UNIVERSITY OF GHANA

COLLEGE OF BASIC AND APPLIED SCIENCES

THE GROWTH, YIELD, AND QUALITY OF LETTUCE (*Lactuca sativa* L.) AS INFLUENCED BY SPENT MUSHROOM SUBSTRATE AND INORGANIC FERTILIZATION

BY

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DECLARATION

I, FORGIVE ABLA NYAMUAME, hereby declare that this thesis, except for appropriately acknowledged references cited, represents the results of my research as a student of the Department of Crop Science, College of Basic and Applied Sciences, University of Ghana during the 2022/2023 academic year. I further confirm that this thesis has not been previously submitted, either in its entirety or partially, to attain any degree at this university or anywhere else.

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This research work is dedicated to Almighty God for His grace and divine protection, and my lovely husband, Mr. Felix Kwame Wedzi, my son, Wisdom Mawuli Adenyo, and his future siblings. I say, God bless you.

ABSTRACT

The research was conducted at the University of Ghana's Soil and Irrigation Research Centre (SIREC) from July 2023 to September 2023. The study evaluated lettuce responses to different rates of spent mushroom substrate (SMS) manure and NPK (23-10-5) fertilizers. The experiment was laid in a Randomized Complete Block Design (RCBD) with four replications and nine treatments. Thus, poultry manure, different rates of spent mushroom substrate (SMS) manure, NPK and combinations of SMS manure and NPK. Data was analyzed using GenStat (12th Ed.), and means were separated using Tukey's HSD. Results showed positive effects of soil amendments on lettuce growth. NPK at 400 kg/ha produced the highest average leaf number (24 in season one, 23 in season two at 6 weeks after transplanting). The highest average yields were obtained with NPK 400 kg/ha (47.1 Mt/ha season one; 48.6 Mt/ha season two), significantly higher than SMS alone. Integration of SMS manure and NPK improved growth and yield compared to SMS alone. Leaf nutrient concentrations (N, P, K) were unaffected by treatments. Post-harvest soil analysis showed increases in pH, nitrogen, and phosphorus, while electrical conductivity, organic matter, calcium, magnesium, and potassium remained unchanged. The study recommends that farmers adopt integrated SMS manure and NPK fertilizer use for optimum lettuce yield, with a preferred application rate of SMS manure at 20 t/ha combined with NPK 400 kg/ha as side-dressing. Due to delayed nitrogen release in SMS manure, it should be applied at least four weeks before transplanting, earlier than poultry manure.

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CHAPTER ONE

1.0 INTRODUCTION

Lettuce (*Lactuca sativa* L.) is a globally important green leafy vegetable widely grown and consumed for its culinary and nutritional value (Bentil *et al*., 2019). According to Kim *et al*. (2011), lettuce has several uses, including salads, sandwiches, and burgers, and can also be used as a garnish. According to Owusu-Ansah *et al*. (2016) and Ofori *et al*. (2017), Ghanaian farmers undertake both commercial and subsistence farming of lettuce. Lettuce is usually cultivated during the rainy season and in locations with cool temperatures and good drainage. Areas in Ghana noted for large-scale cultivation of lettuce are the Volta, Ashanti, and Eastern regions (Bentil *et al*., 2019).

Lettuce (*Lactuca sativa* L.) is a highly perishable leafy vegetable crop that requires optimal growth conditions to attain marketable yield and quality. Available statistics show that lettuce production in Ghana is increasing because of its high demand in local markets. In 2018, Ghana's export of lettuce was valued at USD 2.9 million (FAOSTAT, 2020). This gives a clear indication of the foreign exchange that can be obtained from the export of lettuce from the country. The average yield of lettuce in Ghana ranges between 5-10 tons per hectare, with the highest yield recorded in the Eastern region (Bentil *et al*., 2019). This is, however, still below the world average of 20 to 40t/ha (FAOSTAT, 2020).

Lettuce typically requires 100-200 kg N per hectare, 30-50 kg P per hectare, and 100-200 kg K per hectare for optimum growth (Hartz *et al*., 2013). Lettuce also necessitates an adequate and balanced availability of trace elements (Fe, Mn, Zn, Cu, B, and Mo) to avert nutrient deficiencies and foster vigorous growth (Kopsell *et al*., 2018).

Poor soil fertility is a common constraint in many tropical and subtropical regions where lettuce is cultivated. One of the predominant challenges is nutrient deficiency, particularly N, P and K which significantly impacts both yield and leaf quality (Alam *et al*., 2010).

Crop fertilization offers a practical solution to the problem of nutrient deficiency in lettuce production. Applying balanced fertilizers, either organic, inorganic, or integrated nutrient sources, ensures that essential nutrients are readily available throughout the crop's lifecycle. Nitrogen fertilization, in particular, has been shown to significantly enhance lettuce leaf biomass, chlorophyll content, and overall yield (Bustan *et al*., 2020).

Studies have shown that a combination of organic and inorganic fertilizer is good for growth and yield of crops and also beneficial for the environment, as the application of inorganic fertilizers alone has negative long-term effects such as nutrient imbalances, soil acidification, soil degradation, and the depletion of beneficial soil microorganisms and reduced soil fertility (Reganold *et al*., 2011). Additionally, inorganic fertilizers often contribute to water pollution through leaching and runoff. The excessive release of nutrients, particularly N and P, can contaminate water bodies, causing eutrophication and harmful algal blooms (Sharpley *et al*., 2013). Even though inorganic fertilizers can dissolve quickly and provide essential nutrients immediately after they are applied to the soil, their continuous use can be detrimental to the soil over time. Unlike inorganic fertilizers, nutrients from organic sources are released slowly, improving the organic carbon (C) and water holding capacity, maintaining the C: N ratio, and nutrient retention capacity of the soil, among others. In addition to nutrient provision, Kiros *et al*. (2018) and Yadav *et al*. (2010) noted that incorporating organic manure can enhance microbial activity in the soil. Thus, organic manure application in conjunction with inorganic fertilizers serves as a vital strategy to enhance the overall health and productivity of soils.

Alotaibi *et al*. (2021) and Shrestha *et al*. (2020) reported that various types of organic manure have been employed in lettuce cultivation, resulting in significant enhancements in the growth, yield, quality, and nutrient uptake of lettuce. One important organic manure, which is abundant in supply (Dhar, 2017; Zisopoulos *et al.*, 2016) but has had limited application in vegetable production, particularly lettuce, is spent mushroom substrate.

SMS is rich in essential plant nutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). In temperate climates such as Europe and North America, SMS has been effectively utilized to enhance soil fertility and support the cultivation of cereals, vegetables, and forage crops (Medina *et al*., 2009; Ahlawat *et al*., 2010). In field studies conducted in Italy, tomato and lettuce plants grown with SMS amendments exhibited improved vegetative growth and higher yields compared to conventional fertilization methods (Zucconi *et al*., 2003).

Additionally under tropical climates, SMS has shown promising results. For example, Oghenekaro and Ogboghodo (2014) demonstrated that incorporating SMS into sandy loam soils significantly increased maize growth and soil organic carbon levels in Nigeria. In temperate soils, applications of SMS have led to increased microbial biomass, thereby enhancing nutrient cycling and suppressing soilborne pathogens. Similar effects have also been observed in tropical settings, where SMS boosts microbial enzyme activity and soil aggregation, creating more resilient soils under intensive cropping systems (Uzoma *et al*., 2017). Spent mushroom substrate is, therefore a viable organic source for crop production.

Worldwide mushroom output reached an estimated 48.3 million tonnes in 2022, with roughly 5 kg of SMS produced per 1 kg of mushrooms, implying >240 million tonnes of SMS generated globally in that year alone. Mushroom production in Ghana rose markedly from 120 t in 2010 to about 300 t in 2015, and further to approximately 688 t by 2017 (Ravlikovsky *et al*., 2024). According to Mensah & Acheampong (2023), the Global SMS generation is estimated to exceed 240 million tonnes/year, based on global mushroom production illustrating a substantial annual yield of organic by-product from local mushroom farming. The combination of global production trends and national mushroom output accurately indicates that SMS could meaningfully contribute to the country's demand for organic soil amendments in crop production.

The increase in production levels raises significant concerns regarding the spent mushroom substrate, which constitutes the principal waste product generated during the process of mushroom cultivation (Levanon and Danai, 1995). In commercial mushroom cultivation, a kilogram (1 kg) of fresh mushroom can generate a fresh spent mushroom substrate (SMS) of 2.5 kg (Zisopoulos *et al.* 2016). There is therefore an indication that considerable quantities of SMS are produced daily by these mushroom farmers. Owing to this phenomenon, the huge tons of spent mushrooms generated, improper disposal and utilization can cause adverse environmental problems. It is therefore imperative to find an alternative use for the SMS.

Furthermore, Spent Mushroom Substrate (SMS) could be increasingly favoured over poultry manure in sustainable crop production due to its balanced nutrient profile, lower pathogenic risk, and improved soil-conditioning properties. One of the key advantages of SMS is its reduced risk of pathogen contamination and odour emission. Poultry manure, although rich in nitrogen, often harbours harmful bacteria such as *Salmonella* and *E. coli,* posing risks to both crops and farm workers if not properly composted (Mensah & Acheampong, 2023). In contrast, SMS has undergone partial microbial degradation during mushroom cultivation, significantly reducing its biological hazard (Martin et al., 2023; Gupta et al., 2024).

Furthermore, SMS provides more stable organic matter than poultry manure. It contains lignin-rich residues like sawdust and straw, which decompose slowly, thereby enhancing long-term soil structure and moisture retention (Zhang *et al*., 2014). This contrasts with poultry manure, which, while nutrient-dense, can lead to rapid nutrient leaching and soil salinization if applied in excess (Yao et al., 2007; Mahmoud et al., 2024). Additionally, SMS has been shown to improve cation exchange capacity (CEC) and promote beneficial microbial activity in the rhizosphere, both of which are critical for sustained crop growth (Gupta et al., 2024; Pintarič et al., 2024). The general objective of this study was to evaluate the different rates of spent mushroom substrate manure (SMS) and NPK fertilizers on the growth, yield, and quality parameters of lettuce.

The study had the following specific objectives:

i. Assess the effect of varying rates of spent mushroom substrate (SMS) manure and NPK fertilizers on the vegetative growth and yield parameters of lettuce.

ii. Compare the quality attributes of lettuce as influenced by the addition of varying rates of spent mushroom substrate (SMS) manure and NPK fertilizer to the soil, and

iii. Determine the effect of the spent mushroom substrate (SMS) manure on the physic-chemical quality of the soil.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and distribution of lettuce

Lettuce is a widely cultivated leafy vegetable scientifically known as *Lactuca sativa* L. It belongs to the Asteraceae family, one of the largest families of flowering plants. The species was first formally classified by Carl Linnaeus in Species Plantarum in 1753, establishing its taxonomic placement in the genus *Lactuca* (Linnaeus, 1753). Its domestication is traced to the Eastern Mediterranean and Western Asia, where it evolved from its wild ancestor *Lactuca serriola*, commonly known as prickly lettuce. The earliest documentation of lettuce cultivation appears in ancient Egyptian art and writings around 2500 BCE, where it was originally grown for oil-rich seeds before being selected for edible leaves (Linnaeus, 1753; Hedrick, 1919). Lettuce is now widely grown in many countries around the globe except Antarctica, with distinct cultivar groups such as crisphead, romaine, butterhead, and loose-leaf types being dominant in different agroecological zones. Notable among these countries are the United States, Australia, Canada, Mexico, Europe, and Asia (Zohary & Hopf, 1993; Kumar *et al*., 2013).

2.2 Botany of lettuce

Lettuce (*Lactuca sativa* L.) is an annual, cool-season crop widely cultivated for its edible leaves. It belongs to the family Asteraceae, also known as Compositae, and is classified within the tribe Cichorieae, a group characterized by the presence of milky latex, ligulate flowers, and taproot systems (Hoffmann, 1890–1894; Linnaeus, 1753).

Morphologically, lettuce displays substantial diversity across its cultivars. It generally features a rosette of leaves, which can vary in texture, shape, and coloration depending on the cultivar group (e.g., crisphead, butterhead, romaine, and loose-leaf). The plant forms a flowering stalk during bolting, producing yellow, ligulate flowers arranged in capitula, typical of the Asteraceae family (Hedrick, 1919). Each flower yields a single-seeded fruit known as an achene, which is dispersed naturally by wind or manually during cultivation.

Botanical studies confirm that lettuce originated from the wild progenitor *Lactuca serriola*, which shares features such as spiny leaf margins and latex production. The transition from *L. serriola* to domesticated L. sativa involved selection for larger, tenderer leaves, delayed bolting, and reduced bitterness, resulting in the current diversity of horticultural types (Zohary & Hopf, 1993).

2.3 Uses of lettuce and nutritional composition of lettuce

Lettuce is consumed fresh in salads, sandwiches, and soups, and is also used as a garnish (Fernandez-Segovia *et al*., 2011). Lettuce has anti-inflammatory and antioxidant properties, and as a result, has been used for medicinal purposes for centuries (Ozturk *et al*., 2019).

Fernandez-Segovia *et al.* (2011) indicated that lettuce provides essential nutrients, including dietary fiber, vitamins A and C, as well as essential minerals such as calcium and iron. Munir *et al*. (2016) also indicated that lettuce is a low-calorie vegetable with high water content and provides minerals, vitamins, and fiber, among others. Munir *et al.* (2016) further posited that the nutritional profile of lettuce exhibits variation contingent upon the specific cultivar as well as the prevailing growing conditions. On average, lettuce contains 95% water, 1.5% protein, 0.8% carbohydrates, and 0.2% fat.

2.4 Climatic and soil requirements of lettuce

Kumar *et al*. (2013) observed that lettuce serves as a crop that thrives in cooler seasons, and consequently performs well within a temperature range of 15°C to 25°C. The authors noted that, although the crop can endure low temperatures around 5°C and high temperatures around 30°C for brief durations, extended exposure to elevated temperatures may induce bolting in the plant and diminish yield. Lettuce thrives in well-drained, loamy soils with a pH of 6.0–6.8 and requires consistent moisture for optimal leaf development (Sturtevant, 1919).

The ideal soil for lettuce is soil very rich in organic manure and well-drained. The ideal pH for the optimal growth of lettuce is between the ranges of 6.0 to 7.5. Lettuce demonstrates sensitivity to soil salinity; elevated salt concentrations can precipitate stunted growth and diminished yields. Lettuce requires adequate moisture for optimal growth. For improved yield and high-quality leaves, soil fertility is critical, and the addition of nutrients through the incorporation of organic matter into the soil is necessary (Kumar *et al*., 2013; Obeng-Ofori *et al*., 2007).

2.5 Nutrient requirements of lettuce

The lettuce crop requires a balanced supply of essential nutrients for optimum growth and yield. These nutrients are categorized into macronutrients and micronutrients. The macronutrients essential in substantial quantities encompass nitrogen, phosphorus, potassium, calcium, and magnesium.

Nutrients required by the lettuce plant in lesser amounts include boron, zinc, iron, manganese, and copper.

According to Zhao *et al*. (2007), nitrogen is crucial for the growth, leaf development, and general vigour of the plant. According to the author, a nitrogen deficiency can lead to stunted growth and pale leaves, while excessive nitrogen, on the other hand, can cause overly lush foliage with reduced head formation and increased susceptibility to diseases. Hochmuth (2000) reported that phosphorus is necessary for healthy root systems and early plant establishment; its unavailability will cause poor root development and delayed maturity. Similarly, potassium confers disease resistance to plants, performs a crucial role in plant water regulation, and is vital in enzyme action. Potassium is very useful in the formation of sturdy stems as well as leaves, and a deficiency can cause a marginal leaf burn and reduced resistance to environmental stresses (Resh, 2013). Calcium is said to be vital for cell wall structure and membrane stability (Frantz *et al*., 2011). According to Sonneveld and Voogt (2009), for effective photosynthesis to take place, magnesium, which is a central component of chlorophyll, is required.

Microelements are also vital for the growth and development of lettuce. Marschner (2012) found Iron, Manganese, and Copper to be essential for the development of lettuce. The author reported that Iron is critical for chlorophyll synthesis and electron transport in photosynthesis. Iron deficiency often results in chlorosis, starting with the youngest leaves. Manganese is also involved in photosynthesis, respiration, and nitrogen assimilation. Symptoms of Magnesium deficiency include interveinal chlorosis and necrotic spots on older leaves. Copper is important for photosynthesis and lignin synthesis. Deficiency symptoms include young leaves that are small, pale, and distorted. Zinc and Boron are also needed in the development of the lettuce plant. Alloway (2008) indicated that Zinc is essential for enzyme function and protein synthesis. According to the author, zinc deficiency can cause stunted growth, small leaves, and shortened internodes. Sonneveld and Voogt (2009) further indicated that boron performs a vital task in the formation of cell walls coupled with reproductive development. A boron deficiency may result in distorted growth patterns and the appearance of black necrotic lesions on the foliage.

2.6 Sources of nutrients for lettuce production

Fertilizers are substances that can be natural (organic) or synthetic (inorganic), supplying essential nutrients to the soil. They promote plant growth and increase crop productivity. These substances are vital in modern agriculture because they help replace nutrients lost from the soil due to continuous cropping and intensive farming practices (Banerjee *et al.*, 2023). In their natural state, soils often lack enough nutrients necessary for sustained crop development, a problem worsened by frequent cultivation and limited natural nutrient replenishment (Thirumala Akash & Ahmed, 2022). Therefore, to maximize crop yield and keep soil fertile, it is crucial to apply the right type and amount of fertilizer, based on the specific nutrient needs of the crops and the current soil conditions.

Concerning their sources or origins, fertilizers can be broadly categorized into organic and inorganic types. Inorganic fertilizers are fertilizers that are produced from inorganic substances, whereas organic fertilizers are derived from living organisms (animals and plants).

2.6.1 Chemical fertilizers

Chemical fertilizers are extensively utilized by farmers owing to their capacity to deliver nutrients more rapidly compared to organic fertilizers. Mounirou *et al*. (2023) reported that the highest total yield of lettuce was achieved with a joint application of goat manure, biochar, and 100% NPK**,** emphasizing the superior immediate response of plants to NPK in comparison with organic amendments alone. Similarly, Adekiya *et al.* (2020) showed that NPK significantly improved growth and yield components in crops compared to organic sources, due to its predictable nutrient composition and faster uptake.

Chemical fertilizers can be classified into compound or mixed fertilizers and straight or simple fertilizers. Simple fertilizers consist solely of one nutrient element; for instance, urea and potash, while compound fertilizers comprise more than one of the basic nutrients, namely N, P, and K (Norman, 2004; Tisdale *et al*., 1993).

The major challenge associated with obtaining inorganic fertilizer is the high cost. Again, inorganic fertilizers have negative long-term effects such as nutrient imbalances, soil acidification, soil degradation, the depletion of beneficial soil microorganisms, and reduced soil fertility (Reganold *et al*., 2011). Additionally, inorganic fertilizers often contribute to water pollution through leaching and runoff. The excessive release of nutrients, particularly nitrogen and phosphorus, can contaminate water bodies, causing eutrophication and harmful algal blooms (Sharpley *et al*., 2013). There is therefore a rising concern about the health implications of chemical fertilizers owing to the threat they pose to livelihood and environmental sustainability.

2.6.2 Organic fertilizers

Even though the application of organic fertilizers dates back millennia, used in ancient civilizations such as Rome, Greece, and various Asian societies, their importance has resurged in modern agriculture due to growing concerns over soil degradation and the environmental impact of synthetic inputs. Historical records and archaeological evidence reveal long-standing practices such as composting and the use of farmyard manure to enhance soil fertility (Van Zwieten, 2018). This renewed interest in organic fertilizers is attributable to the exorbitant costs associated with chemical fertilizers and their protracted adverse impacts on the soil's chemical properties (Tirol-Padre *et al.*, 2007; Norman, 2004).

The use of organic fertilizers offers several benefits, including their ability to enhance soil microbial activity, increase soil organic matter, improve soil structure, and modify soil chemical properties. The improvement in the above-mentioned characteristics helps to maintain the soil's productivity (Bhattacharyya *et al.*, 2010; Lasmini *et al.*, 2015).

That notwithstanding, there are a few challenges associated with obtaining and using organic fertilizers. It will be difficult to obtain organic manure in areas with insufficient organic waste management systems or areas with low livestock populations (Kuźniar *et al.*, 2018). Furthermore, organic fertilizers are often less consistent in composition compared to synthetic fertilizers, which can hamper their nutrient availability and effectiveness (Rasse *et al.*, 2018). The nutrient composition of organic fertilizers is dependent on the feedstock used and the decomposition process, making it more difficult to determine the precise nutrient levels. They also release nutrients slowly over time through the process of mineralization, which depends on microbial activity and environmental conditions (Rasse *et al*., 2018). Aside from being too bulky to easily transport from point of production to point of use, organic fertilizers derived from animal manure or compost may contain pathogens like bacteria, viruses, or fungi that can pose health risks to plants, animals, or humans (Tambone *et al*., 2015).

2.6.3 Sources of organic manure

Organic manure is defined as waste materials derived from cattle dung, excreta of other animals, rural and urban composts, other animal wastes, crop residues, and last but not least, green manures (FAO, 2006; ICAR, 1964). Abbey *et al*. (2001) stated that most organic substances emanate from farmyard manure, green manure, decayed plant roots, remnants of crops, and dead soil microorganisms.

Parnes (2013) articulated that the principal sources of organic manure are animal manure and plant materials. Sources of animal manure encompass excreta from cattle, goats, sheep, horses, pigs, and poultry. Green manure, seaweed, mulch, cover crops, crop residues, compost, and biological nitrogen fixation constitute plant sources of organic manure. In Ghana, poultry (chicken) manure is the most abundant form of animal-derived organic manure, contributing the largest share of total livestock manure production, approximately 48%, between 2010 and 2020. Its high availability makes it the most widely used organic fertilizer in the country (Seglah *et al*., 2022). Annually, between 2010 and 2020, Ghana produced on average 1.27 Mt of chicken manure each year (Seglah *et al*., 2022). These figures establish chicken manure not only as the most abundant organic fertilizer but also as a crucial resource for soil fertility and sustainable waste valorisation.

Another important organic manure that has not been fully exploited is spent mushroom substrate. It is important to note that large quantities of spent mushroom substrate are produced daily in the country. Ghana's commercial mushroom production grew from 120 t in 2010 to 687.7 t in 2017, primarily using Pleurotus ostreatus (oyster mushrooms) (Ravlikovsky *et al.*, 2024; Anobir and Acheampong, 2023).

According to Levanon and Danai (1995), the main concern in the mushroom production enterprise is how to dispose of the SMS, which constitutes a major waste in the production of mushrooms. Zisopoulos *et al.* (2016) indicated that a kilo of fresh mushroom can generate a fresh spent mushroom substrate of 2.5 kg in commercial mushroom cultivation.

Various organizations, including the Ministry of Food and Agriculture and non-governmental organizations, are actively involved in promoting mushroom cultivation to enhance food security, income generation, and employment opportunities in Ghana (Mensah *et al.*, 2020). With increasing interest and support, the mushroom production sector in Ghana has the potential for further expansion in the coming years. The implication is that spent mushroom substrate is in abundance and readily available as an organic manure.

2.6.4 Nutrient Composition of Important Organic Manure Sources

According to Dewes and Hunsche (1998), the amount of nutrients present in animal manure is significantly influenced by the type of animal species. The author reported that other factors, such as the composition of the animals' feed, the quantity and quality of bedding materials, the storage duration, and conditions, can affect the amount of nutrients derived from animal manure.

Earlier studies have reported that poultry manure contains substantial amounts of three key nutrient elements, nitrogen, phosphorus, and potassium, when analyzed (Sinnadurai, 1992; Baffour, 1985). Again, Amanullah *et al*. (2010) revealed that poultry manure encompasses all essential nutrients that are needed for the optimal growth of plants. According to Amanullah *et al*. (2007), it is crucial, however, to acknowledge that factors such as the moisture content of manure, the type and age of manure, and the litter-to-manure ratio, coupled with the age and dietary regimen of the bird, can significantly influence the chemical composition of poultry manure. Amanullah *et al*. (2007) observed that the kind and number of chemical properties in poultry manure differ depending on the nature of the feed and the age and type of birds. Table 2.1 presents the nutritional composition of distinct poultry manure from different poultry production systems.

Table 2.1: Nutrient composition of poultry manure types

Particulars	Cage manure	Broiler house	Deep litter
Fe (ppm)	970 - 1450	970 - 1370	930 – 1380
Zn (ppm)	290 - 460	160 - 315	90 – 308
Cu (ppm)	80 - 172	27 - 47	24 – 42
Mn (ppm)	370 - 590	190 - 350	210 - 380
C/N ratio	5.8 - 7.6	9.4 - 11.2	9.5 - 11.5
Total N (%)	3.63 - 5.30	2.40 - 3.60	1.70 - 2.20
Total P_2O_5 (%)	1.54 - 2.90	1.56 - 2.80	1.41 - 1.81
Total K_2O (%)	2.5 - 2.90	1.4 - 2.31	0.93 - 1.30
Mg (%)	0.40 - 0.56	0.42 - 0.65	0.45 - 0.68
Ca (%)	0.80 - 1.02	0.86 - 1.11	0.90 - 1.10

Source: Amanullah *et al*. (2007)

Poultry manure serves as a rich reservoir of nutrients, including nitrogen, phosphorus, and potassium, all of which are indispensable for plant growth. The nutritional composition of poultry droppings can differ based on the age, breed, feed type of the birds, and management practices of the farm (Kaihua *et al*., 2017). In general, fresh poultry manure contains high levels of nitrogen and phosphorus, with a nitrogen-phosphorus-potassium (NPK) ratio of approximately 3:1:1 (Girma *et al*., 2015). The high nitrogen content of poultry manure makes it a suitable fertilizer for leafy vegetables like lettuce, which have high nitrogen requirements (Kaihua *et al*., 2017).

Table 2. Average Analysis of Spent Mushroom Substrate

Contents	Units	Avg. Fresh	Weathered
Na (%)		0.21 - 0.33	0.06
K %		1.93 - 2.58	0.43
Mg%		0.45 - 0.82	0.88
Ca%		3.63 - 5.15	6.27
Al%		0.17 -0.28	0.58
Fe%		0.18 - 0.34	0.58
P%	.	0.45 - 0.69	0.84
N,NH4 %		0.06 -0.24	0
Organic N%		1.25 - 2.15	2.72
Total %N		1.42 - 2.05	2.72
Solids		33.07 - 40.26	53.47
Volatile Solids	.	52.49 - 72.42	54.24
pH		5.8 - 7.7	7.1
N-P-K (PPM)	.	1.8 - 0.6 - 2.2	2.7 - 0.8 - 0.47

Source: Beyer (2023)

Spent mushroom substrate, like poultry manure, contains various mineral elements, including potassium, phosphorus, calcium, and magnesium, which are important for plant growth and development, making it a useful material for soil amendment. Table 2.2 presents the nutritional compositions of the fresh and dry spent mushroom substrates. The substrate also contains varying organic and inorganic compounds, including lignocellulose, chitin, proteins, lipids, and minerals. The nutrient levels in spent mushroom substrate (SMS) can vary based on the type of mushroom cultivated, the substrate composition, and the cultivation practices. Chen *et al*. (2018) hinted that the average nutrient levels in SMS were approximately 1.6-2.2% N, 0.3-0.5% P, and 0.5-1.4% K. However, it is important to note that these ranges can still vary based on the specific state of mushroom cultivation.

Dias *et al*. (2017) indicated that the major constituent of SMS is lignocellulose, which accounts for close to 70 - 80% of the dry weight. The lignocellulose is said to contain cellulose, hemicellulose, and lignin, which are complex polymers that provide structural support to the mushroom fruiting body. According to Sánchez (2009), chitin is another major component of SMS, representing approximately 10 – 20% of the dry weight. Chitin is a nitrogen-containing polysaccharide that forms the exoskeleton of insects and crustaceans and provides rigidity to the mushroom cell walls.

Present in SMS are proteins and lipids, which are in smaller quantities compared to lignocellulose and chitin. The proteins present in SMS account for up to 5 - 10% of the dry weight and consist of various amino acids (Chang and Miles, 2004). On the contrary, the amount of lipids in SMS accounts for less than 5% of the dry weight and consists of fatty acids and glycerol (Dias *et al*., 2017).

Chang and Miles (2004) reported that SMS is an excellent source of various minerals (K, Ca, Mg, P). These minerals are important for plant growth and development, making SMS a valuable soil amendment. Sánchez (2009) also indicated that SMS applications can enhance soil structure, augment water-holding capacity, and furnish essential nutrients to plants. Compared to poultry manure and cow dung, another benefit of spent mushroom substrate is its light weight, which makes it quite easy to transport from the production site to the point of use.

2.7 Effect of organic manure on nutritional and physical properties of soil

Poultry manure application enhances the organic status of the soil, thereby improving its structural stability, reducing its bulk density, and augmenting its porosity (Young, 1997). This phenomenon facilitates root penetration, ensures adequate aeration, mitigates soil erosion, and enhances the soil capacity to retain water. Agbede *et al*. (2008) asserted that the incorporation of poultry manure into the soil improved some physical soil properties such as soil bulk density, temperature, soil porosity, and moisture content.

The application of poultry manure to acidic soils has elevated the pH of the soil from 5.7 to 6.1 (Decutt, 2012). The resulting change in the soil pH can be attributed to the utilization of oyster shells in poultry feeds, which has contributed to the composition of calcium in the poultry manure. According to Chellemi and Lazarovits (2002), the amendment of soil with poultry manures not only elevated soil pH but also diminished the exchangeable acidity within the soil matrix. Parallel observations were reported by Onwu *et al*. (2014), who noted that the incorporation of poultry manure mitigated soil acidity while augmenting available phosphorus, nitrogen content, organic matter content, exchangeable cations, and cation exchange capacity.

Khalid *et al*. (2014) and Adeleye *et al*. (2010) found that the amendment of soil with poultry manure significantly ensured the availability of soil chemical constituents such as organic content, total nitrogen, available phosphorus, pH, potassium, cation exchange capacity, water holding capacity, and base saturation. Adeleye *et al*. (2010) also observed that there was a notable improvement in the soil moisture content due to the incorporation of poultry manure into the soil; the authors attributed this phenomenon to the manure's hygroscopic properties. Agbede *et al*. (2010) and Zhang *et al*. (2009) reported that the application of poultry manure has significantly lifted the level of soil organic carbon as opposed to soils with the sole application of NPK fertilizers. According to Adekiya *et al*. (2014), Ojeniyi *et al*. (2013), and Ayeni and Adetunji (2010), the levels of soil chemical properties such as iron, pH, among others, rose owing to the incorporation of poultry manure into the soil.

There have been several studies that have reported the positive effect of SMS on soil chemical properties. According to Rehman *et al*. (2017), the application of SMS resulted in an enhancement of most of the chemical properties of the soil. Similar observations were made by Wang *et al*. (2020). However, some researchers have documented the adverse effects of SMS on soil chemical characteristics. Zhang *et al*. (2019) reported that the application of SMS elevated soil electrical conductivity, which consequently increased soil salinity. Zhang *et al.* (2018) previously indicated that the SMS application raised soil pH, a change that could potentially induce soil alkalinity and adversely affect plant growth and development.

Spent mushroom substrate has also been recognized for its substantial role in enhancing the physical properties of soil. The application of SMS improved soil water retention while concurrently reducing soil bulk density and soil penetration resistance (Li *et al*., 2017). Zhao *et al.* (2018) also found that amending the soil with SMS enhanced soil porosity and aggregate stability. The implications of these findings suggest that such amendments facilitate root penetration and water percolation, thereby promoting optimal growth and development of crops.

When used effectively, SMS has the propensity to improve and maintain soil quality for improved crop growth and yield. This claim has been confirmed by several studies, which have reported that the incorporation of SMS into the soil can improve the fertility and quality of the soil (Tang *et al*., 2024; Paredes *et al*., 2016; Iglesias *et al*., 2025; Mallick & Sanyal, 2023; Primec *et al*., 2024). It was demonstrated that the SMS amendment significantly increased soil nutrient availability and microbial biomass. This phenomenon created the ideal of environmental conditions and ultimately enhanced lettuce growth and development (Liang *et al*., 2019). Borgognone *et al*. (2017) reported that the soil water retention capacity and organic matter content were increased with the use of SMS.

The incorporation of spent mushroom substrate into the soil has been shown to enhance the nutrient composition of the soil. The particular parameters that experienced significant alterations included the organic matter content of the soil, total nitrogen concentration, and the availability of phosphorus (Day *et al*., 2019). As noted by Yang *et al*. (2016), the application of SMS led to improvements in soil water retention capacity, bulk density, and porosity; these changes collectively contributed to an increase in agricultural productivity. The application of SMS also decreased soil erosion by enhancing soil stability and reducing soil loss (Chen *et al*., 2020). The abundance of beneficial microbes in the soil, specifically bacteria and fungi, increased with the application of SMS (Yuan *et al*., 2017). These beneficial microbes are important for soil biological processes, such as nutrient cycling and decomposition of organic matter. Furthermore, Fan *et al*. (2018) reported a rise in the available phosphorus content, total nitrogen, soil organic matter, and soil enzyme activity, with the application of SMS.

SMS contains a significant amount of organic matter, which can improve soil physical properties such as aeration, water-holding capacity, and porosity, all of which support root growth and nutrient uptake in lettuce (Uzun, 2004). Enhanced root development, in turn, promotes better shoot growth and leaf expansion. SMS also acts as a biological stimulant, enhancing soil microbial activity and possibly suppressing soilborne pathogens (Medina *et al.*, 2009). A healthy rhizosphere indirectly promotes vigorous vegetative growth by reducing biotic stress. Finally, studies suggest that integrated application, combining SMS with inorganic fertilizers or nutrient-rich manures, greatly enhances its efficacy in supporting vegetative growth. This approach allows immediate nutrient availability from the fertilizer and long-term soil conditioning from SMS (Zeng *et al.*, 2022).

2.8 Effect of organic manure on the growth of lettuce

Studies have shown a positive outcome of poultry manure application on some vegetative parameters of vegetables, including lettuce. This is because poultry manure serves as a good and excellent reservoir of nutrients and organic matter, and has, over the years, been used as a soil amendment in lettuce production. A study by Zia and Fatima (2018) revealed that poultry manure application increased the biomass, stem diameter, plant height, and leaf area of lettuce. It is worth noting that, even though poultry manure is a great soil amendment for lettuce, the rate and timing of application are key to avoiding nutrient imbalances and environmental pollution.

In a study conducted by Adekiya and Ojeniyi (2015), the authors documented that the vegetative growth metrics such as chlorophyll content, leaf area, plant height, and shoot and root dry mass of lettuce were substantially augmented as a result of the incorporation of poultry manure. The investigators ascribed the growth-enhancing properties of poultry manure to its elevated levels of nitrogen, phosphorus, and potassium. In a similar vein, Ghaffari *et al*. (2016) demonstrated that the incorporation of poultry manure at varying doses (0, 5, 10, and 15 t/ha) significantly improved lettuce's plant height, leaf area, as well as both fresh and dry weights. The researchers posited that the enhanced vegetative growth of lettuce following the utilization of poultry manure as an organic amendment can be attributable to its substantial organic matter content, which serves to ameliorate soil structure and augment nutrient accessibility.

Irrespective of the irrigation strategy employed, Wang *et al*. (2018) noted that the application of poultry manure markedly enhanced the plant height, leaf area, and both fresh and dry weights of lettuce. In contrast to the positive outcome of poultry manure on the vegetative characteristics of lettuce, Du *et al*. (2017) reported that poultry manure applied at an elevated rate (exceeding 80 t/ha) culminated in diminished growth and yield of lettuce. This phenomenon was ascribed to the excessive salt concentration present in the poultry manure, which induced osmotic stress and hindered nutrient absorption by the plants.

The impact of spent mushroom substrate on the vegetative attributes, namely, root length, shoot length, plant fresh and dry biomass, chlorophyll content, and leaf area, has been investigated by several studies. According to Vivek *et al*. (2019), lettuce plant height and fresh and dry weight were significantly increased with the addition of different concentrations of SMS. Similarly, the application of SMS enhanced shoot length and leaf area in lettuce seedlings (Amin *et al*., 2021). In a similar study, it was observed that lettuce plants treated with SMS demonstrated higher chlorophyll content than the control group (Saba and Khan, 2018).

According to Dourado *et al*. (2016), spent mushroom substrate (SMS) used as a soil amendment in lettuce production improved plant growth, root development, and nutrient uptake. This effect was possible because the spent mushroom substrate contains high levels of nutrients, organic matter, and beneficial microorganisms.

2.9 Effect of organic manure on the yield of lettuce

Incorporating poultry manure in the soil has significantly increased the yield parameters of lettuce. Poultry manure applied at a rate of 5 tons per hectare increased the yield of lettuce as compared to the control (Singh *et al*., 2019). The result suggests that poultry manure has the potential to improve the yield of lettuce. Despite the ability of poultry manure to improve the yield of lettuce, excessive application can lead to a decline in yield due to nutrient imbalances and toxicity.

According to Ali *et al*. (2015), the incorporation of poultry manure (10 t/ha) significantly enhanced lettuce growth, yield, and quality. This result is consistent with that of Elkhatib *et al*. (2019), who found increased yield and quality of lettuce compared to the control treatment when the soil was amended with poultry manure (10 t/ha).

A study by Hong *et al*. (2019) indicated that the incorporation of poultry manure (5, 10, and 15 t/ha) significantly increased the lettuce yield as opposed to the control treatment. The highest yield was reported on plots amended with 15 t/ha. Different application rates of poultry manure ranging from 5 to 25 t/ha significantly increased lettuce yield and quality compared to the control treatment (Abd El-Satar *et al*., 2016). The authors further observed that a 20 t/ha poultry manure application rate gave the maximum yield.

Yadvinder-Singh (2009), however, demonstrated that poultry litter releases a significant portion of its nitrogen (46%) and phosphorus (15–17%) rapidly within 60 and 20 days, respectively, after application. The rapid mineralization resulted in a relatively short-lived residual effect, making it less suitable for sustained nutrient supply without reapplication in successive crop cycles.

Research has shown that the yield of lettuce was improved with the application of a spent mushroom substrate. To buttress this, Paudel *et al*. (2016) indicated that the incorporation of SMS into the soil greatly increased the yield of lettuce compared to the control. Similarly, Roy *et al*. (2015) reported increased crop yield and enhanced nutrient content of crops with the application of mushroom substrate manure as a fertilizer.

In a soilless culture of lettuce, Liao *et al*. (2014) investigated the influence of SMS on the performance of lettuce and reported that the addition of SMS to the growing medium significantly increased lettuce yield compared to the control without SMS. Mirdehghan *et al*. (2015) also reported that the application of SMS to the soil largely increased lettuce yield. The authors, however, noted that higher rates of SMS did not provide any additional benefits. Sun *et al*. (2020) made a similar observation by recording a higher lettuce yield compared to the control. Again, the incorporation of SMS into the growth medium significantly increased lettuce yield and leaf area (Wang *et al*. 2017).

These findings give a clear indication of the benefits associated with the use of SMS manure as an organic fertilizer. This present study will further build on what has already been established by earlier works and also investigate the influence of integrated use of SMS manure and NPK fertilizer on the performance of lettuce, as well as some soil characteristics. The outcome of this current study will ensure that spent mushroom substrates are put to very good use to prevent environmental pollution with mushroom substrate waste and also improve crop yield and soil quality.

The integration of organic and inorganic fertilizers has been widely documented to enhance the growth and yield of short-duration crops like lettuce. Saah *et al*. (2022) demonstrated that combining biochar, a form of organic amendment, with reduced rates of inorganic nitrogen (NPK) fertilizer significantly improved nitrogen use efficiency and resulted in lettuce yields comparable to or even exceeding those achieved with full NPK application. This finding underscores the potential of integrated nutrient systems in optimizing resource use and sustaining productivity. Supporting this, Bahadur *et al*. (2009) reported that the combined use of organic manures and biofertilizers significantly increased head weight and quality parameters of lettuce compared to the sole use of organic inputs. Their results indicate that integration not only improves yield metrics but also enhances produce quality, likely due to a more balanced and sustained nutrient release.

Further evidence by Reddy and Reddy (2011), although based on a tomato-onion cropping system, reinforces the efficacy of integrated nutrient management. Their study found that combining organic manures with inorganic fertilizers enhanced the availability of major nutrients (N, P, K) in the soil, contributing to improved crop yield and soil health.

In alignment with these findings, Demir *et al*. (2024) observed that lettuce grown under a regime of reduced chemical fertilizer combined with microbial amendments produced higher yields than crops receiving either full-rate NPK or microbial treatments alone. This suggests a synergistic effect where microbial inputs improve nutrient availability and soil biology, amplifying the benefits of reduced synthetic inputs.

2.10 Effect of organic manure on the nutritional and chemical composition of lettuce

Zhang *et al*. (2014) found that organic fertilizer, including poultry manure, greatly improved the nitrogen composition of lettuce more than chemical fertilizer. Again, the deployment of poultry manure as an organic amendment resulted in significantly higher levels of N, P, and K content in lettuce compared to chemical fertilizers (Girma *et al*. 2015; Xin *et al*. 2016). Kaihua *et al.* (2017) found that the application of high doses of poultry manure resulted in elevated levels of arsenic and lead in lettuce. However, when poultry manure was applied at lower doses, there was no significant effect on the levels of heavy metals in the lettuce.

The nutritional and chemical composition of lettuce can be influenced by the spent mushroom substrate. Dourado *et al.* (2016) reported that spent mushroom substrate can improve the quality of lettuce by increasing its antioxidant activity and reducing its nitrate content. Similarly, Khettari *et al*. (2020) found that the incorporation of SMS into the soil raised the protein and mineral content of lettuce. The study further found that SMS enhanced the accumulation of beneficial compounds such as phenolic acids, flavonoids, and carotenoids, which have potential health benefits.

Roy *et al*. (2015) also established that the utilization of mushroom substrate manure as a fertilizer enhanced the nutrient content of crops. It is, however, imperative to undertake further study to establish the optimum rate of application and its effect on the safety and quality of lettuce. A study by Kwon and Kim (2017) also confirmed that lettuce grown in the SMS-based substrate had significantly higher levels of nitrogen, phosphorus, potassium, and calcium. Additionally, the lettuce grown in the SMS-based substrate had higher levels of antioxidants such as phenolic compounds and flavonoids compared to the control substrate.

Findings from Li *et al*. (2020) indicated that the SMS application raised the levels of N, P, and K in the lettuce compared to the control. Lettuce grown in the SMS-based substrate had significantly lower levels of heavy metals such as lead, cadmium, and chromium (Zhang *et al*., 2019). In investigating the levels of nitrate and nitrite in lettuce, Xu *et al*. (2018) found that lettuce grown in SMS-based substrate had significantly lower levels of nitrate and nitrite compared to those grown in peat-based substrate.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

Two separate field experiments were carried out at the University of Ghana's Soil and Irrigation Research Centre (SIREC) located at Kpong in the Lower Manya Krobo District of the Eastern Region of Ghana from July 2023 to September 2023. The GPS coordinates for the location are 6°13'N, 00°07'E.

3.2 Experimental area and climatic conditions

Soil and Irrigation Research Centre (SIREC) is located at (6°13'N, 00°07'E). The soil type at SIREC is predominantly clayey soils. According to a soil survey conducted by the Food and Agriculture Organization (FAO) in 1981, the soil at SIREC is classified as the soil clayey and classified as a Typic Calcicustert a Vertisol, (FAO, 1981). This soil type is characterized by high levels of iron and aluminum oxides, which can lead to low soil fertility and poor crop growth if not properly managed (Ofori, 1999).

The rainfall pattern at SIREC is bimodal, with two distinct rainy seasons from April to July and September to November. The mean annual rainfall is approximately 900 mm, with variations in amount and distribution across the year. The dry season lasts from December to March, during which time irrigation is necessary for crop production (Smith *et al.*, 2018).

The climatic conditions at SIREC are typical of the West African sub-region, characterized by high temperatures and humidity throughout the year. The mean annual temperature is approximately

27°C, with variations across the year. The dry season is typically associated with higher temperatures and lower humidity, while the rainy season is associated with lower temperatures and higher humidity.

The climatic data at the experimental site during the two growing seasons are indicated in Table 3.1. Season one covered the period from 5th July to 16th August 2023, whilst the second season covered 19th August to 30th September 2023.

Table 3.1: Average Monthly Temperature and Rainfall at the experimental site during the two seasons

Month & Year	Temperature (°C)	Rainfall (mm)
July, 2023	25.60	13.30
August, 2023	29.66	12.00
September, 2023	32.30	13.74

3.3 Experimental design and treatments

The Randomized Complete Block Design (RCBD) was the experimental design used for the study. The experiment consisted of nine (9) treatments with four (4) replications for each treatment (Table 3.2).

Table 3.2: Treatment codes and their interpretations

S/n	Treatment code	Treatments
1	**T_1**	Control – Poultry manure at 15 t/ha
2	**T_2**	Spent mushroom substrate manure at 15 t/ha
3	**T_3**	Spent mushroom substrate manure at 20 t/ha
4	**T_4**	NPK 23-10-5 at 300kg/ha
5	**T_5**	NPK 23-10-5 at 400kg/ha
6	**T_6**	Spent mushroom substrate manure at 15 t/ha before transplanting and NPK 23-10-5at 300kg/ha as side-dressing
7	**T_7**	Spent mushroom substrate manure at 20 t/ha before transplanting and NPK 23-10-5at 300kg/ha as side-dressing
8	**T_8**	Spent mushroom substrate manure at 15 t/ha before transplanting and NPK 23-10-5 at 400kg/ha as side-dressing
9	**T_9**	Spent mushroom substrate manure at 20 t/ha before transplanting and NPK 23-10-5at 400kg/ha as side-dressing

3.4 Experimental layout

The plot dimension was 1.7 m x 1.2 m, covering a total area of 2.04 m^2 and a total number of 36 plots. The planting distance was 20 cm x 20 cm. The spent mushroom substrate was obtained from some mushroom farmers in the Greater Accra Region and kept under shade for further decomposition. The variety of lettuce used was '*Eden*'.

3.5 Cultural practices

3.5.1 Land preparation

The experimental field underwent preparation by slashing, which was subsequently succeeded by ploughing and harrowing. A fortnight later, the field was treated with herbicide (Glyphosate) at 900 g of active ingredient (isopropyl amine salt) per hectare. The area was lined and pegged into distinct blocks and plots two weeks after the herbicide was applied. Each plot was then transformed into a bed for the first experiment, and the same land preparation procedure was replicated for the second experiment on a separate field.

3.5.2 Application of fertilizers

In the treatments that incorporated spent mushroom substrate (SMS) manure and poultry manure, these organic amendments were integrated into the soil two (2) weeks before the transplanting of seedlings. The beds were subsequently irrigated consistently to promote the efficient decomposition of the manure.

For the treatments necessitating NPK fertilizer as a side dressing, the application of fertilizer was executed in two installments at one (1) and three (3) weeks after transplanting.

3.5.3 Nursing of seeds

The lettuce seeds were sown in seed trays. After sowing, the seed trays were put in a shade house to prevent direct sunlight and the impact of raindrops from dispersing the seeds. The seedlings were transplanted three weeks after germination.

3.5.4 Irrigation

The seedlings received uniform watering (predominantly daily). In instances of rainfall, irrigation was conducted two days following the precipitation event. This protocol aimed to maintain adequate moisture levels within the root zone of the seedlings. The application of water was done using watering cans.

3.5.5 Crop Protection Measures

Weeds that proliferated on the beds and within the inter-plot areas were manually managed through hand-picking and hoeing, respectively, on a bi-weekly basis. Grasshoppers and cutworms were controlled through the application of Attack 5% WDG (Emamectin Benzoate 5%) at a concentration of 2 g per litre of water. The prevention of fungal diseases was achieved by spraying Agrithane (Mancozeb 80WP) at a rate of 2 g per litre of water at seven-day intervals.

3.6 Soil and Spent Mushroom Substrate Analysis

Soil samples collected from the experimental site underwent comprehensive analysis both before and after the experimental period. Additionally, the spent mushroom substrate manure was subjected to analysis at the Soil Science Laboratory of the University of Ghana, Legon, while lettuce samples were similarly analyzed at the Ecological Laboratory of the University of Ghana, Legon. The soil samples were systematically obtained from the experimental site before the application of the amendments and transplanting of lettuce seedlings for both physical and chemical assessments. The sampling methodology involved a Z-plane approach utilizing a soil auger (McKeague *et al*., 2001; Bennett and George, 2008; Haling *et al*., 2020). A total of seven soil samples were extracted from the upper layer of 0-15 cm, commensurate with the shallow root system characteristic of lettuce. All undecomposed organic materials and extraneous stones within the soil samples were meticulously removed. The seven samples were homogenized and air-dried, and a representative sample was subsequently prepared for analysis.

A representative sample of the spent mushroom substrate manure employed in the two experimental trials was collected for examination of its chemical properties.

3.6.1 Determination of soil and SMS pH

Soil pH was determined using an electrometric method by Peech (1965). A mixture of soil and distilled water is prepared in a 1:1 ratio (for soil) and a 1:5 ratio (for spent mushroom substrate (SMS) manure). Ten grams of sieved soil and SMS manure were placed into a beaker, and distilled water was added to create a suspension. The mixture was stirred for 30 minutes and allowed to settle for one hour. A calibrated pH meter was then used to measure the pH of the supernatant.

3.6.2 Total digestion of SMS manure

Total digestion of SMS manure was performed to prepare the sample for nutrient analysis. A small amount (0.1 g) of SMS manure was placed in a conical flask, followed by the addition of 5 ml of concentrated sulfuric acid. The flask was left overnight to facilitate the breakdown of organic matter. Afterward, the sample was heated until white fumes emerge, indicating the complete digestion of organic material. Hydrogen peroxide (H_2O_2) was then gradually added to clear the solution. The digest was cooled and diluted with distilled water, filtered into a volumetric flask, and brought to the final volume for nutrient analysis, including phosphorus, nitrogen, calcium, potassium, and magnesium.

3.6.2.1 Determination of total nitrogen (N) in SMS manure

Total nitrogen was measured using Markham distillation equipment. A 5 ml aliquot of the digest was placed into the distillation apparatus, and 5 ml of 40% sodium hydroxide (NaOH) was added. The mixture was distilled, and the resulting distillate was collected into 5 ml of 2% boric acid with an indicator. The distillate was then titrated with 0.01 M hydrochloric acid (HCl) until a colour change occurred, indicating the nitrogen content. The percentage of nitrogen was calculated using a formula that accounts for the titrant's molarity and the distillate volume.

3.6.2.2 Determination of total phosphorus (P) in SMS manure

Phosphorus was determined using a colorimetric method. (Watanabe and Olsen, 1965). A 1 ml aliquot of the digest was mixed with a pH-adjusting reagent and neutralized until a yellow colour was produced. Eight milliliters of reagent B (ascorbic acid in ammonium molybdate solution) were added, and the mixture was shaken to allow colour development. The resulting blue colour was measured using a colorimeter at 880 nm. Phosphorus content was calculated by comparing the absorbance with standards.

3.6.2.3 Determination of total potassium (K) in SMS manure

Potassium concentration was measured using flame photometry. A 2 ml aliquot of the digest was diluted and introduced into the flame photometer. Potassium levels were determined based on the photometer readings, using standards to calibrate the instrument. The potassium percentage was calculated based on the concentration in the digest and the dilution factor.

3.6.2.4 Determination of magnesium (Mg) in SMS manure

Magnesium was analyzed using atomic absorption spectrophotometry (AAS). A 5 ml aliquot of the digest was diluted and introduced into the AAS. The instrument measured the magnesium concentration in both the digest and a blank solution. The magnesium percentage was calculated using the concentration difference and the dilution factor.

3.6.2.5 Determination of calcium (Ca) in SMS manure

Calcium was also determined via AAS. A 10 ml aliquot of the digest was diluted, and the calcium concentration was measured using AAS at a wavelength of 422.7 nm. The percentage of calcium was calculated using a formula that included the digest volume, the concentration difference between the sample and blank, and the dilution factor.

3.6.2.6 Determination of organic carbon in SMS manure

Organic carbon was determined using a titration method. A 0.1 g sample of SMS manure was reacted with potassium dichromate and sulfuric acid in an Erlenmeyer flask. The mixture was titrated with ferrous ammonium sulfate until a colour change was observed. The volume of titrant used was recorded, and the percentage of organic carbon was calculated using a formula that accounted for the volume of reagents and the sample weight. The result was multiplied by 1.729 to convert organic carbon to organic matter.

3.6.3 Total nitrogen determination in soil samples

The Kjeldahl method was used to determine total nitrogen in soil (Black, 1965). A 2 g soil sample was mixed with a digestion accelerator (potassium sulfate, copper sulfate, selenium) and 5 ml of sulfuric acid. The mixture was heated until it became clear. After digestion, the sample was diluted, and a 5 ml aliquot was distilled with sodium hydroxide. The distillate was titrated with 0.01N HCl to determine nitrogen content, and the nitrogen percentage was calculated based on the titrant's molarity and the sample's weight.

3.6.4 Available phosphorus (P) determination in soil samples

Available phosphorus was extracted from soil using the Bray 1 method (Bray and Kurtz, 1945). A 5 g soil sample was shaken with Bray 1 solution (ammonium fluoride and hydrochloric acid) for 3 minutes. The mixture was filtered, and the filtrate was analyzed using a colorimeter. Phosphorus content was determined by measuring the intensity of the blue colour formed, which is proportional to phosphorus concentration.

3.6.5 Determination of total potassium (K) in soil samples

Potassium in soil samples was measured using flame photometry. A 2 ml aliquot of the prepared soil digest was diluted and introduced into the flame photometer. The concentration of potassium was calculated based on the readings from the photometer and compared to standard solutions.

3.6.6 Determination of organic carbon in soil samples

Organic carbon in soil was measured using the Walkley-Black method (Walkley and Black, 1934). A 0.5 g soil sample was treated with potassium dichromate and sulfuric acid, and the mixture was titrated with ferrous sulfate. The organic carbon content was calculated using the volume of titrant, with corrections for incomplete combustion and converted to cmolc/kg.

3.6.7 Cation exchange capacity (CEC) of soil samples

CEC was measured by saturating the soil with ammonium acetate. A 10 g soil sample was shaken with ammonium acetate solution, filtered, and washed with methanol to remove excess ammonium ions. The soil was then leached with potassium chloride, and the cations were distilled and titrated. The CEC was calculated based on the volume of titrant and the concentration of ammonium in the distillate.

3.6.8 Determination of electrical conductivity (EC) of soil samples

Soil EC was determined by creating a soil-water slurry. Ten grams of soil was mixed with 20 ml of deionized water, shaken, and allowed to settle. The electrical conductivity of the supernatant was measured using a conductivity meter, which was calibrated with a potassium chloride solution.

3.8.9 Determination of extractable soil cations (Ca_{+} and Mg_{+})

Calcium and magnesium were extracted from soil using ammonium acetate, followed by analysis with AAS. A 10 g soil sample was shaken with ammonium acetate, filtered, and the filtrate was analyzed. The concentrations of calcium and magnesium were calculated using the readings from AAS.

3.6.10 Particle size analysis

The Bouyoucos Hydrometer method was used to determine soil texture (Day, 1965). A 40 g soil sample was dispersed in sodium hexametaphosphate solution, agitated, and the suspension's sedimentation was measured using a hydrometer. The percentages of sand, silt, and clay were calculated from the hydrometer readings at specific time intervals, allowing for the classification of soil texture.

The distribution values were used to determine the textural class of the soils using the USDA textural triangle presented in Appendix 1.

3.7 Data collection

Data were gathered concerning vegetative growth characteristics, yield and yield components, as well as quality attributes of lettuce. Four randomly selected plants from the four central rows within each treatment plot were designated and tagged for data collection. The data collection commenced one-week post-transplanting and continued until the point of harvest.

3.7.1 Vegetative growth characteristics

The vegetative parameters measured were;

3.7.1.1 Number of leaves

The total quantity of leaves on six tagged lettuce plants was enumerated at weekly intervals and at the time of harvest. The mean number of leaves per plant for each treatment plot was subsequently computed.

3.7.1.2 Chlorophyll content

A spectrophotometer was employed to assess the absorption of light by the leaves, allowing for the calculation of chlorophyll content in the tagged plants. The mean chlorophyll content for each treatment plot was then ascertained.

3.7.1.3 Normalized Difference Vegetative Index (NDVI)

The NDVI was assessed utilizing a handheld, three-channel radiometer (Rapidscan CS-45, Holland Scientific, Lincoln, Nebraska, USA) within each plot every five days. Measurements were conducted at an approximate height of 90 cm above the apex of the crop canopy from 15 days after transplanting (DAT) to 45 DAT. The instrument quantifies crop reflectance at wavelengths of 670 nm (red) and

780 nm (near infrared), which was subsequently employed to compute the NDVI using the standard formula:

$$NDVI = \frac{near\ infrared\ (780nm) - red(670nm)}{near\ infrared(+red}$$

$$NDVI = \frac{780nm - 670nm}{780\text{nm} + 670nm}$$

3.7.1.4 Stem girth

The measurement of stem girth was done by determining the circumference of the lettuce stems using a pair of digital Vernier callipers for the two tagged lettuce plants. The mean stem girth for each treatment plot was subsequently calculated.

3.7.1.5 Root length

A meter rule was employed to quantify the length of each lettuce specimen among the six designated plants. The mean root length for each specific treatment plot was ascertained in the following manner;

$$Mean\ root\ length = (l1 + l2 + l3 + l4 + l5 + l6)/6$$

3.7.2 Yield and Yield Components

The yield and yield components measured are as follows; total fresh yield, stem weight, and leaf weight.

3.7.2.1 Fresh leaf weight

The weight of the leaves from the tagged harvested lettuce plants were segregated and quantified utilizing a digital weighing scale, subsequently determining the mean leaf weight for each treatment.

3.7.2.2 Fresh stem weight

The stem weight of the tagged harvested lettuce specimens was measured using a digital weighing scale, from which the mean stem weight was calculated for each treatment.

3.7.2.3 Fresh root weight

The root weight of the tagged harvested lettuce specimens was assessed with a digital weighing scale, and the mean root weight was subsequently established for each treatment.

3.7.2.3 Fresh and dry weight of biomass

A total of six (6) lettuce specimens were systematically uprooted from each treatment plot during the harvest phase. The lettuce specimens were subjected to cutting and chopping, with the fresh weight recorded using an electronic balance. The plant materials were then subjected to oven-drying at 70 °C for 48 hours until a constant weight was reached. The desiccated samples were subsequently weighed using an electronic balance to ascertain the dry yield of the specimens.

3.7.2.4 Total fresh yield

The cumulative fresh weight of the harvested lettuce specimens was quantified using a digital weighing scale, leading to the determination of the total fresh yield for each treatment.

3.7.3 Quality attributes of lettuces

The following chemical composition and quality attributes of lettuces were determined: Nitrogen, Phosphorus, and Potassium.

3.7.3.1 Determination of Total Nitrogen (N)

The total nitrogen of the lettuce leaves was determined using the Micro-Kjeldahl Method (Black, 1965). Lettuce samples were oven-dried, ground, and digested using a mixture of 98% H_2SO_4 + 30% H_2O_2 until clear. The digest is then distilled (after adding NaOH), with released NH_3 captured in a boric acid solution and back-titrated with HCl to quantify total nitrogen.

3.7.3.2 Determination of Total Phosphorus (P)

The total phosphorus of the lettuce leaves was determined using the Vanadium-Molybdate (Yellow) Colorimetric. After the same H_2SO_4–H_2O_2 digest, in 3.7.3.1, 1 mL aliquots were reacted with using ascorbic acid reagent to produce a blue colour. Absorbance was with a spectrometer at ~ 420 nm.

3.7.3.3 Determination of Total Potassium (K)

The total potassium in the lettuce leaves was determined using Flame Photometry. A 2 mL aliquot of the digest was introduced into a flame photometer. Potassium concentration was determined using a calibration curve, following Shanmugavelu & Sevugaperumal (2021).

3.8 Data analysis

The data collected underwent analysis using analysis of variance (ANOVA) with GenStat 12th Edition software. Means were compared by employing Tukey's Honestly Significant Difference (HSD) at 5% level of significance ($P < 0.05$).

CHAPTER FOUR

4.0 RESULTS

4.1. Vegetative growth of lettuce grown under different rates of spent mushroom substrate (SMS) manure and NPK fertilizer application

The parameters used as indices of vegetative growth were the number of leaves, canopy coverage, chlorophyll content, stem girth, and root length.

4.1.1 Number of leaves

Tables 4.1 and 4.2 show the influence of soil amendment on the trend of lettuce leaves development in seasons 1 and 2, respectively. The leaves' development rose with each passing week. The number of leaves was at its highest at 6 WAT for all the soil amendments in both seasons. In season one, plots amended with NPK 23-10-5 at 400kg/ha (T_5) registered the highest number of leaves (24) at 6 WAT but were statistically the same as the remaining treatments except plots amended with SMS manure at 20 t/ha (T_3) (Table 4.1).

In season two (Table 4.2), plots amended with NPK 23-10-5 at 400kg/ha (T_5) again had the highest number of leaves (23) at 6 WAT but was not significantly different from the other treatments except plots amended with SMS manure at 15 t/ha (T_2), SMS manure at 20 t/ha (T_3), and SMS manure at 15 t/h before planting and NPK 23-10-5 at 300kg/ha as side-dressing (T_6).

Table 4.1: Effect of soil amendment on the number of leaves of lettuce for season one

Treatments	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
T_1	6 c	7 ab	12 bc	18 c	23 b
T_2	4 a	5 a	8 a	12 a	18 ab
T_3	4 abc	7 ab	9 a	12 a	16 a
T_4	5 bc	7 b	10 abc	16 bc	21 ab
T_5	6 c	8 b	13 c	19 c	24 b
T_6	4 ab	6 ab	8 a	13 ab	18 ab
T_7	5 abc	6 ab	9 a	14 ab	19 ab
T_8	5 abc	6 ab	9 ab	14 ab	19 ab
T_9	5 abc	6 ab	9 ab	14 ab	20 ab

**Means followed by the same letters are not significantly different from each other*

Table 4.2: Effect of soil amendment on the number of leaves of lettuce for season two

Treatments	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
T_1	5 b	8 d	11 cd	16 cd	21 bc
T_2	4 a	6 a	8 a	12 a	16 ab
T_3	5 ab	6 ab	8 a	12 ab	15 a
T_4	5 b	7 bcd	10 bc	15 bc	20 abc
T_5	5 b	8 cd	12 d	18 d	23 c
T_6	4 ab	6 abc	8 a	13 ab	17 ab
T_7	5 ab	6 ab	9 ab	13 abc	18 abc
T_8	5 ab	7 abcd	9 abc	13 abc	18 abc
T_9	5 b	7 abcd	9 abc	13 abc	18 abc

**Means followed by the same letters are not significantly different from each other*

4.1.2 Chlorophyll content

The effect of soil amendment on the trend of chlorophyll development in lettuce leaves in both seasons, one and two, is indicated in Tables 4.3 and 4.4, respectively. The development of chlorophyll in the leaves followed the same pattern in both experiments. The levels of chlorophyll content in the leaves for most of the soil amendments increased from 2 WAT to 5 WAT and began to decrease from 5 WAT to 6 WAT.

In both experiments, as in the number of leaves, the application of NPK 23-10-5 at 400kg/ha (T_5) produced the highest chlorophyll levels from 2 WAT to 6 WAT but was not significantly different ($P \leq 0.05$) from the remaining treatments. The lowest levels of chlorophyll were also achieved in both experiments at 5 WAT and 6 WAT with the application of SMS manure at 20 t/ha (T_3) (Tables 4.3 and 4.4).

Table 4.3: Effect of soil amendment on the chlorophyll content of lettuce for season one

Treatments	**2 WAT**		**3 WAT**		**4 WAT**		**5 WAT**		**6 WAT**	
T_1	29.2	a	36.1	ab	30.7	a	32.8	a	32.4	a
T_2	25.3	a	26.7	a	35.4	a	36.8	a	36.6	a
T_3	23.7	a	31.1	ab	35.0	a	32.6	a	31.9	a
T_4	28.8	a	31.7	ab	36.2	a	36.0	a	35.9	a
T_5	31.2	a	33.6	ab	36.9	a	41.6	a	39.3	a
T_6	27.2	a	38.5	b	35.5	a	39.9	a	39.0	a
T_7	22.1	a	36.3	ab	36.8	a	36.8	a	37.0	a
T_8	23.6	a	37.4	b	34.8	a	37.0	a	35.8	a
T_9	25.0	a	35.4	ab	35.4	a	36.6	a	37.5	a

**Means followed by the same letters are not significantly different from each other*

Table 4.4: Effect of soil amendment on the chlorophyll content of lettuce for season two

Treatments	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
T_1	29.2 a	36.3 ab	30.8 a	33.2 a	32.5 a
T_2	25.3 a	26.6 a	35.4 a	36.9 a	36.8 a
T_3	23.9 a	31.1 ab	35.2 a	32.5 a	32.0 a
T_4	28.8 a	31.6 ab	36.1 a	35.9 a	35.8 a
T_5	31.5 a	33.4 ab	37.2 a	41.4 a	39.2 a
T_6	27.3 a	38.5 b	35.6 a	40.1 a	39.2 a
T_7	22.1 a	36.4 ab	37.0 a	36.8 a	37.1 a
T_8	23.8 a	37.4 b	34.9 a	36.9 a	36.4 a
T_9	25.0 a	35.3 ab	35.6 a	36.3 a	37.6 a

**Means followed by the same letters are not significantly different from each other*

4.1.3 Normalized Difference Vegetation Index (NDVI)

Presented in Tables 4.5 and 4.6 are the effects of soil amendment on the trend of leaf canopy development in lettuce for seasons one and two, respectively. There was a significant difference in the NDVI at 15 DAT and 30 DAT among the different treatments in season one (Table 4.5). However, there was no significant difference in the NDVI of the lettuce among the different amendments at 20 DAT, 25 DAT, 35 DAT, and 40 DAT in season one. In season two, no statistical difference was observed in the NDVI among the different treatments at 15 DAT, 20 DAT, 25 DAT, 30 DAT, 35 DAT, and 40 DAT (Table 4.6).

Table 4.5 Effect of soil amendment on the NDVI of lettuce for season one

Treatments	15 DAT	20 DAT	25 DAT	30 DAT	35 DAT	40 DAT
T_1	0.33 c	0.30 a	0.45 a	0.56 ab	0.70 a	0.70 a
T_2	0.16 a	0.16 a	0.38 a	0.41 ab	0.55 a	0.64 a
T_3	0.15 a	0.25 a	0.33 a	0.34 a	0.54 a	0.58 a
T_4	0.28 bc	0.28 a	0.48 a	0.60 b	0.66 a	0.67 a
T_5	0.23 abc	0.20 a	0.50 a	0.59 ab	0.69 a	0.67 a
T_6	0.20 ab	0.37 a	0.36 a	0.50 ab	0.64 a	0.70 a
T_7	0.18 ab	0.28 a	0.37 a	0.48 ab	0.63 a	0.67 a
T_8	0.19 ab	0.19 a	0.43 a	0.43 ab	0.61 a	0.65 a
T_9	0.23 abc	0.22 a	0.44 a	0.51 ab	0.67 a	0.70 a

**Means followed by the same letters are not significantly different from each other*

Table 4.6 Effect of soil amendment on the NDVI of lettuce for season two

Treatments	15 DAT	20 DAT	25 DAT	30 DAT	35 DAT	40 DAT
T_1	0.38 a	0.46 a	0.61 a	0.64 a	0.64 a	0.64 a
T_2	0.29 a	0.38 a	0.48 a	0.51 a	0.51 a	0.51 a
T_3	0.18 a	0.33 a	0.47 a	0.47 a	0.45 a	0.45 a
T_4	0.38 a	0.43 a	0.58 a	0.63 a	0.62 a	0.62 a
T_5	0.37 a	0.48 a	0.63 a	0.69 a	0.69 a	0.69 a
T_6	0.22 a	0.37 a	0.48 a	0.55 a	0.55 a	0.55 a
T_7	0.32 a	0.42 a	0.54 a	0.52 a	0.51 a	0.50 a
T_8	0.33 a	0.39 a	0.48 a	0.52 a	0.50 a	0.50 a
T_9	0.33 a	0.45 a	0.51 a	0.53 a	0.52 a	0.51 a

**Means followed by the same letters are not significantly different from each other*

4.1.4 Stem girth

The effect of soil amendment on the stem girth of lettuce for seasons one and two is shown in Tables 4.7 and 4.8. Significant differences were observed in the mean stem girth of lettuce plants in both seasons one and two at 3 WAT and 4 WAT. There was, however, no statistical difference ($P \leq 0.05$) in the stem girth of lettuce plants at 2 WAT, 4 WAT, 5 WAT, and 6 WAT in both seasons.

In season one, the stem girth of lettuce plants from plots amended with NPK 23-10-5 at 300 kg/ha (T_4) recorded the largest stem girth at 3 WAT (6.0 mm) and 4 WAT (9.0 mm), but was not significantly different from plots amended with PM at 15 t/ha (T_1) and NPK 23-10-5 at 300 kg/ha (T_5).

Similarly, in the second season, the stem girth of lettuce plants amended with NPK 23-10-5 at 300 kg/ha (T_4) registered the largest stem girth of 5.9 mm and 9.0 mm at 3 WAT and 4 WAT, respectively. The highest mean stem girth is statistically the same as those recorded by lettuce plants from plots amended with PM at 15 t/ha (T_1) and NPK 23-10-5 at 300 kg/ha (T_5).

Table 4.7: Effect of soil amendment on the stem girth (mm) of lettuce plants for season one

Treatments	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
T_1	2.6 a	4.4 ab	7.6 bc	11.5 a	18.6 a
T_2	1.9 a	3.7 a	4.7 a	8.5 a	12.9 a
T_3	1.6 a	3.7 a	4.1 a	8.5 a	12.9 a
T_4	2.4 a	6.0 b	9.0 c	11.6 a	17.3 a
T_5	2.5 a	4.4 ab	7.6 bc	11.5 a	14.3 a
T_6	1.7 a	3.3 a	5.3 ab	9.3 a	13.7 a
T_7	2.0 a	3.5 a	5.8 ab	8.8 a	13.6 a
T_8	2.1 a	3.8 a	5.1 ab	9.3 a	14.7 a
T_9	2.1 a	3.6 a	4.2 a	8.8 a	13.7 a

**Means followed by the same letters are not significantly different from each other*

Table 4.8: Effect of soil amendment on the stem girth (mm) of lettuce plants for season two

Treatments	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
T_1	2.4 a	4.3 ab	7.5 bc	11.5 a	18.6 a
T_2	1.8 a	3.7 a	4.6 a	8.4 a	12.9 a
T_3	1.6 a	3.7 a	4.2 a	8.5 a	12.9 a
T_4	2.4 a	5.9 b	9.0 c	11.6 a	17.2 a
T_5	2.7 a	4.4 ab	7.6 bc	11.8 a	14.3 a
T_6	1.6 a	3.3 a	5.3 ab	9.5 a	13.7 a
T_7	2.0 a	3.4 a	5.8 ab	8.8 a	13.6 a
T_8	2.1 a	3.8 a	5.1 ab	9.3 a	14.6 a
T_9	2.1 a	3.4 a	4.2 a	8.8 a	13.7 a

**Means followed by the same letters are not significantly different from each other*

4.1.5 Root length

The effect of soil amendments on the root length of lettuce plants for both seasons one and two is presented in Table 4.9. There was no significant difference in the root length of lettuce plants across the different treatments in both seasons one and two.

Table 4.9: Effect of soil amendments on the stem girth and root length of lettuce at harvest

Treatments	Season One	Season Two
T_1	7.9 a	7.7 a
T_2	7.2 a	7.1 a
T_3	5.9 a	6.0 a
T_4	7.0 a	7.1 a
T_5	7.1 a	6.9 a
T_6	5.9 a	5.8 a
T_7	5.8 a	6.0 a
T_8	6.2 a	6.1 a
T_9	6.0 a	6.1 a

**Means followed by the same letters are not significantly different from each other*

4.2 Yield and yield components of lettuce grown under different rates of spent mushroom substrate (SMS) manure and NPK fertilizer application

The following parameters were used as indices of yield: leaf weight, stem weight, root weight, shoot, and total fresh yield.

4.2.1 Fresh Leaf Weight

The influence of soil amendments on the leaf weight of lettuce plants at harvest is indicated in Table 4.10. There were statistical differences ($P \leq 0.05$) in the leaf weight of lettuce plants at harvest in both seasons one and two. In season one, the application of NPK 23-10-5 at 400kg/ha (T_5) produced the highest average fresh leaf weight of 200g, which was statistically the same as that of the other treatments except SMS manure at 15 t/ha (T_2) and SMS manure at 20 t/ha (T_3). In season two, the highest average leaf weight of 206g was obtained from plots amended with NPK 23-10-5 at 400kg/ha; it was, however, not statistically different from the average leaf weight produced by the other treatments except those from plots amended with SMS manure at 15 t/ha (T_2) and SMS manure at 20 t/ha (T_3) (Table 4.10).

4.2.2 Fresh Stem weight

Table 4.10 presents the influence of soil amendments on the average fresh stem weight of lettuce plants at harvest. There were significant differences ($P \leq 0.05$) among the different treatments for the two seasons. In both seasons one and two, the highest average stem weight of 29g was produced by the NPK 23-10-5 at 400kg/ha amended plot (T_5); this was, however, not significantly different from that of the PM at 15 t/ha (T_1) and NPK 23-10-5 at 300kg/ha (T_4). control (24g) (Table 4.10).

Table 4.10: Effect of soil amendment on the fresh leaf and stem weight of lettuce

Treatments	Season One				Season Two			
	Fresh leaf weight (g)		Fresh Stem weight (g)		Fresh leaf weight (g)		Fresh Stem weight (g)	
T_1	160	b	24	cd	182	b	24	cd
T_2	76	a	13	abc	72	a	13	abc
T_3	75	a	7	a	72	a	7	a
T_4	165	b	20	bcd	179	b	20	bcd
T_5	200	b	29	d	206	b	29	d
T_6	132	ab	13	abc	135	ab	13	abc
T_7	131	ab	12	ab	135	ab	11	ab
T_8	154	b	13	abc	144	ab	13	abc
T_9	162	b	15	abc	151	b	15	abc

**Means followed by the same letters are not significantly different from each other*

4.2.3 Fresh root weight

The influence of soil amendments on the fresh root weight of lettuce plants at harvest is presented in Table 4.11. There were no significant differences ($P \leq 0.05$) in the average fresh root weight of lettuce plants at harvest in both seasons of the one and two experiments.

Table 4.11: Effect of soil amendment on the fresh root weight (g/plant) of lettuce

Treatments	Season One	Season Two
T_1	4.7 a	4.8 a
T_2	2.2 a	2.1 a
T_3	3.9 a	3.9 a
T_4	5.9 a	5.8 a
T_5	5.0 a	4.9 a
T_6	2.7 a	2.7 a
T_7	2.7 a	2.6 a
T_8	3.1 a	3.4 a
T_9	2.9 a	3.4 a

**Means followed by the same letters are not significantly different from each other*

4.2.4 Fresh and dry shoot biomass

The effect of soil amendment on the fresh and dry shoot biomass of lettuce is indicated in Table 4.12. There were significant differences ($P \leq 0.05$) in the fresh and dry shoot biomass of lettuce plants at harvest in both seasons one and two when soil amendments were applied (Table 4.12). In season one, the application of NPK 23-10-5 at 400kg/ha (T_5) produced the heaviest average fresh shoot biomass of 240g, which was statistically the same as the average fresh shoot biomass from the control plot (T_1) (199g), NPK 23-10-5 at 300kg/ha plot (T_4) (205g), SMS manure at 15 t/ha before transplanting and NPK 23-10-5 at 400 kg/ha as side-dressing (T_8) (162.6) and SMS manure at 15 t/ha before transplanting and NPK 23-10-5 at 400 kg/ha as side-dressing (T_9) (169.3). For the average dry shoot biomass, the application of NPK 23-10-5 at 400kg/ha (T_5) produced significantly ($P \leq 0.05$) higher average dry biomass (75.7g) compared to the other amendments (Table 4.12).

In season two, the highest average fresh shoot biomass (239.8g) was obtained from plots amended with NPK 23-10-5 at 400kg/ha; it was, however, not statistically different from the average fresh shoot biomass produced by the control (T_1) (199.1g), NPK 23-10-5 at 300kg/ha plot (T_4) (205.2g), and SMS manure at 15 t/ha before transplanting and NPK 23-10-5 at 400 kg/ha as side-dressing (T_9) (169.2). The NPK 23-10-5 at 400kg/ha (T_5) amendment produced a significantly ($P \leq 0.05$) higher average dry shoot biomass of 75.6g compared to the other amendments (Table 4.12).

4.12 Effect of soil amendments on the fresh and dry shoot biomass of the lettuce plant

Treatments	**Season One**				**Season Two**			
	Fresh shoot biomass (g/plant)		**Dry shoot biomass (g/plant)**		**Fresh shoot biomass (g/plant)**		**Dry shoot biomass (g/plant)**	
T_1	199.2	cd	43.3	ab	199.1	cd	43.1	ab
T_2	86.8	ab	34.8	ab	86.7	ab	34.6	ab
T_3	82.1	a	26.8	a	82.0	a	26.7	a
T_4	205.3	cd	51.5	b	205.2	cd	51.4	b
T_5	240.0	d	75.7	c	239.8	d	75.6	c
T_6	154.2	abc	39.2	ab	154.0	abc	39.1	ab
T_7	149.0	abc	44.7	ab	148.7	abc	44.8	ab
T_8	162.6	bcd	51.1	b	159.9	bc	51.1	b
T_9	169.3	cd	48.9	ab	169.2	cd	48.9	ab

**Means followed by the same letters are not significantly different from each other*

4.2.5 Total fresh yield

Table 4.13 shows the influence of soil amendments on the total fresh yield of lettuce at harvest. Significant differences ($P \leq 0.05$) were observed in the total fresh yield among the different soil amendments in both seasons one and two. In season one, the application of NPK 23-10-5 at 400kg/ha (T_5) produced the highest yield of 47.1 Mt/ha; this was however not significantly different ($P \leq 0.05$) from the yield from the other plots except those from plots amended with SMS manure at 15 t/ha (T_2) (17.9 Mt/ha) and SMS manure at 20 t/ha (T_3) (17.7 Mt/ha). The lowest yield of 17.9 Mt/ha and

17.7 Mt/ha was recorded on the SMS manure at 15 t/ha (T_2) and SMS manure at 20 t/ha (T3) plots, respectively (Table 4.13).

In season two, similar findings were made; plots amended with NPK 23-10-5 at 400kg/ha (T_5) produced the highest yield (48.6 Mt/ha). This was, however, statistically ($P \leq 0.05$) the same as the yield from the other treatments except for lettuce plants coming from plots amended with SMS manure at 15 t/ha (T_2) (16.8 Mt/ha) and SMS manure at 20 t/ha (T_3) (16.8 Mt/ha). SMS manure at 15 t/ha and SMS manure at 20 t/ha produced the lowest yield of 16.8 Mt/ha in season two.

Table 4.13: Effect of soil amendments on the total fresh yield (Mt/ha) of lettuce at harvest

Treatments	**Season One**		**Season Two**	
T_1	37.7	b	42.8	b
T_2	17.9	a	16.8	a
T_3	17.7	a	16.8	a
T_4	38.7	b	42.2	b
T_5	47.1	b	48.6	b
T_6	31.0	ab	31.7	ab
T_7	30.9	ab	31.7	ab
T_8	36.1	b	33.8	ab
T_9	38.0	b	35.5	b

**Means followed by the same letters are not significantly different from each other*

4.3 Mineral composition of lettuce leaves as affected by application of different rates of spent mushroom substrate (SMS) manure and NPK fertilizer

4.3.1 Nitrogen content

There was no significant difference ($P \leq 0.05$) in the N content of lettuce leaves among the different amendments applied in season one. Season two, however, saw some significant differences ($P \leq 0.05$) among the amendments (Table 4.14). In season two, the control plots produced lettuce plants with higher N content of 2.63% but were statistically the same as the other amendments except lettuce leaves produced from NPK 23-10-5 at 300kg/ha (T_4) (1.71%), and NPK 23-10-5 at 400kg/ha (T_5) (1.83%) which had significantly lower N content (Table 4.14).

4.3.2 Phosphorus content

There were no significant differences ($P \leq 0.05$) in the P content in the lettuce leaves among the various soil amendments in both seasons (Table 4.14). The P content of the lettuce leaves ranged between 0.47% to 0.51% in season one of the experiments. In season two, the range of the P content of lettuce leaves was between 0.45% and 0.48% (Table 4.14).

4.3.3 Potassium content

Table 4.14 indicates that there were no significant differences ($P \leq 0.05$) observed in the percentage content of K in the lettuce leaves among the various amendments in both seasons. The K content in the leaves of the lettuce ranged from 8.22% to 8.91% in the first season of the experiment. In season two, the range of the K content in the leaves of the lettuce plant was between 6.94% and 8.02% (Table 4.14).

Table 4.14: Effect of soil amendments on the quality attributes (nutritional composition) of lettuce

Treatments	Season One						Season 2					
	% K		% N		% P		% K		% N		% P	
T_1	8.91	a	2.32	a	0.50	a	8.00	a	2.63	c	0.48	a
T_2	8.90	a	2.38	a	0.51	a	8.05	a	2.54	bc	0.46	a
T_3	8.90	a	2.39	a	0.51	a	8.02	a	2.56	bc	0.46	a
T_4	8.40	a	2.13	a	0.49	a	6.99	a	1.71	a	0.45	a
T_5	8.36	a	2.18	a	0.49	a	6.94	a	1.83	ab	0.45	a
T_6	8.38	a	2.32	a	0.49	a	6.97	a	1.98	abc	0.45	a
T_7	8.26	a	2.45	a	0.47	a	7.68	a	2.44	abc	0.46	a
T_8	8.25	a	2.29	a	0.47	a	7.65	a	2.28	abc	0.46	a
T_9	8.22	a	2.39	a	0.47	a	7.63	a	2.40	abc	0.47	a

**Means followed by the same letters are not significantly different from each other*

4.4 Quality of organic manure (PM and SMS) and soil quality before and after the experiment

4.4.1 Poultry manure analysis

Table 4.15 indicates some chemical properties of the poultry manure used in both seasons one and two. Even though the manure was collected from the same source and analysed before each season, the organic matter content of poultry manure used in season two was slightly higher (65.61%) compared to season one (61.90%). Similarly, the percentages of N, P, K, Ca, and Mg were generally observed to be higher in the poultry manure used in season two than in season one (Table 4.15).

4.4.2 Spent Mushroom Substrate Manure Analysis

The chemical properties analyzed were higher in the SMS manure used in season two compared to that of season one (4.15). The percentage of organic matter content for both seasons one (50.56%) and two (52.08%), was high. The other chemical properties, such as N, P, K, Ca, and Mg, were very low for the SMS manure used in both seasons. The levels of N, P, and K in the poultry manure were higher compared to those of the SMS manure. This could account for the high yields recorded in the poultry manure-amended plots as opposed to the SMS manure-amended plots.

Table 4.15: Chemical properties of poultry manure and spent mushroom substrate used in seasons 1 and 2

	PM		SMS	
Chemical properties	**Season 1**	**Season 2**	**Season 1**	**Season 2**
pH (1:2.5 H_2O)	7.50	7.73	-	-
Organic Carbon (%)	35.30	37.42	29.2	30.1
Organic Matter (%)	61.90	65.61	50.6	52.1
Total Nitrogen (%)	2.42	2.57	1.2	1.3
C/N ratio	14.60	15.48	-	-
Phosphorus (%)	1.23	1.30	0.2	0.2
Ca2+ (%)	3.35	3.55	0.0880	0.0906
Mg2+ (%)	2.15	2.28	0.0089	0.0092
Total Potassium (%)	1.62	1.72	0.0036	0.037
% Moisture	11.40	12.08	-	-

4.4.3 Chemical Properties of soil before and after harvesting

The chemical and physical properties of the soil at the experimental site before planting are presented in Table 4.16. The results of the analysis showed that the soil was slightly alkaline. According to the CSIR-SRI Soil Test Interpretation Guide, the average nitrogen levels in the soil were adequate for the growth and development of lettuce plants. The potassium levels were also found to be very high in the soil. The phosphorus levels were generally low in the soil. Again, the Ca levels in the soil before planting were generally high. Similarly, the Mg levels in the soil were also high. The organic matter content of the soil was also adequate (1.82%).

The physical soil analysis indicates that the textural class of the soil is sandy clay, comprising 49% sand, 8% silt, 42% clay in season one and 48% sand, 9% silt, 43% clay in season two.

Tables 4.17 and 4.18 present post-planting soil analyses for two cropping seasons at 0–15 cm depth, comparing the effects of different soil amendment treatments. These include poultry manure (PM), spent mushroom substrate (SMS), inorganic fertilizer (NPK 23-10-5), and combinations thereof. The parameters assessed include soil pH, electrical conductivity (EC), organic carbon (%C), total nitrogen (%TN), available phosphorus (Av. P), and exchangeable cations (Ca, Mg, Na, and K).

All treatments increased or maintained pH above neutral (~7.0). The highest pH was observed in T_3 (SMS manure 20 t/ha) and T_2 (SMS manure 15 t/ha) in both seasons, suggesting SMS has an alkalizing effect. The combined treatments (T_6 – T_9) maintained moderate pH (6.85–7.04). The lowest EC was in the control (T_1), while T_6 and T_8 (SMS + NPK) had the highest EC (0.63–0.68 mS/m) in both seasons. The highest %C was recorded in T_2, T_3, and T_5 (pure organic or higher NPK rate). Pure SMS and SMS-NPK combinations generally improved %TN more than control and NPK alone. T_4 (NPK only) had a relatively high %TN. T_3 (SMS 20 t/ha) and T_9 (SMS 20 t/ha + NPK 400 kg/ha) also showed consistently high %TN. Phosphorus availability significantly increased with combined applications. T_9 and T_8 yielded the highest Av. P levels (36.86 and 32.92 mg/kg in season one; 39.44 and 35.23 mg/kg in season two). Ca and Mg were highest in SMS-NPK combinations, particularly in T_9 and T_7, enhancing nutrient balance. Na levels remained moderate and comparable across treatments. K levels were highest in T_4 and T_1, potentially from poultry manure and inorganic K content, but generally stable across treatments.

Table 4.16: Soil analysis at the experimental site at 0 -15 cm depth before planting

Soil analysis	
Chemical properties	
pH	7.51
EC (ms/m)	0.29
%C	1.05
%TN	0.21
AV. P (mg/kg)	14.47
Ca (Cmol/kg)	23.90
Mg (Cmol/kg)	10.23
Na (Cmol/kg)	3.10
K (Cmol/kg)	1.16
Physical properties	
% Sand	49
% Silt	9
% Clay	43
Textural class	Sandy Clay

Table 4.17: Soil analysis at the experimental site at 0 -15 cm depth after planting for season one

Treatments	PH	EC (ms/m)	%C	%TN	AV. P (mg/kg)	Ca (Cmol/kg)	Mg (Cmol/kg)	Na (Cmol/kg)	K (Cmol/kg)
T_1	6.95	0.07	0.99	0.08	19.47	22.81	8.86	1.28	0.61
T_2	7.35	0.26	1.05	0.10	25.48	23.95	7.84	1.30	0.52
T_3	7.60	0.25	1.01	0.25	28.92	23.91	7.76	1.22	0.60
T_4	7.10	0.37	0.82	0.26	27.43	22.77	7.73	1.39	0.64
T_5	7.15	0.38	1.09	0.20	26.04	23.44	8.65	1.26	0.57
T_6	6.85	0.63	0.87	0.22	29.14	23.86	8.31	1.24	0.56
T_7	7.00	0.52	1.09	0.24	31.94	24.69	8.65	1.70	0.57
T_8	6.85	0.63	0.72	0.25	32.92	24.13	8.73	1.45	0.52
T_9	7.00	0.54	0.91	0.24	36.86	24.23	9.13	1.27	0.51

Table 4.18: Soil analysis at the experimental site at 0 -15 cm depth after planting for season two

Treatments	PH	EC (ms/m)	%C	%TN	AV. P (mg/kg)	Ca (Cmol/kg)	Mg (Cmol/kg)	Na (Cmol/kg)	K (Cmol/kg)
T_1	6.98	0.07	1.08	0.09	20.83	23.00	8.94	1.29	0.66
T_2	7.39	0.28	1.14	0.10	27.27	24.14	7.91	1.31	0.56
T_3	7.64	0.27	1.10	0.26	30.94	24.10	7.83	1.23	0.64
T_4	7.14	0.40	0.89	0.28	29.35	22.95	7.80	1.40	0.69
T_5	7.19	0.41	1.19	0.22	27.86	23.63	8.73	1.27	0.62
T_6	6.88	0.68	0.95	0.23	31.18	24.05	8.39	1.25	0.61
T_7	7.04	0.56	1.19	0.25	34.18	24.89	8.72	1.71	0.61
T_8	6.88	0.68	0.78	0.27	35.23	24.32	8.81	1.47	0.57
T_9	7.04	0.58	1.00	0.25	39.44	24.42	9.21	1.28	0.55

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of soil amendments on the vegetative growth of lettuce

The results of the two experiments showed an increase in the vegetative parameters of lettuce with the application of the different soil amendments. The number of leaves, canopy coverage, chlorophyll content, stem girth, root length, fresh shoot, stem, and root biomass were all affected by the application of the different soil amendments.

NPK fertilizer application improved the growth parameters of the lettuce plant better than the poultry manure (control) and the SMS manure when applied alone. This finding can be attributed to the readily available nutrient profile of inorganic fertilizers compared to organic sources. NPK fertilizers provide immediate and balanced proportions of essential macronutrients such as N, P, and K, which are crucial during the vegetative and early growth phases of lettuce. As a fast-growing leafy vegetable, lettuce benefits significantly from rapid nutrient availability. This observation aligns with findings from Mounirou *et al*. (2023), who reported that the highest total yield of lettuce was achieved with a joint application of goat manure, biochar, and 100% NPK, emphasizing the superior immediate response of plants to NPK in comparison with organic amendments alone. Similarly, Adekiya *et al*. (2020) showed that NPK significantly improved growth and yield components in crops compared to organic sources, due to its predictable nutrient composition and faster uptake.

The poultry manure, when solely applied, was able to positively impact most of the vegetative parameters of the lettuce plant due to its rich and excellent source of nutrients and organic matter; however, SMS, when applied alone, even at high levels of 20t/ha, could not. This finding could be attributed to variations in their nutrient composition and decomposition dynamics**.** While SMS does contain organic matter and some residual nutrients, it is generally lower in immediately available forms of NPK compared to poultry manure (Zhang *et al*., 2014). Its slow mineralization rate means that nutrients are not rapidly released into the soil, especially in the early stages of plant development when demand is high. Even at high application rates (e.g., 20 t/ha), SMS may not provide sufficient readily available nitrogen to support rapid vegetative growth, which is particularly crucial for short-cycle crops like lettuce.

The integrated utilization of chemical fertilizers and SMS manure significantly improved the vegetative growth parameters of the lettuce plant. The findings of this present study showed that SMS manure at 20 t/ha combined with NPK 23-10-5 at 300 kg/ha as side-dressing produced more leaves in both seasons, which were higher in weight compared to the sole use of SMS manure. Soil amendment is said to positively influence the vegetative parameters of lettuce (Zia and Fatima, 2018; Adekiya and Ojeniyi, 2015; Ghaffari *et al*., 2016; Wang *et al*., 2018; Vivek *et al*., 2019; Dourado *et al*., 2016). Nitrogen is key in the growth of crops; about 0.23% of nitrogen is adequate for the proper growth and development of plants, including lettuce. In this study, the nitrogen content of the amendments used was found to be adequate; it is therefore possible that it might have contributed to improving some of the vegetative parameters of the lettuce plant.

Findings from the present study revealed that the integrated use of NPK fertilizer and SMS enhanced the growth parameters of the lettuce plant. The findings of this current study agree with the findings of Vivek *et al*. (2019) that the application of different rates of SMS to the soil increased some of the vegetative parameters, such as the height, fresh, and dry weight of the lettuce plant. Similarly, Amin *et al*. (2021) found that the addition of SMS manure to the soil enhanced shoot length and leaf area in lettuce seedlings. The findings of this study are also in conformity with the work of Saba and Khan (2018), who observed that lettuce plants treated with SMS demonstrated higher chlorophyll content than the control group. The results from this study also agree with an earlier study by Dourado *et al*. (2016), who concluded that SMS manure used in amending the soil in lettuce production improved plant growth, root development, and nutrient uptake. Finally, studies suggest that integrated application, combining SMS with inorganic fertilizers or nutrient-rich manures, greatly enhances its efficacy in supporting vegetative growth. This approach allows immediate nutrient availability from the fertilizer and long-term soil conditioning from SMS (Zeng *et al*., 2022).

The possibility of the SMS manure improving most of the vegetative parameters of lettuce stems from the fact that the SMS contains a significant amount of organic matter, which can improve soil physical properties such as aeration, water-holding capacity, and porosity, all of which support root growth and nutrient uptake in lettuce (Uzun, 2004). Enhanced root development, in turn, promotes better shoot growth and leaf expansion. SMS also acts as a biological stimulant, enhancing soil microbial activity and possibly suppressing soilborne pathogens (Medina *et al*., 2009). A healthy rhizosphere indirectly promotes vigorous vegetative growth by reducing biotic stress.

5.2 Effect of soil amendments on the yield of lettuce

The findings from the study revealed that the yield parameters of the lettuce plant were affected by the different soil amendments. The integrated use of SMS and NPK performed better than the single use of SMS manure. This observation is grounded in the concept of nutrient synergy and balance in integrated soil fertility management (ISFM). SMS, while rich in organic matter and some residual nutrients, typically has a slow mineralization rate and may not immediately supply sufficient available nitrogen (N), phosphorus (P), and potassium (K) to meet the early growth demands of fast-growing crops like lettuce. NPK fertilizers, on the other hand, provide immediately soluble and plant-available nutrients, especially nitrogen, which is crucial for vegetative growth and chlorophyll synthesis. By integrating both, the NPK supplies quick-acting nutrients, while SMS improves soil structure and supports long-term nutrient release, thus combining a short-term boost with long-term sustainability.

The integrated use of SMS manure improved the yield of lettuce compared to the straight use of SMS manure. Even though earlier studies did not study the effect of the integrated use of SMS and NPK fertilizer on the lettuce yield as opposed to the straight use of the SMS manure, there have been studies supporting the finding that the integrated use of organic manure with inorganic fertilizers improves the yield of crops. Saah *et al*. (2022) found that combining biochar (organic) with reduced NPK rates produced comparable or superior lettuce yields, enhancing nutrient use efficiency. According to Bahadur *et al*. (2009), integrated application led to higher head weight and quality compared to organic manures alone. Similarly, the study by Reddy and Reddy (2011) confirms enhanced yield and nutrient availability with integrated nutrient strategies in short-duration crops. Demir *et al*. (2024) also noted that lettuce treated with reduced NPK plus microbial amendments outperformed those treated with full NPK or organics alone.

Even though poultry manure improved the yield of the lettuce plants, SMS manure also has the potential to increase the yield of lettuce. Garg and Bahla (2008) found that spent mushroom substrate (SMS) manure also contains a balanced mix of nutrients. Furthermore, Roy *et al*. (2015) noted that SMS manure can also enhance crop yields; however, the results are typically less pronounced than with poultry manure. However, spent mushroom substrate (SMS) manure is characterized by a slow mineralization rate, which influences the timing and availability of nutrients to crops. This gradual decomposition process means that a substantial portion of the nutrients within SMS is released over an extended period, rather than immediately upon application. Consequently, when the same field is replanted with lettuce in successive cycles, SMS can continue to supply nutrients, thereby exhibiting a residual fertilizing effect (Uzun, 2004).

In contrast, poultry manure, although rich in readily available nitrogen and phosphorus, tends to decompose and release nutrients rapidly. This can lead to a shorter residual impact, making it less effective for supplying nutrients in subsequent planting cycles unless reapplied (Yadvinder-Singh, 2009). Therefore, while poultry manure may support vigorous initial growth, SMS proves advantageous in rotational or continuous cropping systems, particularly for short-duration crops like lettuce, due to its long-lasting nutrient contribution and soil-conditioning properties (Zhang *et al*., 2014).

5.3 Effect of soil amendments on the quality attributes of lettuce

Findings from the study showed that the application of the different soil amendments did not affect the accumulation of N, P, and K in the leaves of the lettuce plants. This finding disagrees with earlier findings by Khettari *et al*. (2020), who reported an increase in the protein and mineral content of lettuce with the application of SMS manure. Similarly, this study disagrees with the work of Roy *et al*. (2015), who established that the use of mushroom substrate as a fertilizer enhanced the nutrient content of crops. The outcome of this current study further disagrees with that of Kwon and Kim (2017), who asserted that lettuce grown in the SMS-based substrate had significantly higher levels of nitrogen, phosphorus, potassium, and calcium. Finally, this current study is not in line with the findings of Li *et al*. (2020), who demonstrated that SMS applied to the soil increased the levels of N, P, and K in the leaves of the lettuce plant compared to the control.

5.4 Effect of soil amendments on soil chemical properties

The results of the soil analysis from the experimental site before the amendment of the soil showed that some of the soil's chemical properties were available at varying levels.

Potassium, calcium, and magnesium were at significant or adequate levels in the soil. The soil was vertisol, and according to Srivastava *et al*. (2002), vertisol generally has high calcium levels; this could account for the high levels of calcium in the soil. Also, the organic matter and nitrogen levels were adequate in the soil. Phosphorus was, however, found to be low in the soil. Amending the soil enhanced some of the chemical properties of the soil when the soil was analyzed after harvesting.

Results from the experiment indicated that amending the soil enhanced the soil pH, nitrogen, sodium, and phosphorus levels after harvest. Electrical conductivity, organic matter content, calcium, magnesium, and potassium were, however, not improved after harvest. The soils amended with SMS manure had a higher % N compared to the poultry manure amended plots. This finding could be attributed to the slow release of the N in the SMS manure through the mineralization process. The implication of this is that the N in the poultry manure was released into the soil early and was utilized by the plants for proper growth and development, whilst the N in the SMS was released late, making it not readily available to the plants but available in the soil. Given the slow nitrogen (N) mineralization and prolonged nutrient release pattern of spent mushroom substrate (SMS), the most effective strategy to maximize its benefit involves a staggered or pre-seasonal application. The SMS should be incorporated into the soil 3–4 weeks before transplanting or direct seeding. This gives soil microbes time to begin mineralizing organic N, converting it into plant-available nitrate (NO_3^-) and ammonium (NH_4^+) by the time seedlings are actively growing. Early decomposition accelerates nutrient cycling, as supported by Medina *et al.* (2009), who showed that pre-incorporation improved nutrient availability in later growth stages.

There was a decrease in the organic carbon, organic matter content, calcium, magnesium, and potassium levels of the soil after amending it. However, according to Onwu *et al.* (2014), soil amendment with poultry manure increased some of the chemical characteristics of the soil, such as the cation exchange capacity, organic matter content, and exchangeable cations. Khalid *et al.* (2014), Adekiya *et al.* (2014), Ojeniyi *et al.* (2013), Adeleye *et al.* (2010), and Agbede *et al.* (2010) all reported that the amendment of the soil with poultry manure significantly increased the available potassium and organic matter of the soil after harvest. Rehman *et al.* (2017) and Wang *et al.* (2020) all indicated that applying SMS increased soil organic matter content, exchangeable potassium, and cation exchange capacity. These findings disagree with those of the present study, where lower levels of organic carbon, organic matter content, calcium, magnesium, and potassium were observed after harvest. This observation could be attributed to the fact that the lettuce plants made excessive use of the nutrients in the soil, thereby depleting the levels of some of the nutrients after harvest, since lettuce is considered a heavy feeder. This assumption is supported by Kumar *et al.* (2013) and Obeng-Ofori *et al.* (2007), who reported that soil fertility is critical for improved yield and high-quality lettuce leaves, and that the addition of organic matter and nutrients is necessary.

Electrical conductivity of the soil, which measures the salinity of the soil, increased after harvest with the integrated use of SMS and NPK fertilizer. In line with this current finding, Zhang *et al*. (2019) reported increased soil electrical conductivity with the application of SMS to soil, which would lead to a rise in the salt content of the soil, which is undesirable. The increase in soil electrical conductivity (EC) observed after harvest in soils treated with integrated SMS and NPK fertilizer is primarily due to the accumulation of soluble salts in the soil. This accumulation is caused by the combined release of soluble salts from the immediate impact of NPK fertilizer, and the gradual nutrient mineralization from SMS. While increased EC reflects higher nutrient presence, excessive salinity over time may pose risks to sensitive crops and soil health, necessitating monitoring and adequate leaching**.** On the contrary, the poultry manure amendment, however, witnessed a reduced electrical conductivity. In support of the findings of this study, poultry manure is found to reduce the electrical conductivity of soil (Agbede, 2010; Ano and Agwu, 2006; Chellemi and Lazarovits, 2002).

The nitrogen, sodium, and phosphorus levels of the soil were improved after harvest with soil amendments. Several authors reported the same findings that soil amendments with poultry manure and SMS can improve the levels of nitrogen, sodium, and phosphorus in the soil after harvest (Adekiya *et al*., 2014; Onwu *et al*., 2014; Day *et al*., 2019).

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. The soil amendments improved all the vegetative parameters measured for lettuce plants.
2. NPK fertilisation improved the growth parameters of lettuce more than poultry or SMS manure.
3. The integrated use of NPK fertilizer and SMS manure improved the vegetative attributes of the lettuce plants compared to the straight use of SMS manure alone.
4. The application of SMS manure and NPK 23-10-05 amendment resulted in better yield components and total yield of lettuce compared to the sole SMS manure.
5. Application of sole SMS and poultry manure amendments resulted in higher concentrations of nitrogen, phosphorus, and potassium in the lettuce leaves as compared to the combined SMS manure and NPK 23-10-05 amendment.
6. All the soil amendments applied enhanced the nitrogen, soil pH, and phosphorus levels after harvest.
7. The soil electrical conductivity, organic matter content, calcium, magnesium, and potassium were, however, not improved after harvest of lettuce.

6.2 Recommendations

The following recommendations are made based on the conclusions drawn from this study.

Firstly, for optimal lettuce yield quality, farmers must adopt the integrated approach using NPK fertilizer and SMS manure. A rate of 20 t/ha SMS before planting and 400 kg/ha of NPK 23-10-5 as side-dressing is preferred.

Secondly, due to the late release of N in the SMS manure, it should be applied much earlier than poultry manure. At least the application of the SMS manure should be done four weeks before transplanting the lettuce plant.

More studies should be conducted to ascertain the impact of the age of SMS manure on its nutritional composition and the yield and yield components of lettuce. This study will establish the right age of the SMS manure where nutrients can be easily released to the growing plant.

Further studies are needed to establish the residual impact of SMS application on the yield and yield components of lettuce. This is relevant because the first cycle of production might not have utilized most of the nutritional composition of the manure.

Other varieties of lettuce should also be evaluated with the SMS manure, and the effects on the yield and yield components evaluated.

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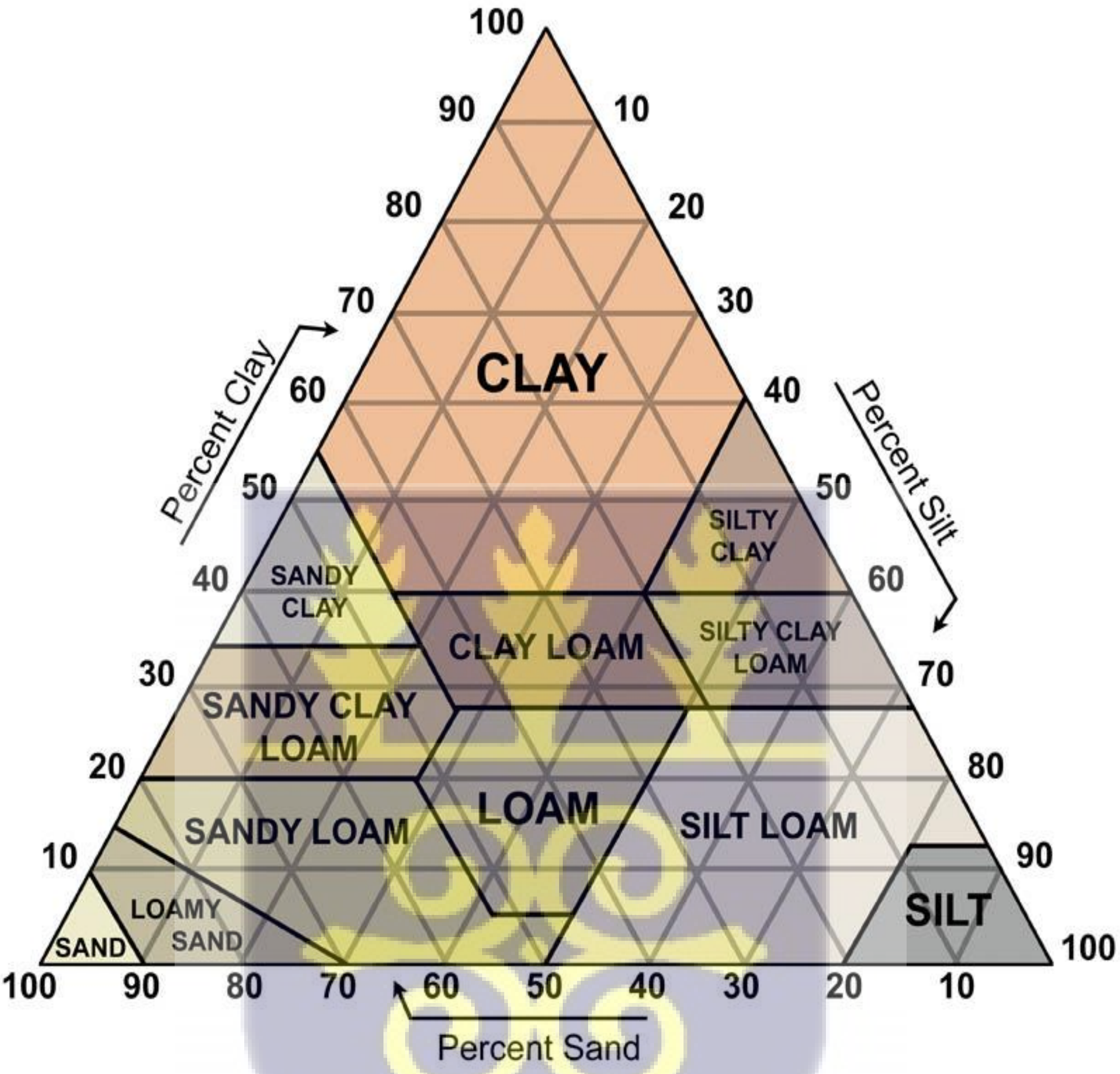
APPENDICES

Appendix 1: Soil texture triangle



Source: www.soilsensor.com/soil types

Appendix 2: Analysis of variance (ANOVA) for experiment one

Variate: %K

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	95.15	31.717	4.88	
Treatments	8	2.913	0.364	0.06	1
Residual	24	156.064	6.503		
Total	35	254.127			

Variate: %N

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	2.313	0.771	4.06	
Treatments	8	0.3512	0.0439	0.23	0.981
Residual	24	4.5596	0.19		
Total	35	7.2238			

Variate: %P

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	0.098732	0.03291	11	
Treatments	8	0.007113	0.00089	0.3	0.96
Residual	24	0.071791	0.00299		
Total	**35**	**0.177635**			

Variate: Canopy_coverage_D_15

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	0.024119	0.00804	2.97	
Treatments	8	0.114114	0.01426	5.27	<.001
Residual	24	0.06496	0.00271		
Total	**35**	**0.203193**			

Variate: Canopy_coverage_D_20

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	0.11495	0.03832	2.92	
Treatments	8	0.13512	0.01689	1.29	0.295
Residual	24	0.31451	0.0131		
Total	**35**	**0.56458**			

Variate: Canopy_coverage_D_25

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	0.055355	0.01845	2.96	
Treatments	8	0.100574	0.01257	2.02	0.088
Residual	24	0.149429	0.00623		
Total	**35**	**0.305358**			

Variate: Canopy_coverage_D_30

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	0.0689	0.02297	2.07	
Treatments	8	0.23642	0.02955	2.67	0.03
Residual	24	0.26599	0.01108		
Total	**35**	**0.57131**			

Variate: Canopy_coverage_D_35

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	0.008282	0.00276	0.38	
Treatments	8	0.109555	0.01369	1.9	0.106
Residual	24	0.172547	0.00719		
Total	**35**	**0.290385**			

Variate: Canopy_coverage_D_40

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	0.01091	0.00364	0.67	
Treatments	8	0.047465	0.00593	1.09	0.405
Residual	24	0.130946	0.00546		
Total	**35**	**0.189321**			

Variate: Chlorophyll_W_2

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	63.35	21.12	1.29	
Treatments	8	293.7	36.71	2.24	0.06
Residual	24	393.07	16.38		
Total	**35**	**750.12**			

Variate: Chlorophyll_W_3

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	5.73	1.91	0.11	
Treatments	8	441.66	55.21	3.23	0.012
Residual	24	409.76	17.07		
Total	**35**	**857.15**			

Variate: Chlorophyll_W_4

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	437.16	145.72	5.75	
Treatments	8	107.42	13.43	0.53	0.822
Residual	24	607.95	25.33		
Total	**35**	**1152.53**			

Variate: Chlorophyll_W_5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	25.8	8.6	0.38	
Treatments	8	266.26	33.28	1.47	0.221
Residual	24	544.59	22.69		
Total	**35**	**836.64**			

Variate: Chlorophyll_W_6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	8.15	2.72	0.14	
Treatments	8	211.04	26.38	1.34	0.272
Residual	24	472.38	19.68		
Total	**35**	**691.57**			

Variate: Dry biomass_weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	3821.94	1273.98	14.63	
Treatments	8	5978.72	747.34	8.58	<.001
Residual	24	2089.98	87.08		
Total	**35**	**11890.65**			

Variate: Fresh biomass_weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	36411	12137	11.6	
Treatments	8	86628	10829	10.35	<.001
Residual	24	25105	1046		
Total	**35**	**148144**			

Variate: Fresh root_weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	136.902	45.634	12.39	
Treatments	8	49.947	6.243	1.69	0.151
Residual	24	88.413	3.684		
Total	**35**	**275.262**			

Variate: Fresh shoot_weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	29445.3	9815.1	11.32	
Treatments	8	54661.7	6832.7	7.88	<.001
Residual	24	20813.6	867.2		
Total	**35**	**104920.6**			

Variate: Fresh stem_weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	434.41	144.8	5.97	
Treatments	8	1479.11	184.89	7.62	<.001
Residual	24	582.37	24.27		
Total	**35**	**2495.89**			

Variate: Moisture Content D.15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	9.922	3.307	1.25	
Treatments	8	19.085	2.386	0.9	0.533
Residual	24	63.713	2.655		
Total	**35**	**92.72**			

Variate: Moisture Content D.20

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	5.78	1.93	0.18	
Treatments	8	55.95	6.99	0.64	0.735
Residual	24	261.2	10.88		
Total	**35**	**322.93**			

Variate: Moisture Content D.25

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	73.371	24.457	6.23	
Treatments	8	39.839	4.98	1.27	0.306
Residual	24	94.279	3.928		
Total	**35**	**207.489**			

Variate: Moisture Content D.30

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	41.521	13.84	2.72	
Treatments	8	43.336	5.417	1.06	0.42
Residual	24	122.287	5.095		
Total	**35**	**207.143**			

Variate: Moisture Content D.35

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	154.29	51.43	3.23	
Treatments	8	250.72	31.34	1.97	0.095
Residual	24	381.94	15.91		
Total	**35**	**786.95**			

Variate: Moisture Content D.40

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	756.83	252.28	2.8	
Treatments	8	321.86	40.23	0.45	0.88
Residual	24	2159.14	89.96		
Total	**35**	**3237.82**			

Variate: No_of_leaves_W_2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	2.0833	0.6944	2.17	
Treatments	8	13	1.625	5.09	<.001
Residual	24	7.6667	0.3194		
Total	**35**	**22.75**			

Variate: No_of_leaves_W_3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	6.3056	2.1019	3.49	
Treatments	8	18.2222	2.2778	3.78	0.005
Residual	24	14.4444	0.6019		
Total	**35**	**38.9722**			

Variate: No_of_leaves_W_4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	12	4	4.36	
Treatments	8	78.8889	9.8611	10.76	<.001
Residual	24	22	0.9167		
Total	**35**	**112.8889**			

Variate: No_of_leaves_W_5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	29	9.667	4.3	
Treatments	8	230	28.75	12.78	<.001
Residual	24	54	2.25		
Total	**35**	**313**			

Variate: No_of_leaves_W_6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	29.889	9.963	1.43	
Treatments	8	191.056	23.882	3.42	0.009
Residual	24	167.611	6.984		
Total	**35**	**388.556**			

Variate: Root_length

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	0.5389	0.1796	0.19	
Treatments	8	18.2656	2.2832	2.38	0.048
Residual	24	22.9811	0.9575		
Total	**35**	**41.7856**			

Variate: Stem_girth_W_2

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	3.6964	1.2321	4.3	
Treatments	8	3.74	0.4675	1.63	0.168
Residual	24	6.8711	0.2863		
Total	**35**	**14.3075**			

Variate: Stem_girth_W_3

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	4.1021	1.3674	2.6	
Treatments	8	21.5899	2.6987	5.14	<.001
Residual	24	12.6124	0.5255		
Total	**35**	**38.3044**			

Variate: Stem_girth_W_4

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	9.157	3.052	2.41	
Treatments	8	94.112	11.764	9.29	<.001
Residual	24	30.408	1.267		
Total	**35**	**133.677**			

Variate: Stem_girth_W_5

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	14.647	4.882	1.39	
Treatments	8	60.221	7.528	2.15	0.07
Residual	24	84.015	3.501		
Total	**35**	**158.884**			

Variate: Stem_girth_W_6

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	13.698	4.566	0.62	
Treatments	8	125.19	15.649	2.11	0.075
Residual	24	177.896	7.412		
Total	**35**	**316.784**			

Variate: Total_yield_per_hectare

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1630.19	543.4	11.32	
Treatments	8	3026.25	378.28	7.88	<.001
Residual	24	1152.31	48.01		
Total	**35**	**5808.75**			

Appendix 3: Analysis of variance (ANOVA) for experiment two

Variate: %K

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	55.65	18.55	1.48	
Treatments	8	6.85	0.86	0.07	1
Residual	24	300.03	12.5		
Total	**35**	**362.53**			

Variate: %N

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	7.9689	2.6563	24.96	
Treatments	8	3.6889	0.4611	4.33	0.002
Residual	24	2.5543	0.1064		
Total	**35**	**14.2121**			

Variate: %P

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	0.125136	0.04171	7.63	
Treatments	8	0.003437	0.00043	0.08	1
Residual	24	0.131123	0.00546		
Total	**35**	**0.259695**			

Variate: Canopy_coverage_D_15

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	0.007206	0.0024	0.3	
Treatments	8	0.156454	0.01956	2.44	0.043
Residual	24	0.191997	0.008		
Total	**35**	**0.355657**			

Variate: Canopy_coverage_D_20

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	0.013899	0.00463	0.8	
Treatments	8	0.074477	0.00931	1.6	0.177
Residual	24	0.139625	0.00582		
Total	**35**	**0.228001**			

Variate: Canopy_coverage_D_25

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	0.06906	0.02302	2.09	
Treatments	8	0.1231	0.01539	1.4	0.247
Residual	24	0.26403	0.011		
Total	**35**	**0.45619**			

Variate: Canopy_coverage_D_30

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.0042	0.0014	0.14	
Treatments	8	0.17424	0.02178	2.13	0.072
Residual	24	0.24487	0.0102		
Total	35	0.42331			

Variate: Canopy_coverage_D_35

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.00353	0.00118	0.11	
Treatments	8	0.19514	0.02439	2.27	0.058
Residual	24	0.25818	0.01076		
Total	**35**	**0.45685**			

Variate: Canopy_coverage_D_40

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.00325	0.00108	0.1	
Treatments	8	0.19553	0.02444	2.25	0.059
Residual	24	0.26061	0.01086		
Total	**35**	**0.4594**			

Variate: Chlorophyll_W_2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	65.18	21.73	1.31	
Treatments	8	297.89	37.24	2.25	0.06
Residual	24	397.56	16.57		
Total	**35**	**760.64**			

Variate: Chlorophyll_W_3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	5.02	1.67	0.1	
Treatments	8	451.3	56.41	3.42	0.009
Residual	24	396.24	16.51		
Total	**35**	**852.55**			

Variate: Chlorophyll_W_4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	431.68	143.89	5.56	
Treatments	8	111.46	13.93	0.54	0.816
Residual	24	621.48	25.89		
Total	**35**	**1164.62**			

Variate: Chlorophyll_W_5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	30.72	10.24	0.5	
Treatments	8	255.62	31.95	1.56	0.188
Residual	24	490.53	20.44		
Total	**35**	**776.87**			

Variate: Chlorophyll_W_6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	5.8	1.93	0.1	
Treatments	8	207.47	25.93	1.29	0.293
Residual	24	480.7	20.03		
Total	**35**	**693.96**			

Variate: Dry Biomass_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	3831.74	1277.25	14.81	
Treatments	8	5994.57	749.32	8.69	<.001
Residual	24	2069.31	86.22		
Total	**35**	**11895.63**			

Variate: Fresh biomass_weight_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	36021	12007	11.92	
Treatments	8	86622	10828	10.75	<.001
Residual	24	24177	1007		
Total	**35**	**146820**			

Variate: Fresh_root_weight_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	150.916	50.305	13.26	
Treatments	8	47.9	5.987	1.58	0.184
Residual	24	91.084	3.795		
Total	**35**	**289.9**			

Variate: Fresh_shoot_weight_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	27681.8	9227.3	9.33	
Treatments	8	68948	8618.5	8.71	<.001
Residual	24	23745.5	989.4		
Total	**35**	**120375.3**			

Variate: Fresh_stem_weight_g

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	432.08	144.03	5.93	
Treatments	8	1500.89	187.61	7.72	<.001
Residual	24	583.32	24.31		
Total	**35**	**2516.3**			

Variate: Moisture_Content_D_15

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	85.37	28.46	2.74	
Treatments	8	89.79	11.22	1.08	0.408
Residual	24	248.96	10.37		
Total	**35**	**424.12**			

Variate: Moisture_Content_D_20

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	5.33	1.78	0.18	
Treatments	8	42.12	5.27	0.52	0.827
Residual	24	241.54	10.06		
Total	**35**	**289**			

Variate: Moisture_Content_D_25

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	58.61	19.537	5.48	
Treatments	8	51.85	6.481	1.82	0.123
Residual	24	85.53	3.564		
Total	**35**	**195.99**			

Variate: Moisture_Content_D_30

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	41.521	13.84	2.72	
Treatments	8	43.336	5.417	1.06	0.42
Residual	24	122.287	5.095		
Total	**35**	**207.143**			

Variate: Moisture_Content_D_35

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	30.528	10.176	1.36	
Treatments	8	23.674	2.959	0.4	0.912
Residual	24	179.457	7.477		
Total	**35**	**233.659**			

Variate: Moisture_Content_D_40

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	35.176	11.725	3.25	
Treatments	8	35.472	4.434	1.23	0.325
Residual	24	86.634	3.61		
Total	**35**	**157.282**			

Variate: No_of_leaves_W_2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.6667	0.2222	0.57	
Treatments	8	12	1.5	3.86	0.005
Residual	24	9.3333	0.3889		
Total	**35**	**22**			

Variate: No_of_leaves_W_3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	4.75	1.5833	4	
Treatments	8	23.3889	2.9236	7.39	<.001
Residual	24	9.5	0.3958		
Total	**35**	**37.6389**			

Variate: No_of_leaves_W_4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	9	3	4.65	
Treatments	8	64.0556	8.0069	12.4	<.001
Residual	24	15.5	0.6458		
Total	**35**	**88.5556**			

Variate: No_of_leaves_W_5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	16.222	5.407	4.08	
Treatments	8	128.222	16.028	12.1	<.001
Residual	24	31.778	1.324		
Total	**35**	**176.222**			

Variate: No_of_leaves_W_6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	40.972	13.657	2.39	
Treatments	8	198.056	24.757	4.33	0.002
Residual	24	137.278	5.72		
Total	**35**	**376.306**			

Variate: Root_length_cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.5831	0.1944	0.22	
Treatments	8	14.305	1.7881	1.99	0.092
Residual	24	21.5394	0.8975		
Total	**35**	**36.4275**			

Variate: Stem_girth_W_2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	3.3142	1.1047	5.22	
Treatments	8	4.3856	0.5482	2.59	0.034
Residual	24	5.0833	0.2118		
Total	**35**	**12.7831**			

Variate: Stem_girth_W_3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	4.8691	1.623	3.18	
Treatments	8	22.1919	2.774	5.44	<.001
Residual	24	12.2407	0.51		
Total	**35**	**39.3017**			

Variate: Stem_girth_W_4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	9.105	3.035	2.39	
Treatments	8	94.563	11.82	9.32	<.001
Residual	24	30.436	1.268		
Total	**35**	**134.103**			

Variate: Stem_girth_W_5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	19.594	6.531	2.03	
Treatments	8	63.437	7.93	2.46	0.042
Residual	24	77.213	3.217		
Total	**35**	**160.245**			

Variate: Stem_girth_W_6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	13.803	4.601	0.62	
Treatments	8	125.137	15.642	2.1	0.076
Residual	24	178.615	7.442		
Total	**35**	**317.555**			

Variate: Total_yield_per_hectare

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	3	1532.56	510.85	9.33	
Treatments	8	3817.19	477.15	8.71	<.001
Residual	24	1314.63	54.78		
Total	**35**	**6664.38**			

Appendix 4: Soil test interpretation guide

(a) Macronutrients (N, P, K)

	Nitrogen (N)		**Phosphorus (P)**		**Potassium (K)**		
Extraction method	Kjedahl	2N KCL	Bray	Olsen	Ammonium Acetate		Ammonium Bicarbonate
					Base	Available	DTPA
Units	%	ppm	ppm	ppm	meq/10g	ppm	ppm
Levels:							
High	0.23-0.30	41-75	40-100	>25	0.7-2.0	280-800	121-180
Adequate	0.13-0.23	20-41	20-40	15-25	0.45-0.70	175-280	61-120
Low	0.05-0.13	<20	<20	<15	<0.45	<175	<60

(b) Macronutrients (Ca, Mg, S)

	Calcium (Ca)		**Magnesium (Mg)**		**Sulphur (S-SO^4)**
Extraction method	Ammonium Acetate		Ammonium Acetate		KCL 40
Units	meq/100g	ppm	meq/100g	ppm	ppm
Levels:					
High	>10	>2000	>1.5	>180	>10
Adequate	5-10	1000-2000	0.5-1.5	60-180	5-10
Low	<5	<1000	<0.5	<60	<5

(c) Micronutrients

	Iron (Fe)	**Manganese (Mn)**	**Zinc (Zn)**	**Copper (Cu)**	**Boron (B)**
Extraction method	DTPA	DTPA	DTPA	DTPA	DTPA
Units	ppm	ppm	Ppm	ppm	ppm
Levels:					
High	>5.0	>2.0	>1.5	>2.0	>2.0
Adequate	2.5-5.0	0.6-2.0	1.0-1.5	0.6-2.0	0.5-2.0
Low	<2.5	<0.6	<1.0	<0.6	<0.5

(d) Soil properties (pH, organic matter, CEC, TEB, Base Saturation)

Parameter	**pH**	**Organic matter (%)**	**CEC**	**TED**	**Base Saturation (%)**
Levels:					
High*	>6.5	>2.5	>20	>20	>95
Adequate*	5.5-6.5	1.5-2.5	5-20	4-20	85-95
Low*	<5.5	<1.5	<5	<4	<85

** also depends on the crop*

Source: Council for Scientific and Industrial Research-Soil Research Institute (CSIR-SRI)

Appendix 5: Descriptive terms commonly associated with certain 1:1 pH ranges

Term	pH
Extremely acid	<4.5
Very strongly acid	4.5–5.0
Strongly acid	5.1–5.5
Moderately acid	5.6–6.0
Slightly acid	6.1–6.5
Neutral	6.6–7.3
Slightly alkaline	7.4–7.8
Moderately alkaline	7.9–8.4
Strongly alkaline	8.5–9.0
Very strongly alkaline	>9.1

Source: Soil Survey Division Staff, 1993