2693.3	9.16	0.005
Treatment	5	4441.9	888.39	29.91	0.000	743.2	148.6	0.51	0.766
Error	10	297.0	29.70			2941.1	294.1		
Total	17	4947.6				9070.8			

	S1		S2	
Treatment	**Fitted Mean**	**SE Mean**	**Fitted Mean**	**SE Mean**
Farmyard manure	2.03b	3.15	36.65	9.90
Negative control (Soil)	44.97a	3.15	30.32	9.90
Charged Biochar	42.07a	3.15	43.72	9.90
Poultry manure	39.80a	3.15	45.49	9.90
Compost	45.10a	3.15	27.79	9.90
Positive control (NPK + urea)	46.78a	3.15	35.63	9.90

Magnesium

		S1				S2			
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Replication	2	713.5	356.7	1.49	0.272	1316	658.2	2.71	0.115
Treatment	5	1839.8	368.0	1.53	0.264	7462	1492.3	6.14	0.007
Error	10	2400.7	240.1			2429	242.9		
Total	17	4954.0				11207			

	S1S2			
Treatment	**Fitted Mean**	**SE Mean**	**Fitted Mean**	**SE Mean**
Farmyard manure	193.40	8.95	35.26b	9.00
Negative control (Soil)	190.43	8.95	74.16a	9.00
Charged Biochar	169.43	8.95	47.96b	9.00
Poultry manure	195.93	8.95	18.06b	9.00
Compost	196.70	8.95	71.56a	9.00
Positive control (NPK + urea)	200.23	8.95	64.84a	9.00

Calcium

		S1				S2			
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Replication	2	23294	11647	0.84	0.460	20891	10445	3.07	0.092
Treatment	5	998458	199692	14.42	0.000	15319	3064	0.90	0.517
Error	10	138455	13846			34063	3406		
Total	17	1160208				70272			

	S1		S2	
Treatment	**Fitted Mean**	**SE Mean**	**Fitted Mean**	**SE Mean**
Farmyard manure	168.2b	67.9	548.1	33.7
Negative control (Soil)	802.5a	67.9	481.1	33.7
Charged Biochar	799.0a	67.9	550.5	33.7
Poultry manure	803.2a	67.9	561.2	33.7
Compost	802.0a	67.9	555.7	33.7
Positive control (NPK + urea)	794.0a	67.9	569.8	33.7

Organic Matter

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Replication	2	0.5185	0.2592	1.27	0.323	0.4317	0.2158	1.01	0.400
Treatment	5	0.7212	0.1442	0.71	0.632	2.0600	0.4120	1.92	0.178
Error	10	2.0418	0.2042			2.1456	0.2146		
Total	17	3.2814				4.6373			

Treatment	**Fitted Mean**	**SE Mean**	**Fitted Mean**	**SE Mean**
Farmyard manure	4.241	0.261	5.103	0.267
Negative control (Soil)	3.626	0.261	4.942	0.267
Charged Biochar	3.954	0.261	4.885	0.267
Poultry manure	3.931	0.261	5.718	0.267
Compost	4.189	0.261	5.718	0.267
Positive control (NPK + urea)	4.011	0.261	5.229	0.267

Carbon: Nitrogen (C: N) Ratio

		S1				S2			
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Replication	2	19.19	9.593	1.78	0.217	2.491	1.246	0.35	0.716
Treatment	5	56.55	11.309	2.10	0.148	41.475	8.295	2.30	0.123
Error	10	53.77	5.377			36.078	3.608		
Total	17	129.50				80.045			

	S1		S2	
Treatment	**Fitted Mean**	**SE Mean**	**Fitted Mean**	**SE Mean**
Farmyard manure	15.66	1.34	9.69	1.10
Negative control (Soil)	11.12	1.34	10.12	1.10
Charged Biochar	12.22	1.34	8.67	1.10
Poultry manure	11.74	1.34	10.17	1.10
Compost	14.17	1.34	13.16	1.10
Positive control (NPK + urea)	10.61	1.34	8.59	1.10

Lettuce Components and NEB

Season 1

LETTUCE LEAF DIAMETER: 14 DPT

Level		Least Sq Mean	Std Error		
Farmyard manure	A	4.0666667	0.32215	Mean	3.6722222
Compost	A	3.8933333	0.32215	Std Dev	0.5766593
Positive control	A	3.8066667	0.32215	Std Err Mean	0.1359199
Charged Biochar	A	3.7033333	0.32215	Upper 95% Mean	3.9589881
Poultry manure	A	3.5166667	0.32215	Lower 95% Mean	3.3854563
Negative control	A	3.0466667	0.32215	N	18
				Variance	0.3325359
				CV	15.703279
				N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Leaf Diameter	5	5	10	1.1397	0.4006

LETTUCE LEAF DIAMETER: 21 DPT

Level			Least Sq Mean	Std Error		
Positive control	A		7.3200000	0.46916	Mean	6.2872222
Charged Biochar	A	B	6.6566667	0.46916	Std Dev	1.0069161
Compost	A	B	6.5066667	0.46916	Std Err Mean	0.2373324
Poultry manure	A	B	6.1500000	0.46916	Upper 95% Mean	6.7879498
Farmyard manure	A	B	6.1500000	0.46916	Lower 95% Mean	5.7864946
Negative control		B	4.9400000	0.46916	N	18
					Variance	1.0138801
					CV	16.015278
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Leaf diameter	5	5	10	3.2316	0.0540

LETTUCE LEAF DIAMETER: 28 DPT

Level			Least Sq Mean	Std Error		
Positive control	A		11.036667	0.69228	Std Dev	1.6475481
Farmyard manure	A		10.533333	0.69228	Std Err Mean	0.3883308
Compost	A		10.313333	0.69228	Upper 95% Mean	10.390973
Charged Biochar	A	B	9.443333	0.69228	Lower 95% Mean	8.7523603
Poultry manure	A	B	8.880000	0.69228	N	18
Negative control		B	7.223333	0.69228	Variance	2.7144147
					CV	17.212761
					N Missing	0

Mean: 9.5716667

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Leaf diameter	5	5	10	4.9842	0.0150*

LETTUCE LEAF DIAMETER: 35 DPT

Level			Least Sq Mean	Std Error	Mean	13.138333
Positive control	A		15.536667	1.0057	Std Dev	2.330792
Compost	A	B	14.220000	1.0057	Std Err Mean	0.5493729
Farmyard manure	A	B	14.056667	1.0057	Upper 95% Mean	14.297409
Charged Biochar	A	B	13.110000	1.0057	Lower 95% Mean	11.979258
Poultry manure	A	B	11.770000	1.0057	N	18
Negative control		B	10.136667	1.0057	Variance	5.4325912
					CV	17.740393
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Leaf diameter	5	5	10	4.3728	0.0227*

LETTUCE PLANT HEIGHT: 14 DPT

Level			Least Sq Mean	Std Error	Mean	13.027778
Charged Biochar	A		13.800000	0.62642	Std Dev	1.4435111
Positive control	A		13.756667	0.62642	Std Err Mean	0.3402388
Poultry manure	A		13.423333	0.62642	Upper 95% Mean	13.745619
Farmyard manure	A		13.343333	0.62642	Lower 95% Mean	12.309937
Compost	A	B	13.200000	0.62642	N	18
Negative control		B	10.643333	0.62642	Variance	2.0837242
					CV	11.080255
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Plant height	5	5	10	5.0689	0.0142*

LETTUCE PLANT HEIGHT: 21 DPT

Level			Least Sq Mean	Std Error		
Positive control	A		17.333333	0.88359	Std Dev	1.8920795
Charged Biochar	A		17.300000	0.88359	Std Err Mean	0.4459674
Farmyard manure	A	B	16.556667	0.88359	Upper 95% Mean	17.110909
Compost	A	B	16.276667	0.88359	Lower 95% Mean	15.229091
Poultry manure	A	B	16.233333	0.88359	N	18
Negative control		B	13.320000	0.88359	Variance	3.5799647
					CV	11.701172
					N Missing	0

Mean 16.17

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Plant height	5	5	10	3.4432	0.0455*

LETTUCE PLANT HEIGHT: 28 DPT

Level			Least Sq Mean	Std Error	Mean	18.883333
Charged Biochar	A		20.666667	1.0494	Std Dev	2.1063238
Positive control	A		20.000000	1.0494	Std Err Mean	0.4964653
Farmyard manure	A	B	19.086667	1.0494	Upper 95% Mean	19.930784
Compost	A	B	18.846667	1.0494	Lower 95% Mean	17.835883
Poultry manure	A	B	18.523333	1.0494	N	18
Negative control		B	16.176667	1.0494	Variance	4.4366
					CV	11.154407
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Plant height	5	5	10	4.0547	0.0285*

LETTUCE PLANT HEIGHT: 35 DPT

Level			Least Sq Mean	Std Error	Mean	21.561111
Positive control	A		25.100000	1.1516	Std Dev	2.6736863
Charged Biochar	A	B	22.666667	1.1516	Std Err Mean	0.6301939
Farmyard manure		B C	21.443333	1.1516	Upper 95% Mean	22.890704
Compost		B C	21.053333	1.1516	Lower 95% Mean	20.231518
Poultry manure		B C	20.670000	1.1516	N	18
Negative control		C	18.433333	1.1516	Variance	7.1485987
					CV	12.400504
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Plant height	5	5	10	9.1786	0.0017*

LETTUCE NUMBER OF LEAVES: 14 DPT

Level		Least Sq Mean	Std Error	Mean	3.8333333
Poultry manure	A	4.3333333	0.33333	Std Dev	0.6183469
Positive control	A	4.3333333	0.33333	Std Err Mean	0.1457458
Charged Biochar	A	3.6666667	0.33333	Upper 95% Mean	4.14083
Farmyard manure	A	3.6666667	0.33333	Lower 95% Mean	3.5258366
Negative control	A	3.6666667	0.33333	N	18
Compost	A	3.3333333	0.33333	Variance	0.3823529
				CV	16.13079
				N Missing	0

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Number of leaves	5	5	10	1.6667	0.2298

LETTUCE NUMBER OF LEAVES: 21 DPT

Level		Least Sq Mean	Std Error	Mean	6.3888889
Positive control	A	7.3333333	0.33333	Std Dev	0.6978023
Poultry manure	A	6.6666667	0.33333	Std Err Mean	0.1644736
Charged Biochar	A	6.3333333	0.33333	Upper 95% Mean	6.7358978
Compost	A	6.0000000	0.33333	Lower 95% Mean	6.0418799
Farmyard manure	A	6.0000000	0.33333	N	18
Negative control	A	6.0000000	0.33333	Variance	0.4869281
				CV	10.922124
				N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Number of leaves	5	5	10	2.4062	0.1112

LETTUCE NUMBER OF LEAVES: 28 DPT

Level			Least Sq Mean	Std Error	Mean	9.6666667
Poultry manure	A		11.666667	0.59317	Std Dev	1.4552138
Positive control	A	B	10.666667	0.59317	Std Err Mean	0.3429972
Charged Biochar	A	B	9.333333	0.59317	Upper 95% Mean	10.390327
Compost	A	B	9.000000	0.59317	Lower 95% Mean	8.9430059
Negative control	A	B	9.000000	0.59317	N	18
Farmyard manure		B	8.333333	0.59317	Variance	2.1176471
					CV	15.053935
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Number of leaves	5	5	10	3.7838	0.0349*

LETTUCE NUMBER OF LEAVES: 35 DPT

Level			Least Sq Mean	Std Error	Mean	13.444444
Poultry manure	A		15.000000	0.69389	Std Dev	1.6880975
Charged Biochar	A	B	14.333333	0.69389	Std Err Mean	0.3978884
Positive control	A	B	14.333333	0.69389	Upper 95% Mean	14.283916

Level			Least Sq Mean	Std Error		
Compost	A	B	13.000000	0.69389	Lower 95% Mean	12.604973
Farmyard manure	A	B	13.000000	0.69389	N	18
Negative control		B	11.000000	0.69389	Variance	2.8496732
					CV	12.556097
					N Missing	0

(Mean: 13.444444)

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Number of leaves	5	5	10	3.9161	0.0316*

LETTUCE HEAD DIAMETER: 44 DPT

Level			Least Sq Mean	Std Error	Mean	16.758333
Positive control	A		19.056667	0.74669	Std Dev	2.3034022
Poultry manure	A		17.753333	0.74669	Std Err Mean	0.5429171
Charged Biochar	A		17.323333	0.74669	Upper 95% Mean	17.903788
Farmyard manure	A		17.166667	0.74669	Lower 95% Mean	15.612878
Compost	A		16.563333	0.74669	N	18
Negative control		B	12.686667	0.74669	Variance	5.3056618
					CV	13.744817
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Head diameter	5	5	10	7.8739	0.0030*

LETTUCE HEAD DIAMETER: 51 DPT

Levels not connected by the same letter are significantly different

Level			Least Sq Mean	Std Error	Mean	18.968889
Positive control	A		21.033333	0.84654	Std Dev	2.3979572
Charged Biochar	A		19.866667	0.84654	Std Err Mean	0.5652039
Poultry manure	A		19.756667	0.84654	Upper 95% Mean	20.161365
Compost	A		19.343333	0.84654	Lower 95% Mean	17.776413
Farmyard manure	A		19.103333	0.84654	N	18
Negative control		B	14.710000	0.84654	Variance	5.7501987
					CV	12.641527
					N Missing	0

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Head diameter	5	5	10	6.5914	0.0058*

LETTUCE HEAD DIAMETER: 58 DPT

Level		Least Sq Mean	Std Error	Mean	21.193889
Positive control	A	22.786667	0.94848	Std Dev	2.5073378
Charged Biochar	A	22.336667	0.94848	Std Err Mean	0.5909852
Poultry manure	A	22.253333	0.94848	Upper 95% Mean	22.440759
Compost	A	21.786667	0.94848	Lower 95% Mean	19.947019

Farmyard manure	A	B	21.223333	0.94848	N	18
Negative control		B	16.776667	0.94848	Variance	6.2867428
					CV	11.830475
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Head diameter	5	5	10	5.3260	0.0121*

LETTUCE FRESH WEIGHT: 66 DPT

Level			Least Sq Mean	Std Error	Mean	623.05556
positive control	A		774.33333	50.720	Std Dev	136.30091
poultry manure	A		694.00000	50.720	Std Err Mean	32.126432
compost	A	B	645.66667	50.720	Upper 95% Mean	690.8364
farmyard manure	A	B	622.00000	50.720	Lower 95% Mean	555.27471
Charged Biochar	A	B	591.33333	50.720	N	18
negative control		B	411.00000	50.720	Variance	18577.938
					CV	21.876205
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Fresh weight	5	5	10	5.6666	0.0098*

LETTUCE DRY WEIGHT: 66 DPT

Level			Least Sq Mean	Std Error	Mean	35.444444
Positive control	A		44.000000	2.9408	Std Dev	7.6943235
Poultry manure	A		39.333333	2.9408	Std Err Mean	1.8135694
Compost	A	B	36.666667	2.9408	Upper 95% Mean	39.270742
Farmyard manure	A	B	35.333333	2.9408	Lower 95% Mean	31.618147
charged Biochar	A	B	33.666667	2.9408	N	18
Negative control		B	23.666667	2.9408	Variance	59.202614
					CV	21.708123
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Dry weight	5	5	10	5.3769	0.0117*

LETTUCE QUALITY PARAMETERS

Vitamin C in Leaf Tissue

Level		Least Sq Mean	Std Error		
Poultry manure	A	128.63333	20.763	Mean	99.26
Negative control	A	124.65333	20.763	Std Dev	38.672687
Positive control	A	106.70667	20.763	Std Err Mean	9.1152398
Compost	A	95.80333	20.763	Upper 95% Mean	118.49147
Farmyard manure	A	70.44000	20.763	Lower 95% Mean	80.028525
Charged Biochar	A	69.32333	20.763	N	18
				Variance	1495.5767
				CV	38.960999
				N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Vitamin C	5	5	10	2.3715	0.1149

Nitrogen in Leaf Tissue

Level		Least Sq Mean	Std Error		
Compost	A	3.7233333	0.36388	Mean	3.3472222
Charged Biochar	A	3.5900000	0.36388	Std Dev	0.5947694
Farmyard manure	A	3.4033333	0.36388	Std Err Mean	0.1401885
Positive control	A	3.2433333	0.36388	Upper 95% Mean	3.6429941
Poultry manure	A	3.2000000	0.36388	Lower 95% Mean	3.0514504
Negative control	A	2.9233333	0.36388	N	18
				Variance	0.3537507
				CV	17.769045
				N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Leaf tissue N	5	5	10	0.8954	0.5197

Potassium in Leaf Tissue

Level		Least Sq Mean	Std Error		
Farmyard manure	A A	3.9367	0.28562	Mean	3.6622222
Poultry manure	A A	3.6967	0.28562	Std Dev	0.4514103
Positive control	A A	3.6867	0.28562	Std Err Mean	0.1063984
Charged Biochar	A A	3.6733	0.28562	Upper 95% Mean	3.8867033
Compost	A A	3.6300	0.28562	Lower 95% Mean	3.4377412
Negative control	A A	3.3500	0.28562	N	18
				Variance	0.2037712
				CV	12.32613
				N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Leaf tissue K	5	5	10	0.3923	0.8433

Magnesium in Leaf Tissue

Level		Least Sq Mean	Std Error	Mean	0.2166667
Poultry Manure	A	0.22333333	0.00793	Std Dev	0.0123669
Compost	A	0.22000000	0.00793	Std Err Mean	0.0029149
Charged Biochar	A	0.21666667	0.00793	Upper 95% Mean	0.2228166
Farmyard Manure	A	0.21666667	0.00793	Lower 95% Mean	0.2105167
Positive Control	A	0.21333333	0.00793	N	18
Negative Control	A	0.21000000	0.00793	Variance	0.0001529
				CV	5.7078179
				N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Leaf tissue Mg	5	5	10	0.5000	0.7700

Calcium in Leaf Tissue

Level		Least Sq Mean	Std Error	Mean	0.2477778
Charged Biochar	A	0.28333333	0.01563	Std Dev	0.0298142
Compost	A	0.25666667	0.01563	Std Err Mean	0.0070273
Poultry Manure	A	0.25000000	0.01563	Upper 95% Mean	0.2626041
Positive Control	A	0.23666667	0.01563	Lower 95% Mean	0.2329515
Farmyard Manure	A	0.23000000	0.01563	N	18
Negative Control	A	0.23000000	0.01563	Variance	0.0008889
				CV	12.032653
				N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Leaf tissue Ca	5	5	10	1.5800	0.2514

Net Economic Benefit (NEB)

Level				Least Sq Mean	Std Error	Mean	506.78333
Positive control	A			777.536	60.900	Std Dev	210.13727
Poultry manure	A	B		542.628	60.900	Std Err Mean	49.529829
Farmyard manure	A	B		523.117	60.900	Upper 95% Mean	611.28214
Negative control		B	C	362.524	60.900	Lower 95% Mean	402.28453
Compost		B	C	401.225	60.900	N	18
Charged Biochar			C	216.696	60.900	Variance	44157.671
						CV	41.464913
						N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Net Economic Benefit	5	5	10	11.1573	0.001*

Season 2

LETTUCE LEAF DIAMETER: 14 DPT

Level		Least Sq Mean	Std Error		
				Mean	3.2455556
Compost	A	3.5233333	0.17883	Std Dev	0.3214896
Farmyard manure	A	3.3366667	0.17883	Std Err Mean	0.0757758
Positive control	A	3.2633333	0.17883	Upper 95% Mean	3.4054286
Charged Biochar	A	3.2533333	0.17883	Lower 95% Mean	3.0856825
Negative control	A	3.1866667	0.17883	N	18
Poultry manure	A	2.9100000	0.17883	Variance	0.1033556
				CV	9.9055334
				N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Leaf diameter	5	5	10	1.3270	0.3281

LETTUCE LEAF DIAMETER: 21 DPT

Level		Least Sq Mean	Std Error		
				Mean	4.795
Charged Biochar	A	5.6333333	0.28832	Std Dev	0.6774194
Farmyard manure	A B	5.1066667	0.28832	Std Err Mean	0.1596693
Compost	A B	4.9566667	0.28832	Upper 95% Mean	5.1318727
Poultry manure	A B	4.5566667	0.28832	Lower 95% Mean	4.4581273
Positive control	A B	4.5266667	0.28832	N	18
Negative control	B	3.9900000	0.28832	Variance	0.4588971
				CV	14.127621
				N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Leaf diameter	5	5	10	4.1587	0.0264*

LETTUCE LEAF DIAMETER: 28 DPT

Level		Least Sq Mean	Std Error		
				Mean	6.6961111
Compost	A	7.7566667	0.53152	Std Dev	1.1399904
Farmyard manure	A B	7.1133333	0.53152	Std Err Mean	0.2686983
Charged Biochar	A B	6.8733333	0.53152	Upper 95% Mean	7.263015
Poultry manure	A B	6.8733333	0.53152	Lower 95% Mean	6.1292072
Positive control	A B	6.4633333	0.53152	N	18
Negative control	B	5.0966667	0.53152	Variance	1.2995781
				CV	17.024664
				N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Leaf diameter	5	5	10	4.3444	0.0232*

LETTUCE LEAF DIAMETER: 35 DPT

Level			Least Sq Mean	Std Error		
					Mean	9.7155556
Poultry manure	A		10.890000	0.66606	Std Dev	1.3918174
Farmyard manure	A	B	10.566667	0.66606	Std Err Mean	0.3280545
Compost	A	B	9.906667	0.66606	Upper 95% Mean	10.40769
Charged Biochar	A	B	9.846667	0.66606	Lower 95% Mean	9.0234211
Positive control	A	B	9.150000	0.66606	N	18
Negative control		B	7.933333	0.66606	Variance	1.9371556
					CV	14.325659
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Leaf diameter	5	5	10	3.5828	0.0407*

LETTUCE PLANT HEIGHT: 14 DPT

Level			Least Sq Mean	Std Error		
					Mean	8.4727778
Charged Biochar	A		9.1666667	0.52210	Std Dev	0.9702808
Farmyard manure	A	B	8.8566667	0.52210	Std Err Mean	0.2286974
Positive control	A	B	8.6333333	0.52210	Upper 95% Mean	8.9552871
Poultry manure	A	B	8.6333333	0.52210	Lower 95% Mean	7.9902685
Compost	A	B	8.2233333	0.52210	N	18
Negative control		B	7.3233333	0.52210	Variance	0.9414448
					CV	11.451743
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Plant height	5	5	10	3.0644	0.0621

LETTUCE PLANT HEIGHT: 21 DPT

Level			Least Sq Mean	Std Error		
					Mean	10.318333
Farmyard manure	A		10.986667	0.25392	Std Dev	0.6471589
Charged Biochar	A		10.690000	0.25392	Std Err Mean	0.1525368
Compost	A	B	10.366667	0.25392	Upper 95% Mean	10.640158
Poultry manure	A	B	10.366667	0.25392	Lower 95% Mean	9.9965088
Positive control	A	B	10.176667	0.25392	N	18
Negative control		B	9.323333	0.25392	Variance	0.4188147
					CV	6.271933
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Plant height	5	5	10	6.0183	0.0080*

LETTUCE PLANT HEIGHT: 28 DPT

Level			Least Sq Mean	Std Error		
Poultry manure	A		13.143333	0.48331	Mean	12.137222
Farmyard manure	A		12.690000	0.48331	Std Dev	1.0220211
Charged Biochar	A	B	12.333333	0.48331	Std Err Mean	0.2408927
Positive control	A	B	11.913333	0.48331	Upper 95% Mean	12.645461
Compost	A	B	11.890000	0.48331	Lower 95% Mean	11.628983
Negative control		B	10.853333	0.48331	N	18
					Variance	1.0445271
					CV	8.4205519
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Plant height	5	5	10	4.9024	0.0158*

LETTUCE PLANT HEIGHT: 35 DPT

Level				Least Sq Mean	Std Error		
Poultry manure	A			17.323333	0.64411	Mean	15.382778
Charged Biochar	A	B		16.966667	0.64411	Std Dev	1.9216715
Farmyard manure	A	B		16.223333	0.64411	Std Err Mean	0.4529423
Positive control	A	B	C	15.143333	0.64411	Upper 95% Mean	16.338403
Compost		B	C	13.766667	0.64411	Lower 95% Mean	14.427153
Negative control			C	12.873333	0.64411	N	18
						Variance	3.6928212
						CV	12.492357
						N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Plant height	5	5	10	7.3126	0.0040*

LETTUCE NUMBER OF LEAVES: 14 DPT

Level		Least Sq Mean	Std Error		
Poultry manure	A	3.0000000	0.13608	Mean	2.9444444
Charged Biochar	A	3.0000000	0.13608	Std Dev	0.2357023
Farmyard manure	A	3.0000000	0.13608	Std Err Mean	0.0555556
Negative control	A	3.0000000	0.13608	Upper 95% Mean	3.0616564
Positive control	A	3.0000000	0.13608	Lower 95% Mean	2.8272325
Compost	A	2.6666667	0.13608	N	18
				Variance	0.0555556
				CV	8.0049824
				N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Number of leaves	5	5	10	1.0000	0.4651

LETTUCE NUMBER OF LEAVES: 21 DPT

Level			Least Sq Mean	Std Error	Mean	5.1111111
Positive control	A		6.0000000	0.30429	Std Dev	0.7583953
Charged Biochar	A	B	5.6666667	0.30429	Std Err Mean	0.1787555
Farmyard manure	A	B	5.3333333	0.30429	Upper 95% Mean	5.4882522
Negative control	A	B	4.6666667	0.30429	Lower 95% Mean	4.73397
Poultry manure	A	B	4.6666667	0.30429	N	18
Compost		B	4.3333333	0.30429	Variance	0.5751634
					CV	14.838168
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Number of leaves	5	5	10	5.0435	0.0145*

LETTUCE NUMBER OF LEAVES: 28 DPT

Level			Least Sq Mean	Std Error	Mean	7.6111111
Positive control	A		8.6666667	0.23570	Std Dev	0.6978023
Charged Biochar	A	B	8.0000000	0.23570	Std Err Mean	0.1644736
Farmyard manure	A	B	7.6666667	0.23570	Upper 95% Mean	7.9581201
Poultry manure		B	7.3333333	0.23570	Lower 95% Mean	7.2641022
Compost		B	7.0000000	0.23570	N	18
Negative control		B	7.0000000	0.23570	Variance	0.4869281
					CV	9.1682059
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Number of leaves	5	5	10	6.6471	0.0056*

LETTUCE NUMBER OF LEAVES: 35 DPT

Level					Least Sq Mean	Std Error	Mean	10.277778
Positive control	a				11.333333	0.23570	Std Dev	0.8947925
Charged Biochar	a	b			11.000000	0.23570	Std Err Mean	0.2109046
Farmyard manure	a	b	c		10.666667	0.23570	Upper 95% Mean	10.722748
Poultry manure		b	c	d	10.000000	0.23570	Lower 95% Mean	9.8328079
Compost			c	d	9.666667	0.23570	N	18
Negative control				d	9.000000	0.23570	Variance	0.8006536

Level			Least Sq Mean	Std Error	Mean	10.277778
					CV	8.7060891
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Number of leaves	5	5	10	14.9286	0.0002*

LETTUCE HEAD DIAMETER: 44 DPT

Level			Least Sq Mean	Std Error	Mean	18.086111
Charged Biochar	A		19.700000	0.80344	Std Dev	1.9654221
Farmyard manure	A		19.466667	0.80344	Std Err Mean	0.4632544
Poultry manure	A		19.083333	0.80344	Upper 95% Mean	19.063493
Compost	A	B	17.533333	0.80344	Lower 95% Mean	17.10873
Positive control	A	B	17.466667	0.80344	N	18
Negative control		B	15.266667	0.80344	Variance	3.862884
					CV	10.867024
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Head diameter	5	5	10	5.4999	0.0109*

LETTUCE HEAD DIAMETER: 51 DPT

Level			Least Sq Mean	Std Error	Mean	19.963889
Charged Biochar	A		21.666667	0.75810	Std Dev	1.9599524
Farmyard manure	A		21.333333	0.75810	Std Err Mean	0.4619652
Poultry manure	A		20.966667	0.75810	Upper 95% Mean	20.93855
Positive control	A	B	19.416667	0.75810	Lower 95% Mean	18.989227
Compost	A	B	19.333333	0.75810	N	18
Negative control		B	17.066667	0.75810	Variance	3.8414134
					CV	9.817488
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Head diameter	5	5	10	6.9884	0.0047*

LETTUCE HEAD DIAMETER: 58 DPT

Level		Least Sq Mean	Std Error	Mean	21.627778
Charged Biochar	A	23.100000	0.65673	Std Dev	1.6798304
Poultry manure	A	22.550000	0.65673	Std Err Mean	0.3959398
Farmyard manure	A	22.433333	0.65673	Upper 95% Mean	22.463138

Level			Least Sq Mean	Std Error		
Positive control	A	B	21.366667	0.65673	Mean	21.627778
Compost	A	B	21.333333	0.65673	Lower 95% Mean	20.792418
Negative control		B	18.983333	0.65673	N	18
					Variance	2.8218301
					CV	7.767004
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Head diameter	5	5	10	5.5589	0.0105*

LETTUCE FRESH WEIGHT: 66 DPT

Level			Least Sq Mean	Std Error		
					Mean	520.62944
Poultry manure	A		773.33333	69.635	Std Dev	179.08565
Positive control	A	B	595.66667	69.635	Std Err Mean	42.210892
Charged Biochar	A	B	543.88667	69.635	Upper 95% Mean	609.68664
Farmyard manure	A	B	479.78000	69.635	Lower 95% Mean	431.57225
Compost		B	408.89000	69.635	N	18
Negative control		B	322.22000	69.635	Variance	32071.669
					CV	34.39791
					N Missing	0

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Fresh weight	5	5	10	4.6626	0.0186*

LETTUCE DRY WEIGHT: 66 DPT

Level			Least Sq Mean	Std Error		
					Mean	31.833333
Poultry manure	A		47.333333	4.2251	Std Dev	10.955794
Positive control	A	B	36.666667	4.2251	Std Err Mean	2.5823053
Charged Biochar	A	B	33.000000	4.2251	Upper 95% Mean	37.281521
Farmyard manure	A	B	29.333333	4.2251	Lower 95% Mean	26.385145
Compost		B	25.000000	4.2251	N	18
Negative control		B	19.666667	4.2251	Variance	120.02941
					CV	34.416105
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Dry weight	5	5	10	4.8424	0.0165*

LETTUCE QUALITY PARAMETERS

Vitamin C in Leaf Tissue

Level			Least Sq Mean	Std Error	Mean	1.155
Farmyard manure	A		1.3933333	0.08573	Std Dev	0.1903325
Compost	A	B	1.2366667	0.08573	Std Err Mean	0.0448618
Charged Biochar	A	B	1.1633333	0.08573	Upper 95% Mean	1.2496501
Positive control	A	B	1.1333333	0.08573	Lower 95% Mean	1.0603499
Negative control	A	B	1.0566667	0.08573	N	18
Poultry manure		B	0.9466667	0.08573	Variance	0.0362265
					CV	16.479007
					N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Net economic benefit	5	5	10	3.3828	0.0477*

Nitrogen in Leaf Tissue

Level		Least Sq Mean	Std Error	Mean	2.67
Farmyard manure	A	2.9566667	0.45580	Std Dev	0.6859343
Charged Biochar	A	2.7333333	0.45580	Std Err Mean	0.1616763
Compost	A	2.7100000	0.45580	Upper 95% Mean	3.0111071
Poultry manure	A	2.6900000	0.45580	Lower 95% Mean	2.3288929
Negative control	A	2.4866667	0.45580	N	18
Positive control	A	2.4433333	0.45580	Variance	0.4705059
				CV	25.690424
				N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Leaf tissue N	5	5	10	0.4852	0.7802

Potassium in Leaf Tissue

Level		Least Sq Mean	Std Error	Mean	3.6111111
Farmyard Manure	A	3.8633333	0.22743	Std Dev	0.392906
Charged Biochar	A	3.8600000	0.22743	Std Err Mean	0.0926088
Positive Control	A	3.6133333	0.22743	Upper 95% Mean	3.8064987
Poultry Manure	A	3.5766667	0.22743	Lower 95% Mean	3.4157235
Compost	A	3.4700000	0.22743	N	18
Negative Control	A	3.2833333	0.22743	Variance	0.1543752
				CV	10.880475
				N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Leaf tissue K	5	5	10	0.8213	0.5616

Magnesium in Leaf Tissue

Level		Least Sq Mean	Std Error		
				Mean	0.22
Negative Control	A	0.23333333	0.00758	Std Dev	0.0137199
Poultry Manure	A	0.22666667	0.00758	Std Err Mean	0.0032338
Charged Biochar	A	0.22000000	0.00758	Upper 95% Mean	0.2268227
Positive Control	A	0.21666667	0.00758	Lower 95% Mean	0.2131773
Farmyard Manure	A	0.21333333	0.00758	N	18
Compost	A	0.21000000	0.00758	Variance	0.0001882
				CV	6.2363122
				N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Leaf tissue Mg	5	5	10	1.3600	0.3168

Calcium in Leaf Tissue

Level		Least Sq Mean	Std Error		
				Mean	0.2427778
Charged Biochar	A	0.27666667	0.02173	Std Dev	0.0381646
Compost	A	0.25333333	0.02173	Std Err Mean	0.0089955
Negative Control	A	0.25333333	0.02173	Upper 95% Mean	0.2617566
Poultry Manure	A	0.23333333	0.02173	Lower 95% Mean	0.223799
Positive Control	A	0.22666667	0.02173	N	18
Farmyard Manure	A	0.21333333	0.02173	Variance	0.0014565
				CV	15.719969
				N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Leaf tissue calcium	5	5	10	1.0449	0.4434

Net Economic Benefit (NEB)

Level		Least Sq Mean	Std Error		
				Mean	516.8
Poultry manure	A	832.436	105	Std Dev	278.01014
Positive control	A B	715.996	105	Std Err Mean	65.527618
Farmyard manure	A B	475.554	105	Upper 95% Mean	655.05119
Negative control	A B	338.579	105	Lower 95% Mean	378.54881

Level		Least Sq Mean	Std Error	Mean	516.8
Charged Biochar	B	297.904	105	N	18
Compost	B	223.432	105	Variance	77289.636
				CV	53.794531
				N Missing	0

Levels not connected by the same letter are significantly different

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Net Economic Benefit	5	5	10	5.7687	0.011*

Appendix iii: Research Data

Soil and Organic Fertilisers Data

Pre-production

	SEASON 1										SEASON 2									
Treatment	**pH**	**CEC**	**OC**	**N**	**P**	**K**	**Mg**	**Ca**	**OM**	**C:N**	**pH**	**CEC**	**OC**	**N**	**P**	**K**	**Mg**	**Ca**	**OM**	**C:N**
Soil	7.15	4.29	1.26	0.15	67.4	0.26	0.05	0.01	0.82	8.4	7.13	4.12	1.21	0.13	67.62	0.24	0.05	0.03	2.09	9.3
Farmyard manure	7.54	31.71	7.44	2.83	909.2	0.3	0.05	0.01	12.8	2.6	7.54	31.71	7.44	2.83	909.2	0.30	0.05	0	2.17	2.6
Charged Biochar	6.86	22	3.27	0.7	777.2	0.26	0.04	0.01	5.64	4.7	6.86	22.00	3.27	0.7	777.2	0.26	0.04	0.01	5.64	4.7
Poultry manure	8.98	69.43	15.68	1.47	994.8	0.28	0.05	0.01	27.0	10.7	8.98	69.43	15.68	1.47	994.8	0.28	0.05	0.01	27.0	10.7
Compost	8.27	13.14	3.97	0.65	484.5	0.24	0.04	0.01	6.84	6.1	8.27	13.14	3.97	0.65	484.5	0.24	0.04	0.01	6.84	6.1

Post-production

		SEASON 1										SEASON 2									
Rep	**Treatment**	**pH**	**CEC**	**OC**	**N**	**P**	**K**	**Mg**	**Ca**	**OM**	**C:N**	**pH**	**CEC**	**OC**	**N**	**P**	**K**	**Mg**	**Ca**	**OM**	**C:N**
1	FYM	6.65	24	2.49	0.17	105	3	184.2	496.2	4.3	14.6	6.2	32	3.03	0.37	20.14	61.73	18.47	548.33	5.2	8.2
1	-VE	6.57	18	2.36	0.2	115	47.4	189.4	792.1	4.1	11.8	6	33	2.68	0.2	21.45	34.63	76.06	536.25	4.6	13.4
1	Charged Biochar	6.26	22	2.04	0.21	222.5	46.1	182.8	792.7	3.5	9.7	6.2	34	2.6	0.27	16.64	57.61	17.96	564.85	4.5	9.6
1	PM	6.43	26	2.53	0.2	135	45.9	182.6	804.7	4.4	12.7	6.2	28	3.61	0.33	28.87	63.02	18.49	537.02	6.2	10.9
1	Compost	6.33	16	2.4	0.17	97.5	42.1	192.5	793.9	4.1	14.1	6.3	33	3.08	0.28	24.51	9.83	70.22	544.32	5.3	11
1	+VE	6.29	22	2.44	0.23	85.6	46.1	201.3	794.6	4.2	10.6	6.3	33	2.78	0.32	22.32	33.4	70.9	544.92	4.8	8.7
2	FYM	6.33	18	2.53	0.12	110.8	1	195.1	2.6	4.4	21.1	6	36	2.82	0.28	16.21	38.2	70.83	551.98	4.9	10.1
2	-VE	6.21	24	2.04	0.17	72.78	39.5	192.2	807.7	3.5	12	5.9	27	3.03	0.37	27.13	29.32	76.2	597.8	5.2	8.2
2	Charged Biochar	6.25	22	2.04	0.15	92.59	32.2	129.9	798.5	3.5	13.6	6.1	28	3.08	0.37	34.99	63.5	71.86	549.28	5.3	8.3
2	PM	6,32	20	1.82	0.18	105	25.8	206.3	804.1	3.1	10.1	6.3	29	3.52	0.37	24.51	63.41	17.9	598.04	6.1	9.5
2	Compost	6.33	26	2.36	0.15	164.42	46.1	194.1	809.6	4.1	15.7	6.1	34	3.28	0.27	26.69	63.53	74.65	592.84	5.7	12.1
2	+VE	6.14	14	2.27	0.2	123.14	47.7	190.4	796.6	3.9	11.4	6.3	26	3.33	0.37	25.38	63.48	72.84	622.11	5.7	9
3	FYM	6.33	18	2.36	0.21	145.02	2.1	200.9	5.9	4.1	11.2	6.1	30	3.03	0.28	77.36	10.02	16.47	544.11	5.2	10.8
3	-VE	6.25	18	1.91	0.2	83.93	48	189.7	807.8	3.3	9.6	6.2	28	2.89	0.33	20.57	27.01	70.22	309.37	5.0	8.8
3	Charged Biochar	6.32	28	2.8	0.21	193.32	47.9	195.6	805.9	4.8	13.3	6.3	26	2.82	0.35	40.67	10.04	54.06	537.5	4.9	8.1
3	PM	6.46	22	2.49	0.2	146.67	47.7	198.9	800.7	4.3	12.5	6	35	2.82	0.28	104.01	10.05	17.78	548.57	4.9	10.1
3	Compost	6.23	16	2.53	0.2	139.24	47.1	203.5	802.5	4.4	12.7	6.3	25	3.59	0.22	33.68	10.01	69.8	529.8	6.2	16.3
3	+VE	5.93	24	2.27	0.23	97.14	46.54	209	790.8	3.9	9.9	6.2	27	2.99	0.37	29.31	10	50.78	542.27	5.2	8.1

Growth Components Data

Leaf Diameter (cm)

		Season 1				Season 2			
Replication	**Treatment Name**	**14 DPT**	**21 DPT**	**28 DPT**	**35 DPT**	**14 DPT**	**21 DPT**	**28 DPT**	**35 DPT**
1	Farmyard manure	4.9	6.7	10.6	13.1	3.22	4.73	6.74	10.16
1	Negative control (Soil)	2.64	4.4	6.36	8.9	3.69	4.41	5.98	10.14
1	Charged Biochar	4	6.3	8.99	11.1	3.03	5.68	7.09	9.89
1	Poultry manure	2.99	5.22	8.27	11.66	2.77	4.67	7.28	12.07
1	Compost	4.6	6.58	9.08	13.66	3.32	5.82	9.7	11.15
1	Positive control (NPK+Urea)	3.86	6.93	10.05	15.89	3.33	4.43	7.35	9.98
2	Farmyard manure	3.2	5.42	9.89	13.27	3.57	5.47	6.79	10.36
2	Negative control (Soil)	3.6	6.37	8.9	12.4	2.77	3.5	4.44	7.17
2	Charged Biochar	3.59	7.07	9.9	13.9	3.22	5.55	6.77	10.64
2	Poultry manure	3.8	6.6	9.1	12.1	2.62	3.78	5.96	9.58
2	Compost	3.91	7.47	12.8	17.28	3.35	4.47	6.77	9.23
2	Positive control (NPK+Urea)	4.11	7.73	11	16.28	3.16	4.36	5.96	8.6
3	Farmyard manure	4.1	6.33	11.11	15.8	3.22	5.12	7.81	11.18
3	Negative control (Soil)	2.9	4.05	6.41	9.11	3.1	4.06	4.87	6.49
3	Charged Biochar	3.52	6.6	9.44	14.33	3.51	5.67	6.76	9.01
3	Poultry manure	3.76	6.63	9.27	11.55	3.34	5.22	7.38	11.02
3	Compost	3.17	5.47	9.06	11.72	3.9	4.58	6.8	9.34
3	Positive control (NPK+Urea)	3.45	7.3	12.06	14.44	3.3	4.79	6.08	8.87

Plant Height (cm)

Season 1					Season 2				
Replication	**Treatment**	**14 DPT**	**21 DPT**	**28 DPT**	**35 DPT**	**14 DPT**	**21 DPT**	**28 DPT**	**35 DPT**
1	Farmyard manure	12.33	15	17.7	20.3	8.17	10.5	12.67	15.8
1	Negative control (Soil)	9.6	12.4	14.3	15.8	7.37	9.57	11.13	12.4
1	Charged Biochar	13.8	16	18.7	20.2	8.33	10.37	12.1	16.83
1	Poultry manure	12.3	14.2	16	18.37	8.3	10.2	12.7	17.53
1	Compost	12.33	15	17.1	19.63	6.37	9.97	12.27	11.77
1	Positive control (NPK+Urea)	13.77	18.5	20.37	24.9	7.97	9.73	11.67	16.03
2	Farmyard manure	15	17.17	19.73	21.4	9.3	11.53	12.4	17.2
2	Negative control (Soil)	11.3	13.73	17.5	19.8	6.73	9.3	10	12.07
2	Charged Biochar	13.6	16.6	21.2	22.5	9.6	10.93	12.73	17.4
2	Poultry manure	13.17	16.5	18	19.67	8.3	10.1	12.33	16.87
2	Compost	14.67	18.5	20.77	22.3	8.93	10.43	10.43	13.5
2	Positive control (NPK+Urea)	14.67	16.5	18.8	24.6	8.33	9.83	11.37	14.57
3	Farmyard manure	12.7	17.5	19.83	22.63	9.1	10.93	13	15.67
3	Negative control (Soil)	11.03	13.83	16.73	19.7	7.87	9.1	11.43	14.15
3	Charged Biochar	14	19.3	22.1	25.3	9.57	10.77	12.17	16.67
3	Poultry manure	14.8	18	21.57	23.97	9.3	10.8	14.4	17.57
3	Compost	12.6	15.33	18.67	21.23	9.37	10.7	12.97	16.03
3	Positive control (NPK+Urea)	12.83	17	20.83	25.8	9.6	10.97	12.7	14.83

Number of Leaves

Season 1					Season 2				
Replication	**Treatment**	**14 DPT**	**21 DPT**	**28 DPT**	**35 DPT**	**14 DPT**	**21 DPT**	**28 DPT**	**35 DPT**
1	Farmyard manure	4	6	8	13	3	6	8	10
1	Negative control (Soil)	4	5	9	11	3	5	7	9
1	Charged Biochar	4	6	9	13	3	6	8	11
1	Poultry manure	5	7	13	16	3	5	8	10
1	Compost	3	6	8	12	2	4	7	10
1	Positive control (NPK+Urea)	4	7	11	14	3	6	8	11
2	Farmyard manure	4	6	9	13	3	5	8	11
2	Negative control (Soil)	4	5	9	11	3	5	7	9
2	Charged Biochar	4	7	10	16	3	5	8	11
2	Poultry manure	4	6	10	13	3	4	7	10
2	Compost	4	7	10	14	3	4	7	9
2	Positive control (NPK+Urea)	4	7	9	13	3	6	9	11
3	Farmyard manure	3	6	8	13	3	5	7	11
3	Negative control (Soil)	3	5	9	11	3	4	7	9
3	Charged Biochar	3	6	9	14	3	6	8	11
3	Poultry manure	4	7	12	16	3	5	7	10
3	Compost	3	6	9	13	3	5	7	10
3	Positive control (NPK+Urea)	5	8	12	16	3	6	9	12

Head Diameter (cm)

		Season 1			Season 2		
Replication	**Treatment**	**44 DPT**	**51 DPT**	**58 DPT**	**44 DPT**	**51 DPT**	**58 DPT**
1	Farmyard manure	16.97	18.67	20.7	21.1	22.7	23.65
1	Negative control (Soil)	13.6	15.6	17.73	16.5	17.8	19.75
1	Charged Biochar	15.87	18.1	20.87	20.5	22	23.2
1	Poultry manure	17.93	18.77	19.87	20.55	21.75	22.8
1	Compost	16.63	18.83	21.33	17.4	18.7	20.45
1	Positive control (NPK+Urea)	18.47	20.8	23.13	16	18.1	19.95
2	Farmyard manure	17.63	19.87	22.37	20	22.2	23.2
2	Negative control (Soil)	13.93	15.6	17.67	15	17.2	19.1
2	Charged Biochar	18.77	21.73	23.47	20.1	22.4	23.65
2	Poultry manure	16.73	19.13	22.86	19.5	22.15	23.55
2	Compost	18.03	21.33	23.7	17	19.3	21.3
2	Positive control (NPK+Urea)	18.43	19.9	20.83	18.9	20.65	22.35
3	Farmyard manure	16.9	18.77	20.6	17.3	19.1	20.45
3	Negative control (Soil)	10.53	12.93	14.93	14.3	16.2	18.1
3	Charged Biochar	17.33	19.77	22.67	18.5	20.6	22.45
3	Poultry manure	18.6	21.37	24.03	17.2	19	21.3
3	Compost	15.03	17.87	20.33	18.2	20	22.25
3	Positive control (NPK+Urea)	20.27	22.4	24.4	17.5	19.5	21.8

Yield Components Data

		Fresh weight				Dry weight	
		S1 (g/plant)	S1 t/ha	S2 (g/plant)	S2 (t/ha)	S1 (g/plant)	S2 (g/plant)
Replication	Farmyard manure	577	Fresh (t/ha)	450	1.5	54	28
1	Negative control (Soil)	469	1.9	358.33	1.2	46	22
1	Charged Biochar	570	1.6	585	2.0	40	36
1	Poultry manure	640	1.9	805	2.7	31	49
1	Compost	690	2.1	441.67	1.5	61	27
1	Positive control (NPK+Urea)	773	2.3	730	2.4	60	45
1	Farmyard manure	737	2.6	446.67	1.5	58	27
2	Negative control (Soil)	487	2.5	315	1.1	52	19
2	Charged Biochar	613	1.6	613.33	2.0	58	37
2	Poultry manure	652	2.0	550	1.8	44	34
2	Compost	732	2.2	386.67	1.3	57	24
2	Positive control (NPK+Urea)	730	2.4	653.67	2.2	53	40
2	Farmyard manure	552	2.4	542.67	1.8	28	33
3	Negative control (Soil)	277	1.8	293.33	1.0	21	18
3	Charged Biochar	591	0.9	433.33	1.4	48	26
3	Poultry manure	790	2.0	965	3.2	45	59
3	Compost	515	2.6	398.33	1.3	49	24
3	Positive control (NPK+Urea)	820	1.7	403.33	1.3	41	25
3	Positive control	577	2.7	450	1.5	54	28

Tissue Mineral Nutrient Data

		Season 1						Season 2					
Replication	Treatment	Vitamin C (mg/100g)	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	Vitamin C (mg/100g)	N (%)	P (%)	K (%)	Mg (%)	Ca (%)
1	Farmyard manure	1.8	3.17	4.16	3.96	0.23	0.23	1.3	3.67	0.391	3.81	0.21	0.23
1	Negative control	2.1	2.23	4.34	3.99	0.23	0.24	1.02	2.93	0.39	3.83	0.26	0.28
1	Charged Biochar	2.7	2.67	3.74	3.97	0.22	0.27	1.19	4.33	0.37	3.82	0.22	0.28
1	Poultry manure	2.9	2.9	3.15	3.03	0.23	0.28	0.96	3.47	0.37	3.01	0.24	0.29
1	Compost	1.7	3.57	4.16	3.28	0.23	0.24	1.3	3.13	0.324	3.23	0.21	0.23
1	Positive control	1.9	3	4.19	4.04	0.22	0.26	1.22	3.07	0.322	3.94	0.22	0.23
2	Farmyard manure	2.3	3.17	5.1	4.1	0.21	0.24	1.19	2.6	0.421	3.96	0.21	0.23
2	Negative control	2.4	3.47	4.52	3.03	0.22	0.22	0.96	2.33	0.485	3.01	0.23	0.24
2	Charged Biochar	2.3	3.3	2.46	4.02	0.21	0.34	1.3	1.87	0.359	3.92	0.21	0.33
2	Poultry]manure	3.2	2.8	4.91	3.96	0.21	0.24	0.83	2.2	0.345	3.81	0.23	0.21
2	Compost	2.3	3.77	5.09	3.55	0.22	0.25	1.19	3.13	0.432	3.22	0.21	0.24
2	Positive control	2.4	3.8	5.79	3.99	0.21	0.22	1.02	2.13	0.292	3.89	0.21	0.2
3	Farmyard manure	1.9	3.87	5.29	3.75	0.21	0.22	1.69	2.6	0.459	3.82	0.22	0.18
3	Negative control	2.4	3.07	4.16	3.03	0.18	0.23	1.19	2.2	0.375	3.01	0.21	0.24
3	Charged Biochar	2.5	4.8	5.9	3.03	0.22	0.24	1	2	0.421	3.84	0.23	0.22
3	Poultry manure	3.4	3.9	5.56	4.1	0.23	0.23	1.05	2.4	0.586	3.91	0.21	0.2
3	Compost	1.9	3.83	5.73	4.06	0.21	0.28	1.22	1.87	0.385	3.96	0.21	0.29
3	Positive control	1.8	2.93	5.35	3.03	0.21	0.23	1.16	2.13	0.306	3.01	0.22	0.25

Net Economic Benefit (NEB) Data

Season 1

Repl.	Treatment	Cost of Inputs (COI) (KSh)	Sample fresh weight (g/plant)	Average FWTL (AFWTL)	Total heads/ bed = 30	Total FWTL (g/bed) = 30 * AFWTL/head	Income of Lettuce (IOL) = TFWTL/ AFWTL * KSh. 25	NEB = IOL – COI (Ksh)
1	Farmyard manure	215.6	300; 630; 800	577	30	17,310	685.3	469.7
1	Negative control (Soil)	125.6	740; 700; 520	469	30	14,070	557.0	431.4
1	Charged Biochar	485.6	550; 540; 370	570	30	17,100	677.0	191.4
1	Poultry manure	281.6	700; 725; 495	640	30	19,200	760.1	478.5
1	Compost	365.6	730; 640; 700	690	30	20,700	819.5	453.9
1	Positive control (NPK+Urea)	142.1	1,285; 700,880	773	30	23,190	918.1	776.0
2	Farmyard manure	215.6	660; 930; 835	737	30	22,110	875.3	659.7
2	Negative control (Soil)	125.6	510; 450; 500	487	30	14,610	578.4	452.8
2	Charged Biochar	485.6	600; 450; 440	613	30	18,390	728.0	242.4
2	Poultry manure	281.6	795; 440; 720	652	30	19,560	774.3	492.7
2	Compost	365.6	790; 780; 625	732	30	21,960	869.4	503.8
2	Positive control (NPK+Urea)	142.1	775; 645; 770	730	30	21,900	867.0	724.9
3	Farmyard manure	215.6	500; 470; 685	552	30	16,560	655.6	440.0
3	Negative control (Soil)	125.6	270; 210; 350	277	30	8,310	329.0	203.4
3	Charged Biochar	485.6	400; 510; 605	591	30	17,730	701.9	216.3
3	Poultry manure	281.6	530; 640; 1,200	790	30	23,700	938.2	656.6
3	Compost	365.6	730; 355; 460	515	30	15,450	611.6	246.0
3	Positive control (NPK+Urea)	142.1	840; 730; 890	820	30	24,600	973.9	831.8

Season 2

Repl.	Treatment	Cost of Inputs (COI) (KSh)	Sample fresh weight (g/plant)	Average FWTL (AFWTL)	Total heads/ bed = 30	Total FWTL (g/bed) = 30 * AFWTL/head	Income of Lettuce (IOL) = TFWTL/ AFWTL * KSh. 25	NEB = IOL – COI (Ksh)
1	Farmyard manure	215.6	465; 380; 505	450.0	30	13500	648.3	432.7
1	Negative control (Soil)	125.6	435; 345; 295	358.3	30	10749.9	516.2	390.6
1	Charged Biochar	485.6	535; 595; 625	585.0	30	17550	842.7	357.1
1	Poultry manure	281.6	505; 885; 1025	805.0	30	24150	1159.7	878.1
1	Compost	365.6	295; 440; 590	441.7	30	13250.1	636.3	270.7
1	Positive control (NPK+Urea)	142.1	925; 680; 585	730.0	30	21900	1051.6	909.5
2	Farmyard manure	215.6	585; 275; 480	446.7	30	13400.1	643.5	427.9
2	Negative control (Soil)	125.6	290; 395; 260	315.0	30	9450	453.8	328.2
2	Charged Biochar	485.6	980; 175; 685	613.3	30	18399.9	883.5	397.9
2	Poultry manure	281.6	540; 365; 745	550.0	30	16500	792.3	510.7
2	Compost	365.6	460; 370; 330	386.7	30	11600.1	557.0	191.4
2	Positive control (NPK+Urea)	142.1	746; 740; 475	653.7	30	19610.1	941.7	799.6
3	Farmyard manure	215.6	880; 688; 60	542.7	30	16280.1	781.8	566.2
3	Negative control (Soil)	125.6	210; 285; 385	293.3	30	8799.9	422.6	297.0
3	Charged Biochar	485.6	880; 115; 305	433.3	30	12999.9	624.2	138.6
3	Poultry manure	281.6	1190; 1105; 600	965.0	30	28950	1390.1	1108.5
3	Compost	365.6	525; 295; 375	398.3	30	11949.9	573.8	208.2
3	Positive control (NPK+Urea)	142.1	515; 455; 240	403.3	30	12099.9	581.0	438.9

Table 22: Weather Condition, 2024 to May, 2025

	Jan	Feb	Match	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Total/Average
Rainfall (mm) 2024	205.1	295.5	395.2	415.8	230.1	165.3	115.8	185.4	350.7	405.3	265.9	218.5	3248.6
Temperature (°C) max	25.0	24.4	23.7	22.9	24.7	24.7	24.2	24.1	22.8	22.3	23.7	24.2	23.9
Temperature (°C) min	11.8	12.2	12.6	13.0	12.2	11.5	11.2	11.7	12.7	12.9	12.0	11.8	12.1
Rainfall (mm) 2025	204.5	286.8	395.3	416.2	230.8								1533.6
Temperature (°C) max	25.0	22.7	22.0	23.3	24.8								23.6
Temperature (°C) min	11.8	12.0	12.1	12.1	12.2								12.0

Total Rainfall (mm) October - December, 2024 = **889.7**; February - April, 2025 =**1098.3**

Appendix iv: Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **899585**

Date of Issue: **14/April/2025**

RESEARCH LICENSE

This is to Certify that Mr.. OUSMAN SAIDY of Egerton University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Nakuru on the topic: EFFECTS OF CHARGED BIOCHAR AND SELECTED ORGANIC FERTILISERS ON GROWTH, YIELD, QUALITY, AND PROFITABILITY OF LETTUCE (Lactuca sativa L.) for the period ending : 14/April/2026.

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Research Permit (Continued)

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Appendix v: Abstracts of Publications

Paper 1

International Journal of Scientific Research and Innovative Technology *Vol. 12 No. 2; August 2025*

APPLICATION OF CHARGED BIOCHAR AND SELECTED ORGANIC FERTILISERS SIGNIFICANTLY INFLUENCES GROWTH AND YIELD COMPONENTS OF LETTUCE

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ABSTRACT

Soil degradation due to excessive use of synthetic fertilisers poses challenges to sustainable vegetable production, including lettuce, in many tropical regions. This research aimed at assessing the agronomic and economic potential of organic fertilizers in enhancing productivity of lettuce (*Lactuca sativa* L.). Specifically, it determined the effects of selected organic fertilisers on the growth and yield components of lettuce. It was done in a randomized complete block design with six treatments (negative control-soil, positive control-NPK+Urea, charged biochar, compost, poultry and farmyard manures) replicated three times in two seasons on a farm at Egerton University, Kenya. Iceberg lettuce variety used was grown in a nursery bed for five weeks followed by transplanting to permanent plots, measuring 2 m x 1.5 m and accommodating 30 lettuce plants at 30 cm x 30 cm spacing. Data was collected post-transplant bi-weekly on growth components (plant height, leaf number, leaf diameter) and in the 9th week on head diameter, fresh and dry weights. Data was subjected to analysis of variance using JMP Pro 17th edition statistical software. In seasons 1 and 2, respectively, results showed a significant difference in final growth of lettuce leaf diameter (P= 0.023, 0.041), plant height (P= 0.002, 0.004), leaves (P= 0.032, 0.0002), and head diameter (P= 0.012, 0.011). Similarly, marketable fresh weight yield was significantly (P= 0.010; 0.019) different and ranged from 1.4 to 2.6 t/ha and 1.1 to 2.6 t/ha in seasons 1 and 2, respectively. In this regard, poultry manure promoted the highest marketable fresh weight yield of 2.3 and 2.6 t/ha. In contrast, biochar led to intermediate marketable fresh weight yield of 2.0 and 1.8 t/ha, while negative control had the lowest of 1.4 and 1.1 t/ha. This study revealed effects of organic fertilisers on lettuce productivity. The amendments approach enhanced productivity, implying they could reduce dependence on synthetic fertilisers and promote organic lettuce production. This study recommends adoption of poultry manure in lettuce production to serve as an alternative to synthetic fertilisers. Additionally, further research on long-term effects of charged biochar on lettuce productivity is recommended to be conducted.

Keywords: Leafy vegetables, Lettuce productivity, Organic farming, Nutrient source, Salad, Soil properties

Paper 2

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ASSESSMENT OF CHARGED BIOCHAR AND SELECTED ORGANIC FERTILISERS EFFECTS ON SOIL PROPERTIES, NUTRITIONAL QUALITY, AND PROFITABILITY OF LETTUCE

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ABSTRACT

Excessive use of synthetic fertilisers poses soil degradation challenges that partly constrain sustainable vegetable production in many tropical regions. This research aimed at assessing the agronomic and economic potential of organic fertilisers in enhancing lettuce (*Lactuca sativa* L.) soil properties, nutritional quality, and profitability. Specifically, it determined effects of selected organic fertilisers on soil properties, vitamin C, mineral nutrients (N, P, K, Ca, Mg), and net economic benefit (NEB) of lettuce. It was done in a randomized complete block design with six treatments (negative control-soil, positive control-NPK+Urea, charged biochar, compost, poultry and farmyard manures) replicated three times in two seasons from October 2024 to May 2025 on-farm at Egerton University, Kenya. Iceberg lettuce variety used was grown in a nursery bed for five weeks followed by transplanting to permanent experimental plots, measuring 2m x 1.5m and accommodating 30 lettuce plants at 30cm x 30cm spacing. Data was collected pre- and post-production on soil and organic fertilisers, as well as in the 9th week on lettuce fresh weight, nutritional quality components, and net economic benefit. Data was subjected to analysis of variance using JMP Pro 17th edition program. Numerically, application of organic fertilisers resulted in decreased N, P, pH, OC, OM, but increased K, Ca, Mg, CEC, and C:N in soil after lettuce growth. Nonetheless, all treatments had a pH of 6.1 - 6.5, which was optimal for lettuce growth and development. In seasons 1 and 2, lettuce leaf tissue analysis showed significant (P= 0.001; P= 0.048) differences in vitamin C, ranging from 2.0 – 3.2 and 1.0 – 1.4 meg/100 mg. However, there were no significant (P> 0.05) differences in nutritional minerals N, P, K, Mg and Ca. The NEB varied significantly (P= 0.001; 0.011), with poultry manure giving the highest NEB of 543 – 833/=, while biochar (217/=) and compost (224/=) giving the lowest. This study revealed

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that organic fertilisers influence soil properties, lettuce quality and profitability differently. The organic fertilisers significantly enhanced vitamin C and NEB more than no fertilisers. Adoption of poultry manure would serve as a profitable alternative to synthetic fertilisers, while optimizing quality and soil properties. It recommends further research on long-term effects of biochar on soil properties, lettuce quality and profitability.

Keywords: Cost-benefit analysis, Gross margin analysis, Manure, Mineral nutrients, Net economic benefit, Nutrient source, Vitamins