EVALUATION OF VERMICOMPOST-INORGANIC FERTILIZER COMBINATION ON GROWTH, YIELD AND QUALITY OF STRAWBERRY

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DECLARATION

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

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This thesis has been submitted with our approval as University supervisors

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I dedicate this thesis to my parents, siblings, and husband for all the support they gave me throughout the process.

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LIST OF ABBREVIATIONS

BBCH	Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie scale
DAE	Days after establishment
FAO	Food Agriculture Organization of the United Nations
INM	Integrated nutrient management
NPK	Nitrogen, phosphorus, and potassium
TSS	Total soluble solids
TTA	Total titratable acidity
FW	Fresh weight

GENERAL ABSTRACT

Yield and quality of strawberry is constrained by sub-optimal management of the crop's nutrient. Strawberry require large quantities of nitrogen (N), phosphorus (P) and potassium (K), and other nutrients for vigorous growth, as well as to maximize yield and quality. Synthetic fertilizers provide N, P and K in potentially higher concentrations compared with organic substrates. However, food safety and high production costs have seen a steady increase in the use of organic fertilizers such as vermicompost in strawberry production. Vermicompost is the product of the decomposition of organic matter that uses worms, and in particular red wigglers (*Eisenia fetida*). Vermicompost may not readily release nutrients thus necessitating the judicious combination with synthetic fertilizers. This study was carried out to (i) evaluate the effect of different combinations of inorganic fertilizer and vermicompost on growth and yield of strawberry, and (ii) to determine the effect of different combinations of inorganic fertilizer and vermicompost on quality of strawberry and soil properties. Treatments included a combination of different fractions of inorganic fertilizer and vermicompost, in addition to three controls of sole vermicompost, sole NPK fertilizer and control. Nutrient combinations were 100% NPK, 100% vermicompost , 50% NPK + 50% vermicompost, 75% NPK + 25% vermicompost, 25% NPK + 75% vermicompost, 100% NPK + 100% vermicompost, and unfertilized control. The treatments were applied in Chandler strawberry studied in field experiments for two seasons from October 2020- March 2021 and April 2021-September 2021 in Kabete farm, University of Nairobi. Experiments were set out in a randomized complete block design and replicated three times. Key data comprised plant growth parameters including number of crowns, runners and runner length, yield parameters including the number of fruiting plants, fruit growth rate, number of fruits, and fruit weight. Fruit quality parameters included fruit firmness, fruit color, total soluble sugars, vitamin C, and titratable acidity. Soil parameters consisting of bulk density, penetration resistance, porosity, infiltration rate, and soil microbiology were tested at the end of the second experimental season. Data were analyzed using the 12th edition of GenStat computer software. Treatment means were compared and separated using Fisher's protected least significant difference. Application of vermicompost and inorganic NPK increased strawberry growth and yield compared with unfertilized control. In the first cycle of experimentation, addition of 100% NPK outperformed the other treatments with regards to crop developmental rates and number of crowns per plant. Under 100% NPK, crops produced crowns 13 days earlier compared with 100% VC treatment. However, significant shifts were observed during the second cycle where crops grown under 100% VC matured earlier and produced 9 crowns more compared with 100% NPK. Addition of both inorganic NPK and vermicompost significantly increased the number of fruits and fruit weight compared with unfertilized control. Across the entire sampling period, vermicompost-NPK combination at a rate of 75% VC + 25% NPK surpassed the other treatments in regard to the number of fruits and fruit weight, having a mean of 27 fruits per square meter and a mean fruit weight of 22 grams. These results revealed that use of vermicompost alone or in combination with inorganic fertilizers is beneficial in field grown strawberry for improved growth and yield. In the second objective, there was a positive effect of vermicompost and inorganic NPK on strawberry fruit quality and soil properties. During the two experimental seasons, combination of vermicompost and inorganic NPK significantly influenced the quality of strawberry used compared with the three controls of sole NPK fertilizer, sole vermicompost and unfertilized control. Fruits that received 100% VC as well as 75% VC + 25% NPK outperformed their counterparts in selected fruit quality attributes. 100% VC fertilized plants produced fruits with the highest TSS (10.2). Fruits under 25% NPK + 75% VC as well as 100% VC had the lowest acidity (0.7%) and high vitamin C content of 36.7. Therefore, results from these selected quality attributes suggest that the use of vermicompost in combination with inorganic NPK led to an increase in quality of strawberry. Sole application of vermicompost outperformed its counterparts in regard to soil properties. Under 100% VC, soils had the lowest penetration resistance (3.22), highest infiltration rate (4.20) and highest porosity percentage (58.02%) compared to all other treatments. Soils that received 100% vermicompost had 160% more earthworms and 90% higher total biodiversity compared to soil that received 100% NPK. Soils in the control plots had 53% higher total biodiversity than soils with 100% NPK. In conclusion, addition of vermicompost in combination with inorganic NPK positively influences growth, yield, and quality of strawberry. Across the entire sampling period, sole vermicompost and 75% VC + 25% NPK had optimal results in most key parameters compared to other treatments. Nonetheless, economically optimal combinations of vermicompost and inorganic fertilizer deserve further investigation.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Demand for strawberry is increasing worldwide. In 2020, global strawberry sales were estimated at 9.2 million t with China leading at 3.3 million t, 5% higher than 2019. Between 2008 and 2019, global strawberry production increased by 39.4% (FAO, 2020). Demand for strawberry is generally higher during festive seasons such as Valentines, Easter, and Christmas. Despite the global growth trajectory, strawberry production in Kenya has been declining. In 2014, Kenya recorded a high production of 3940t compared with 1800t in 2018 (FAO, 2020). The area under strawberry production has markedly reduced in recent years. In year 2014,strawberry acreage in Kenya was estimated at 146 ha compared with 64 ha in year 2019 (FAO, 2020). The decline in strawberry production in Kenya could be attributed to crop nutrition constraints, low soil fertility, poor agronomic practices as well as pests and diseases (Wanjukia et al., 2020; Mwari, 2018; Mwangi et al., 2017).

The most important constraint to strawberry production in Kenya is low supply of crop nutrients. Insufficient supply of strawberry crop nutrients impacts both yield and quality of strawberry (Wanjukia et al., 2020). Nitrogen is the most important nutrient in strawberry production. However, potassium, phosphorus, calcium, boron, and zinc are also required in substantial amounts (Nakro et al., 2023). Nitrogen not only increases yield but controls fruit taste and acidity, especially when nitrate availability synchronizes with flowering and fruiting phase (Salman et al., 2022). Phosphorus promotes root development and supports new growth, as well as flower bud formation (Dominguez et al., 2020). Potassium increases fruit sugars, acidity and improves its taste (Paparozzi, 2018). Micronutrients such as Calcium improve fruit firmness and prolong shelf-life while boron increases fruit sugars (Dominguez et al., 2020)

Strawberry plants remain productive for two to three years, and adequate supply of nutrients from either organic or inorganic fertilizer sources is important (Singh and Kaur, 2020). In most environments, literature shows that strawberry crops require NPK at a rate of 40% nitrogen, 80% phosphorus and 80% potassium (Mwangi et al., 2017). Kenyan farmers seldom apply the optimal rate, often resulting in under or over fertilization (Mwari, 2018). In an attempt to find the optimal rate of vermicompost on strawberry, Kumar and Tripathi. (2020) analyzed quantities of major nutrients. They found that to meet the desired amount of 40-80-80 NPK from vermicompost, the recommended amount is 30 t/ha. Conventional organic amendments, such as farmyard manure, in most cases contain low amounts of NPK and are therefore required in substantial amounts to supply the recommended nutrient rates (Naga et al., 2021). Vermicompost, a product of decomposition of food waste by various species of earthworms such as red wiggler worms, is known to have readily available nitrogen, phosphorus, potassium, calcium, boron, beneficial soil microbes and plant growth hormones (Jadhav et al., 2023).

Strawberry are influenced by water and nutrient fluctuations owing to their shallow fibrous root system (Makkar et al., 2023). Nutrient replacement through balanced fertilization of organic and chemical sources creates a good system of providing constant supply of required nutrients to the strawberry crop (Singh et al., 2020). When compared with inorganic fertilizers, the use of organic amendments, such as vermicompost, have been shown to improve nutrient availability and moisture retention (Ahmad et al., 2022). Vermicompost is becoming prevalent as an improved and superior source of plant nutrients, plant development balancing hormones, enzymes and disease suppressing compounds (Singh et al., 2020; Cabilovski et al., 2023)

Supply of the recommended nutrient rates result in high quality fruits that have a long shelf life with the right balance of sugars, acidity, good aroma, and color (Cabilovski et al., 2023). Limited research has been done to assess the effects of a combination of vermicompost and inorganic NPK in different rates on strawberry growth, yield, quality, and shelf life. It is hypothesized that application of vermicompost-inorganic may have synergistic effects on growth, yield and quality of strawberry compared with application of each of nutrient sources independently.

1.2 Statement of the problem

According to FAOSTAT 2020, the total land under strawberry cultivation in Kenya in 2019 was estimated at 30 ha and yielded 239 t. On average the yield was 7.25 t/ha compared with a yield potential of 30 t/ha (FAO, 2020). In most instances, farmers use inorganic fertilizers throughout the growing season. Overuse of these chemical fertilizers causes an imbalance in the availability of soil nutrients resulting in soil degradation (Singh et al., 2020). A previous study done in Kenya has shown that farmers seldom use the right fertilizer rates on strawberry leading to nutrient deficiencies (Mwangi et al., 2017). Nutrient deficiencies in Strawberry results in growth retardation and reduced size of fruits (Singh et al., 2020). Organic sources of nutrients improves both quantity and quality of strawberry fruits especially fruit color and total soluble solids (Paparozzi et al., 2018).

Strawberry, being shallow, fibrous- rooted plants, require adequate supply of nutrients for optimum production and a slight fluctuation in the nutrients, which is the current biggest challenge to strawberry farmers, leads to low returns (Singh and Kaur, 2020). There is need to research on how to adopt integrated nutrient management practices that use the right rates of organic and synthetic fertilizers to supply sufficient nutrients throughout the strawberry growing period. This study therefore seeks to assess the effect of different combinations of inorganic fertilizer and vermicompost on growth, yield, quality, and shelf life of strawberry.

1.3 Justification of the study

Increased use of chemical fertilizers has led to serious soil nutrient losses negatively impacting the soil chemical and biological properties. Nutrient integration results in improved crop productivity as compared to synthetic or organic sources of nutrients used individually. Extensive research has been carried out to recover the quality of soil, increase farm produce while reducing pollution. It is important to come up with an integrated nutrient approach on strawberry production to bridge the yield gap being experienced in Kenya. This study is aimed in evaluating the effects of combined use of vermicompost and inorganic NPK in improving soil quality and enhancing crop growth. This will significantly benefit strawberry farmers reduce their dependency on synthetic fertilizers and increase their yield. The results from this study will guide policy makers in coming up with training guidelines for strawberry farmers in effective combinations of vermicompost and synthetic fertilizers to increase their yield thus bridging the existing production gap.

1.4 Objectives

1.4.1 Broad objective

The broad objective of this study was to explore the optimal combinations of organic and inorganic nutrition regimes for improved growth, yield, and quality of strawberry.

1.4.2 Specific objectives

1. To evaluate the effect of different combinations of inorganic fertilizer NPK and vermicompost on growth and yield of strawberry
2. To determine the effect of different combinations of inorganic fertilizer NPK and vermicompost on selected quality attributes of strawberry fruit and soil properties

1.5 Hypotheses

1. Combination of different amounts of vermicompost and inorganic NPK fertilizer does not increase crop growth and yield of strawberry compared with individual use of either nutrient source.
2. The combination of different rates of vermicompost and inorganic NPK fertilizer does not improve the quality of strawberry fruit and soil properties.

CHAPTER TWO: LITERATURE REVIEW

2.0 Botany and ecology of strawberry

The strawberry (*Fragaria ananassa)* belongs to the rose family, Rosaceae. It is a cross between the wild Virginia strawberry which is endemic in North America and a Chilean variety (Hancock, 2020). It is a short herbaceous crop with a shallow fibrous root system. It has trifoliate, compound serrated leaves. As the crop matures, the root structure becomes hardy, and the "mother"crown develops stolons, commonly known as runners, that root on touching soil. The flowers, normally white, appear in small bunches on thin stems arising from the crown (Warner et al., 2021).

Botanically, the strawberry is categorized as an auxiliary fruit, in which some of the flesh is derived not from the pod but from some adjacent tissue exterior to the carpel. The epidermis contains enlarged flower and is enclosed by many true fruits, which are commonly known as seeds (Hancock, 2020). The strawberry crop produces at its maximum under a balanced nutrient plan. Strawberry grow well in slightly acidic soils, but also grow well in soils having high organic matter. Strawberry crop requires macro- nutrients nitrogen, phosphorus and potassium in high amounts for plant growth, runner production, and fruit bud formation. The crop thrives in hot climate and does not tolerate frost or extremely low temperatures. It requires an average of 8 hours of direct sunlight daily.

2.1 Growth and yield physiology of strawberry

Strawberry plants take three months to fully mature after which they produce consistently for two to three years. At the plants mature, they require a heavy dressing of nitrogen for growth and translocation of proteins, and phosphorus for root formation. Strawberry plants produce crowns that form from the root of the plant and runners that develop into new plants (Celiktopuz et al., 2023). Microorganisms like fungi and bacteria secrete auxins and gibberellins in large quantity during the vermicomposting process which influences strawberry ability to grow and develop runners and crowns (Ramos et al., 2022). Reports in literature, recommend that use of vermicompost in combination with inorganic fertilizers increase fruit production and improve fruit quality through production of plant growth promoters by microorganisms during vermicomposting(Ramos et al., 2022; Domínguez et al., 2020).

2.2 Importance of strawberry

Strawberry are cultivated globally for their attractive red, sweet, and aromatic fruit. The strawberry's unique flavor makes it universally loved in all forms: fresh, frozen, canned, as part of food and drink recipes, and also used as artificial flavoring in cosmetics or perfumes. Strawberry fruit is a great source of vitamins C and K and offers a good dose of fiber, folic acid, manganese, and potassium (Hancock, 2020). Strawberry also have medicinal benefits such as increasing human immunity. The fruit also contains significant amounts of phytonutrients and flavonoids (Warner et al., 2021).

In Kenya, the awareness of strawberry as a high value crop has led to the development of enterprises to increase production, marketing, value addition and consumption. Strawberry farming is profitable even on small scale production (Mwangi et al., 2017). A recent study conducted on major strawberry producing areas in Kenya show that more than 70% of strawberry farmers own less than one-eighth acre, the largest being three acres (Kavutu and Mwangi, 2018). Unlike most short cycle fruits and vegetable crops, strawberry farmers are able to continuously harvest for over five years thus making more income from the crop. Compared to other fruits, strawberry are more economical as they can be harvested up to three times per week, hence providing regular income (Wanjukia et al., 2020). Preference for value added strawberry is on the rise as more people are consuming value-added strawberry products such as juices, yoghurts, ice cream, and cakes strawberry dipped in chocolate. This creates a diversified income, allowing more people to invest in the strawberry value chain (Wanjukia et al., 2020).

2.3 Production trends of strawberry in Kenya

Globally, the main producers of strawberry as of 2020 are China at 3.8 million tons, the United States at 1.4 million t, and Mexico 468 thousand tons (FAO 2020). At the end of 2019, Kenya produced 504 tons, and was ranked number 74 in global strawberry production (FAO 2020). 2014 recorded the highest strawberry production in Kenya at 3940 tons. However, from 2014 to 2020, production has decreased up to 180 tons. The total area used for strawberry production has also decreased gradually ending at 66 ha in 2019 (FAO 2020). Despite the area under cultivation increasing, the overall yield has been on the decline. This decline is mainly due to poor agronomic practices in the production process that is poor nutrition and fertilization programs (Wanjukia et al., 2020).

The most common strawberry varieties grown in Kenya are Pajero, Chandler, Douglas, and Tribute. Major strawberry growing regions in Kenya are Kiambu, Kirinyaga and Nyandarua (Kavutu and Mwangi, 2018). The main system of production in Kenya is in the open fields but the crop does well under protected structures.

2.4 Constraints to strawberry production in Kenya

The highlighted yield gap of strawberry could be attributed to crop nutrient constraints and poor soil fertility. Strawberry is an overly sensitive crop that requires a balanced and steady nutrient supply to achieve high yields and optimum quality. Strawberry, having a shallow fibrous root system, requires a constant availability of nutrients in the topsoil (Kavutu and Mwangi, 2018; Wanjukia et al., 2020). Inorganic sources of NPK, that is urea, muriate of potash, are highly water soluble and hence easily leached. When these minerals are leached, strawberry plants, being shallow rooted, are not able to utilize the nutrients. Farmers often apply these fertilizers at more intervals, and this increases the overall cost of production (Kavutu and Mwangi, 2018). Farmers who depend on conventional organic fertilizers such as manure also need to use high amounts to provide the recommended rate of nutrients and this also increases the cost of production (Wanjukia et al., 2020). It could benefit the farmer to combine both vermicompost and inorganic fertilizers to provide steady nutrient supply since inorganic fertilizers readily provide nutrients to the crop and organic fertilizers slowly release their nutrients hence available over a longer period (Singh and Kumar, 2021).

2.5. Soil fertility constraints

Fast reduction in soil productiveness resulting in low yields is linked to several aspects such as unwarranted and inappropriate use of inorganic fertilizers, rigorous traditional practices and ignoring the use of organic manures individually or integrating with chemical fertilizers (Dominguez et al., 2020). Strawberry crop is perennial and therefore it produces for close to six years. Balanced amounts of manure and chemical fertilizers are required to provide the crop with the recommended amount of nutrients through its productive period (Singh and Kumar, 2021). Inorganic fertilizers, such as NPK provide a fast nutrient source to the plants but are depleted after a short time and this leads to multiple applications of inorganic fertilizers in a growing season. As compared to Inorganic sources of NPK, vermicompost provides a steady release of nutrients and also retains the nutrients over a longer period of time therefore continually providing nutrients to plants (Naga et al., 2021). Vermicompost is well-known to improve the physical, biochemical and biotic properties of soil, therefore providing a good environment for crop growth and development (Singh and Kumar, 2021).

Strawberry plants grow fast and mature within four to five months. The growth rate is greatly affected by ecological conditions, such as sunlight, humidity, temperature, and nutrients (Singh and Kaur, 2020). Owing to its speedy maturity, the crop requires sufficient uptake of macronutrients to meet the photosynthetic demand and satisfactory fruit growth (Dominguez et al., 2020).

2.5.1 Nitrogen nutrition of strawberry

Nitrogen is needed by the crop in the production of proteins and amino acids. Nitrogen application should be based on the requirement of the crop at each developmental stage (Dominguez et al., 2020). Insufficient accessibility of nitrogen increases root growth but hinders shoot growth. Nitrogen surplus on the other hand promotes shoot growth more than root growth. Nitrogen deficiency affects strawberry total biomass, results in small fruits, and severely limits the crop's productivity (Nakro et al., 2023). Nitrogen deficient strawberry crops are immature and yellowish green. Their leavesare undersized and rigid. The crop produces very few runners that are mostly red and very thin. Older leaves of the mature fruit bearing crop develop an orange-reddish color from the leaf tip (Salman et al., 2022).

2.5.2 Phosphorus nutrition of strawberry

Phosphorus is vital to the strawberry crop as it helps in the generation of new cells, root formation,and formation of fruits and seeds. Phosphorus deficient plants have a bluish-purple discoloration on the leaves. In advanced phosphorus deficiency, leaves develop a dark metallic sheen on the upper surface while the underside becomes reddish –purple. Phosphorus deficiency also inhibits shoot development. (Zenda et al., 2021). Though vermicompost, like conventional compost, has high levels of phosphorus, this form of phosphorus is not readily available for plant use since it is incorporated in organic matter.

Generally, farmers should consider integration of both vermicompost and inorganic phosphorus to ensure adequate crop nutrition (Salman et al., 2022).

2.5.3 Potassium nutrition of strawberry

Potassium is particularly important in strawberry quality as it provides a high sugar and acid content, and a good taste to the fruit. It is important for transpiration and regulates stomatal opening and closing, helping improve water use efficiency particularly in periods of moisture stress (Dominguez et al., 2020). Potassium deficient strawberry plants causes brown leaf scorching and curling of the leaf tips. Fruit development is usually reduced in potassium deficient strawberry plants (Sabahat et al., 2021). As compared to inorganic potassium, potassium from vermicompost is available to plants over a longer period as it is slowly released (Zenda et al., 2021).

2.6 Integrated nutrient management in strawberry

Integrated nutrient management (INM) is the conservation of soil productiveness and plant nutrient access to a balanced level to maximize a plant's yield potential by combining all beneficial sources of plant nutrients (Singh and Kumar, 2021). It is the most effective combination of nutrients from both chemical and organic fertilizers resulting in optimal crop produce without degrading soil nutrients or contaminating the surroundings (Savita et al., 2023). INM improves plant's ability to absorption macronutrients N, P and K, and micronutrient inputs and matches the crop nutrient requirements alleviating constraints of nutrient. This is achievable through proper application of a balanced mixture of organic and inorganic fertilizers (Barooah and Datta, 2020).

Integrated nutrient management is important in strawberry production as it provides the crops with adequate amounts of all vital nutrients for optimum growth and productivity (Savita et al., 2023). Strawberry growth and yield is influenced by many factors, the most important being use of the required and appropriate amount of inorganic and chemical fertilizers, which is vital for supporting strawberry's life cycle and yield potential. Integrated nutrient management greatly improves strawberry plant growth in terms of plant vegetative growth, biomass buildup, leaf size, fruit number, size, and firmness which in turn increases overall strawberry productivity (Singh and Kumar, 2021).

2.7 Response of strawberry to inorganic fertilizers

Inorganic fertilizers, being readily available, are released fast to the plant and hence depleted quickly. Previous study has shown that strawberry plants supplied with inorganic fertilizers tend to produce well in the first month as the nutrients are still available to the plants. Production then decreases in the subsequent months as the nutrients are depleted from the soil (Kilic et al., 2021). They are therefore required to be re-applied more often during production season to ensure a constant supply of nutrients. Monthly application of inorganic fertilizers results in higher biomass, higher fruit production and better fruit quality compared to application at establishment only (Dominguez et al., 2020). Potassium, supplied through inorganic fertilizers results in healthy plants with large, sweet fruits. Farmers are advised to use slow-release fertilizers to reduce the number of applications hence reducing the negative effects of fertilizers on the soil (Singh and Kaur, 2020).

2.8 Composition of vermicompost

Vermicompost is the product of non-thermophilic decomposition of organic materials and cattle dung by special worms, mostly the red wigglers. Vermicompost is highly porous and well aerated, giving it a good water holding capacity and drainage (Mupambwa et al., 2022). It is extraordinarily rich in microorganisms and the balanced interactions between earthworms and microorganisms speed up the decomposition process (Singh et al., 2020). Vermicompost is high in major nutrients nitrogen, phosphorus, potassium, sulphur, magnesium and boron and their quantities are influenced by the food waste being decomposed. It also has significant amounts of plant growth hormones and enzymes. Nutrients in vermicompost are readily available to plants. Vermicompost retains nutrients for a long time and often has adequate amount of macro and micronutrients which are released slowly (Makkar et al., 2023). Compared to traditional composting, vermicomposting takes a shorter time to compost and does not require turning like the conventional composting (Singh et al., 2020).

2.8.1 Influence of vermicompost on soil physical properties

Vermicompost, being highly porous, aids the soil in holding water and improves drainage (Akhila and Entoori, 2022). Vermicompost improves soil physical properties such as penetration resistance, porosity, and infiltration rate (Akhila and Entoori, 2022). Vermicompost is enriched with polysaccharides which function as a cementing substance, to create and maintain the soil structure for better aeration, water retention, drainage, and aerobic conditions (Warner et al., 2021). The increase in soil water holding capacity is linked to the highly porous organic matter in vermicompost, which retains sufficient amount of water needed by the plant. Reductions in particle densities are primarily due to the enriched microbial population and activity, which results in increased porosity of the soil (Ramos et al., 2022). In addition, Ramos et al., (2022) showed that progressive use of balanced organic nutrient sources resulted in reduced soil bulk density, and improved porosity and infiltration. The use of compost and animal manure in place of chemical fertilizers positively amended soil physical properties (Ramos et al., 2022; Raza et al., 2022). Thus, organic fertilizer, particularly vermicompost, is a good replacement for conventional fertilizers.

2.8.2 Influence of vermicompost on biological soil properties

Studies show that vermicompost increases the microbial activity of the soil (Ramos et al., 2022; Roy et al., 2022). Due to its high aeration and high porosity properties, vermicompost has a high number of both macro and microorganisms. Vermicompost increases the variety, quantity and performance of macro and microorganisms, providing a wide range of nutrients required for the microorganisms to thrive (Huang and He 2023). Earthworms and termites are high in vermicompost treated soils (Das et al., 2022). The feeding, burrowing, and casting from the earthworms deeply modify soil physical, chemical, and biological properties. Despite the high diversity of tropical earthworms, only a small number of species have been intensively studied in relation to soil processes, and plant growth (Akhila and Entoori, 2022). The high number of macro-organisms in the soil influenced by vermicompost results in fast turnover of organic matter in the soil (Das et al., 2022).

2.8.3 Influence of vermicompost on growth and yield of strawberry

Strawberry plants grown on vermicompost have resulted in more runners and flowers than in plants grown on inorganic fertilizers or conventional composts (Kumar and Tripathi, 2020). Vermicompost promotes strawberry plant flowering, increasing the number of flower and fruit truss produced thus increasing the number of fruits harvested (Naga et al., 2021). This can be attributed to growth stimulating hormones auxins, and flowering hormone gibberellins that are secreted by the red wiggler worms in the vermicomposting process (Ali eta al., 2021). Besides improving crop development and productivity, vermicompost may also improve the nutritional value of strawberry (Cabilovski et al., 2023). For example, use of vermicompost in strawberry production increases the quantity of sugars in the fruits thus increasing total vitamin C in the fruit (Naga et al., 2021).

2.9 Influence of Vermicompost on quality traits of strawberry

Strawberry quality attributes include vitamin C, total soluble solids, fruit color, fruit firmness, and titratable acidity. Different sources of nutrients impact fruit quality. For instance, potassium to nitrogen balance in the fruit production stage improves the quality of strawberry (Dominguez et al., 2020). Vermicompost has been observed to suppress the growth of many fungi, which results in reduced fungal diseases in vermicompost fed strawberry as compared to NPK fed strawberry. Higher quality and marketable strawberry are expected in the integration of vermicompost and NPK than in NPK only (Cabilovski et al., 2023). Similarly, reduced presence of physical malformations, and disease may be as a result of the presence of beneficial fungi, bacteria, yeasts, and algae that reduce disease prevalence (Ali et al., 2021).

Study has shown that strawberry plants that receive vermicompost produce bright colored and sweater fruits with higher quality than those getting chemical fertilizers only (Paparozzi et al., 2018). This may be due to growth promoting hormones and micronutrients found in vermicompost. Though minimal study has been done, several studies have concluded that strawberry crops with improved growth result in fruits with better quality (Ali et al., 2021).

2.9.1 Vitamin C

Vitamin C, which can account for up to 80 mg-100mg per fresh strawberry fruit, is a vital quality indicator (Kilik et al. 2021). The production of vitamin C is highly dependent on the quantity of total soluble sugars in the fruit because strawberry plants produce ascorbic acid from hexose sugars, such as D-glucose and D-galactose (Janurianti et al., 2021). Vitamin C is most sensitive to pre- and post-harvest handling conditions. The amount of vitamin C in harvested fruits and vegetables is determined by agronomic factors, such as soil conditions, and sources of nutrients (Kilik et al. 2021,).

2.9.2 Total soluble solids

Strawberry sweetness has a positive effect on consumer's choice and preference, thus influencing its demand in the market. Total soluble solids, also referred to as total soluble sugars, is an important index for fruit quality as it accounts to about 80% sugar found in strawberry (Janurianti et al., 2021). The sweetness of fruits is mainly affected by soluble sugar contents, mainly glucose, fructose, and sucrose (Kilik et al., 2021). Total sugars for different strawberry varieties range generally from 6.00-12.00% based on the cultivars and genotypes (Naga et al., 2022). Temocico et al. (2019) reported a soluble solids value in the range of 6.30–13.20% in their study examining the total soluble solids of different strawberry cultivars and genotypes.

2.9.3 Titratable acidity

Titratable acidity is an important indicator of fruit quality in strawberry due to the effect of organic acids on fruit flavor. Titratable acidity, as a measure of degree of fruit ripening, is used to predict the preference of quality fruits and fruit juices (Kumar et al., 2020) The maturity of fruit is an important factor to determine how well fruit will store and how it will taste. For some fruits, quality standards based on the ratio of total soluble solids to titratable acidity are followed to ensure consumers purchase quality fruits (Kumar and Tripathi, 2020). In a study conducted on the chandler strawberry variety, the least titratable acidity has been reported in vermicompost treated strawberry compared to inorganic treated strawberry (Gunduz and Ozbay, 2018).

2.9.4 Fruit color

Fruit color is one of the major factors that attribute to fruit quality as it influences a consumer's first impression. Anthocyanin are key players in strawberry color pigmentation. Anthocyanin influence the lightness (L) value of strawberry and determine the color intensity (Bosa et al., 2019; Ruiz et al., 2019). The unique red color of strawberry fruit at different maturity levels is attributed to their concentrated anthocyanin content (Paparozzi et al., 2018). To evaluate the development of strawberry fruit color at different maturity levels, Janurianti et al. (2021) reported a lightness (L) value of strawberry fruit color in the range of 57.60–18.50 for mature strawberry.

2.9.5 Fruit firmness

Fruit firmness is a vital, but extremely variable quality characteristic of strawberry. Genetic origin, climatic conditions, and textural components at the time of testing such as ripeness level influence fruit firmness (Ruiz et al., 2019). Fruit firmness differs based on the cultivar and genotype. Albion strawberries are firmer compared to other varieties (Lalk et al., 2020). Pinheiro et al. (2021), in their research evaluating the adaptation of various strawberry varieties to agro ecological conditions, reported a fruit firmness of 0.83N.

CHAPTER THREE: EVALUATION OF VERMICOMPOST-INORGANIC NPK COMBINATION ON GROWTH AND YIELD OF STRAWBERRY

3.1 Abstract

Strawberry is highly sensitive to fluctuations in nutrition and an optimal combination of both organic and inorganic nutrition sources is required for balanced nutrient supply to the crop. This study focused on evaluation of the effects of combined use of inorganic NPK and vermicompost at different rates for optimal strawberry growth and yield. The experimental trials were done for two seasons, season one beginning in October 2021 and season two ending in September 2022. The experiment included seven treatments arranged as randomized complete block design with three replications. Treatments included 100% NPK, 100% vermicompost, 50% NPK + 50% vermicompost, 75% NPK + 25% vermicompost, 25% NPK + 75% vermicompost, 100% NPK + 100% vermicompost, and unfertilized control. Three morphological plant parameters, crown formation, runner formation, and runner length, were studied in relation to strawberry growth. Key yield parameters, number of fruiting plants, fruit growth rate, number of fruits and fruit weight were studied in relation to strawberry yield. Application of sole vermicompost outweighed performance in regard to all growth parameters compared to its counterparts. Results showed that application of 100% NPK produced the highest number of crowns, 12, with an early crowning of 57 days, compared to control which had a late crowning of 75 days producing an average of 7 crowns in the first season. Addition of vermicompost and Inorganic NPK significantly influenced the fruit growth rate. In the first season, fruits that received 100% NPK has a faster growth rate reaching the maximum expansion at 10 days compared to other treatments where maximum expansion rate was achieved at an average of 12 days. Plants that received 75% VC and 25% VC had significantly higher number of fruits with a mean fruit weight of 22 grams in the second season. These results imply that addition of vermicompost alone or in combination with inorganic NPK improved growth and yield of strawberry. The study therefore concludes that integration of vermicompost with synthetic fertilizers at a rate of 75% VC + 25% NPK is optimal growth and yield of strawberry.

Key words: Nutrition, vermicompost, crop growth rate, crowning, yield

3.2 Introduction

Strawberry is a profitable crop to invest in because of its competitive prices and high demand. Its high global demand has led to an increase in production in recent years (Mwangi, et al., 2017; Kavutu and Mwangi, 2018). The fruit is widely valued for its juicy texture, aroma, and sweet taste. Strawberry fruit is rich in nutrients, vitamin C and antioxidants, making it a fruit of immense health benefit (Janurianti et al., 2021).

Strawberry plants have shallow fibrous roots hence require a steady supply of nutrient for optimal growth and yield. Decreasing soil nutrition is one of the major challenges to strawberry cultivation (Dominguez et al., 2020). One of the fastest ways to boost yield is increasing inputs, in most cases synthetic fertilizers. Recently, with progressive application of synthetic fertilizers, severe environmental challenges have developed (Singh and Kumar, 2021). In this regard, strides have been taken to amend soil nutrition, agricultural production processes and output. One of the effective ways to deal with these challenges is replacing synthetic fertilizers with organic fertilizers (Savita et al., 2023).

The use of organic fertilizers such as vermicompost is vital for maintaining soil fertility and improving crop growth and yield (Makkar et al., 2023). Vermicompost is a product of breakdown and decomposition of organic materials such as food waste and manure by red wiggler worms and microorganisms. Vermicompost is a fine particle, compost-like material, with high pore space, aeration, and microbial diversity, which makes it good in improving soil properties (Jadhav et al., 2023). Use of vermicompost, produced from different sources, like animal manure, kitchen waste or food waste improves seed germination percentage, growth and yield of many fruits and vegetables (Singh et al., 2020). Vermicompost has plant germination and growth promoting materials, such as humic acids, which aid in improving plant growth and yield (Makkar et al., 2023).

Continuous use of inorganic fertilizers negatively affects soil nutrition profile resulting in insufficient availability of nutrients. Use of sole vermicompost may not readily release nutrients to the plant. Minimal study has been done on the effects of combining vermicompost and chemical fertilizers on growth and yield of strawberry under Kenyan agro ecological zones. Therefore, the focus of this study was to evaluate the effects of combination of inorganic NPK and vermicompost on growth and yield of field grown strawberry. The study hypothesized that integration of vermicompost and inorganic NPK consistently improves growth and yield of strawberry.

3.3 Materials and methods

3.3.1 Experiment site

Field experiments were conducted at the University of Nairobi Kabete farm for two seasons. Kabete farm is located 1°14'57'S, 36°44'53'E and 1940 m elevation. The mean minimum temperature in Kabete was 13°C and the maximum temperature was 24°C. There was low rainfall during the October 2020 - Feb 2021 season with the average rainfall being 49.6 mm. April 2021 - September 2021 season had heavier rainfall with the average rainfall being 147.3mm. The soil texture was red clay which was hard when dry and sticky when wet. It had many broken hard pans on the surface and a few fine pores in the sub horizon. The soil was slightly acidic with pH 6.2 on the surface (0-10cm) and pH 5.0 on the bottom horizon (16-30cm).

3.3.2 Treatments and experiment design

The experiment included seven treatments arranged as randomized complete block design with three replications. Each individual trial plot consisted of 36 chandler strawberry plants and the experiment consisted of a total of 21 plots. Treatments consisted of different combinations of inorganic NPK fertilizer and vermicompost. They included 100% NPK, 100% vermicompost, 50% NPK + 50% vermicompost, 75% NPK + 25% vermicompost, 25% NPK + 75% vermicompost, 100% NPK + 100% vermicompost, and control without the supply of nutrients. The inorganic nutrients were sourced from straight fertilizers, of Urea (46% N) for nitrogen, triple super phosphate (44% P) for phosphorus and muriate of potash (60% K) for potassium.

Vermicompost used in this study had 0.8% nitrogen, 1.05% phosphorus and 0.75% potassium. It also had 9.31% organic carbon, and 14.1 C: N ratio. The vermicompost had been obtained from red wiggler worms that had been fed with cow dung and kitchen waste including fruit peels and fresh vegetable waste. Both nutrient sources were applied in two equal fractions at crop establishment and the beginning of the flowering stage. Treatments were laid out in a randomized complete block design and replicated three times.

3.3.3 Experiment management

Prior to planting, the land was prepared to a fine tilth and raised beds of 2 m by 2 m were prepared per experimental plot. Beds were mulched with silver on black 80-micron plastic film and irrigation drip lines laid at a spacing of 30cm. Strawberry splits of chandler F1 variety were planted at 30 cm intervals which resulted in 36 plants/2m^2. The seedlings were left to fully establish before the application of nutrient treatments. Respective fertilizer nutrients and vermicompost were applied. Rainfall was supplemented with drip irrigation at a rate of 500mL per plant on alternate days during the first season and at a rate of 1500mL per plant in the second season on alternate days at three equal times of 500mL each. 500mL cups were randomly placed below drips to measure the amount time needed to fill the cups and recorded. It took 30 minutes and therefore drips were opened for 30 minutes on alternate days.

Weeding was done weekly in the un-mulched parts of the experimental plots by uprooting. The strawberry plants were pruned during the fruiting stage after every two weeks to remove all the old leaves as a way of preventing soil borne fungal diseases, and to promote flower formation. Imaxi 200SC (Imidacloprid) was used at a rate of 10 mL/20 L to control all pests and rodazim 50SC (Carbendazim) was used at a rate of 15 mL/20 L to prevent and control all fungal diseases.

3.4 Data collection

3.4.1 Initial soil and vermicompost nutrient analysis

Soils were sampled and analyzed for nutritional properties before the experiments were set up. The vermicompost was also characterized for nutritional properties. Soil samples were collected to the tillage depth of 20 cm using a soil auger. Samples were analyzed for major nutrient properties including nitrogen, phosphorus, and potassium. Additional nutrients such as magnesium, zinc, calcium, and organic carbon were also analyzed.

Soil pH and vermicompost pH were obtained using a pH meter with soil to water ratio of 1:1.25 (Yang et al., 2022). The study applied the Kjeldahl method to analyze total nitrogen using concentrated sulphuric acid to change organic N to ammonium and then distilled with 10 N NaOH and further titrated with 0.01N HC (Pathak and Reddy, 2021). Mehlich 3 method was used to analyze available phosphorus, Sodium, Potassium, Magnesium and Calcium in the pooled samples using 50mL of double acid (0.95N HCL in 0.025 $(NH_4)_2SO_4$ (Mehlich, 1984). Walkey Black method was used to determine soil organic carbon (Walkey and Black, 1934, Mustapha, 2020).

3.4.2 Weather data and crop phenology

Weather data for the two experiment seasons was acquired from Kabete meteorological station. It included daily rainfall, daily minimum and maximum temperature and relative humidity. Crop phenology was scored periodically to record days to 50% crowning, runnering and flowering following BBCH strawberry growth (Meier et al., 2009)

3.4.3 Crop growth traits

Nine plants were tagged in each plot for repeat measurement of crop growth traits, every two weeks. Traits measured were number of crowns runners, runner length and diameter. The number of crowns were cumulatively hand counted per plant 30, 50, 70 and 90 days after establishment of the crop. Number of primary runners was achieved by cumulatively counting the runners attached to the mother strawberry plant from 10 cm. Number of secondary runner, runners attached to the primary runners, were achieved by hand counting the number of runners attached to another runner from 5 cm.

Runner length was measured using a measuring tape from where the runner is attached to the plant up to the tip of the runner where the new leaves and roots start forming. Runner diameter was measured using a vanier caliper at 25cm from the point of attachment to the plant.

3.4.4 Yield components

Yield parameters were collected from three randomly selected quadrants per plot with each quadrant having three tagged plants. Parameters measured included fruit growth rate, number of fruiting plants, number of fruits and fruit weight. To measure fruit growth rate, three fruits were randomly selected from the time of fruit bud formation and tagged in each quadrant for tracking of fruit expansion rate by measuring the diameter with the use of a vanier caliper on alternate days till maturity. Data was collected to determine days taken to achieve maximum rate of expansion and days taken to achieve maximum maturity. Number of fruiting plants were cumulatively hand counted per plot and total fruit yield recorded every 70, 80, 90 and 100 days after establishment. Fruits were weighed after each harvest to obtain the fruit weight.

3.5 Data Analysis

Data collected was explored using the GenStat 12th Edition statistical program. Prior to analysis, residuals were checked for normal distribution and necessary transformations were done using Stata Version 15 by Stata Corp LLC. Analysis of variance (ANOVA) was used to test for significant differences and the means compared and separated using Fischer's protected least significant difference (LSD) at 5% probability level.

3.6 Results

3.6.1 Weather data and crop phenology

Figures 3.1 presents temperature and rainfall during two experimental seasons from October 2020 - March 2021 and April 2021 - September 2021 in Kabete farm, University of Nairobi. The two seasons are similar to long term averages of rainfall in Kabete. The temperature during the two experimental seasons was typical for growing strawberry. To ensure crop water requirements were met in both seasons, rainfall in the first season was supplemented with drip irrigation at 500mL per plant on alternate days and at 1000mL per day in the second season.

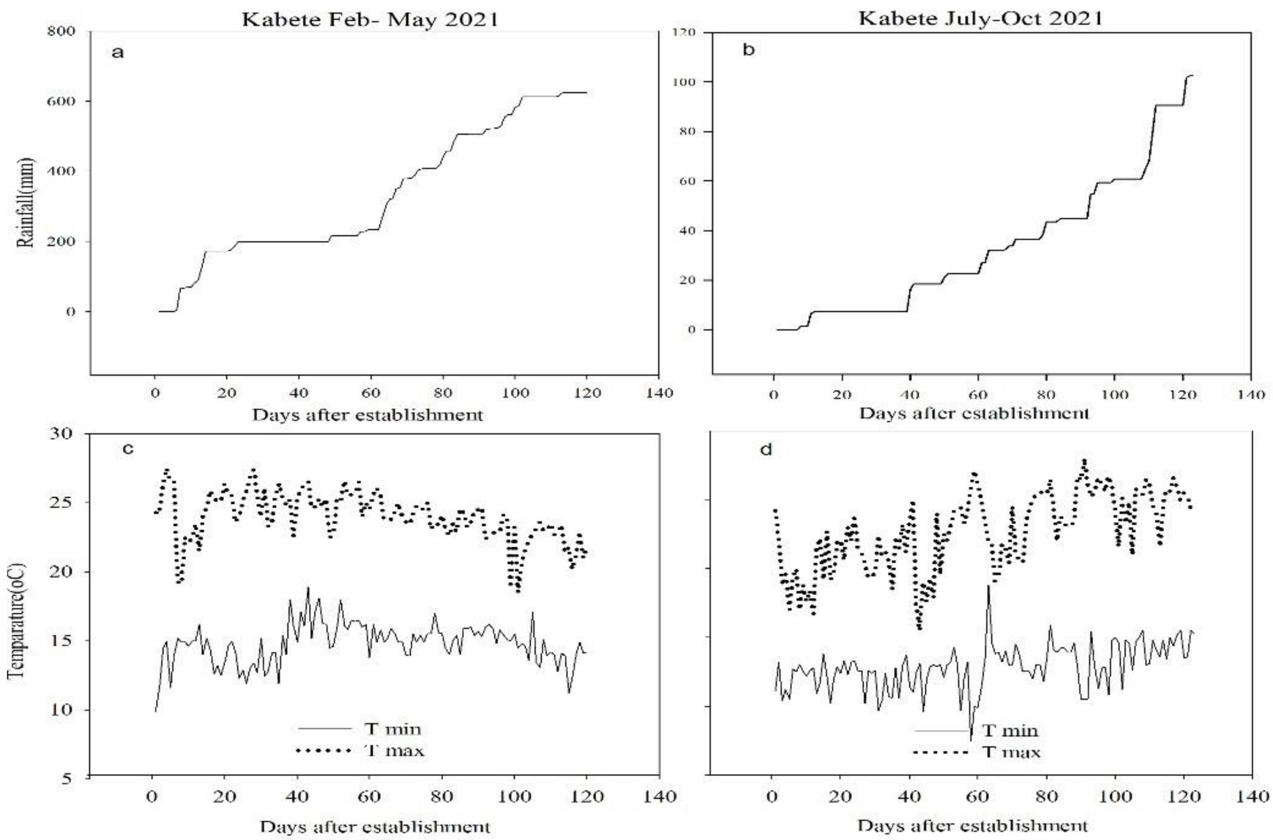

Figure 3.1 Daily rainfall in mm (a and b) and daily maximum (Tmax) and minimum (Tmin) temperature in °C (c and d) during the two experimental seasons in Kabete farm

Table 3.1 shows different strawberry crop developmental stages for both seasons. The addition of the different proportions of N, P and K nutrients, and vermicompost significantly altered the crop developmental rates compared with unfertilized control as shown in table 3.1. In the first experimental season, treatments that received 100% NPK took 13 days less to crown and 12 days less to form runners as compared to the other treatments. In the second season, the reverse was observed where plants that received vermicompost sole fertilization had shorter days from one phenological stage to the other, 5 days crowning, 17 days runnering and 13 days fruiting. On average, plants that received 100% VC had the earliest fruiting time in both seasons, 71 days in season 1 and 76 days in season 2 compared to the other treatments.

Table 3.1 Mean days to 50% crowning, runnering, and fruiting of strawberry grown under different rates of vermicompost and inorganic NPK during two experimental seasons in Kabete farm

Treatment	Season 1			Season 2		
	Crowning	Runnering	Fruiting	Crowning	Runnering	Fruiting
100% NPK	57c	62b	87a	56a	71a	89a
100% VC	70a	74a	71c	51b	54c	76c
Control	56c	75a	93a	58a	72a	96a
50% VC + 50% NPK	60b	70a	84b	58a	65b	92a
75% NPK + 25% VC	62b	64b	66d	57a	73a	85b
25% NPK + 75% VC	62b	76a	73c	50b	62b	79b
100% NPK + 100% VC	49d	71a	85a	55c	73a	94a
Mean	59.7	70.6	80.1	55.2	67.4	87.3
P value	<.001	0.05	<.001	0.005	<.001	<.001
LSD	5.0	10.5	8.1	4.3	5.5	7.7
CV%	1.9	2.5	0.9	1.2	6.2	0.8

VC: vermicompost; NPK: nitrogen, phosphorous and potassium fertilizer; LSD: least significant difference; CV: coefficient of variation. Within a column, means followed by the same letter are not significantly different

3.6.2 Number of crowns

The different combinations of NPK and vermicompost had significant effects on the production of crowns (Table 3.2). In the first season, there were no significant differences in number of crowns during the early phase (30 DAE), but differences were observed as the crop matured. In both seasons, the addition of 100% NPK as well as 100% VC significantly increased the number of crowns per plant compared with control. In the first season, plants that received 100% NPK and those that received 100% VC both had the highest number of crowns at a mean of 11 compared to the control at a mean of 10. In the second season, plants that received 100% VC had the highest number of crowns at 90DAE with a mean of 24.4 compared to the control at a mean of 19.6.

Table 3.2 Mean number crowns of strawberry grown under different rates of vermicompost and inorganic NPK during two experimental seasons in Kabete farm

Treatment	Season 1				Season 2			
	30DAE	50DAE	70DAE	90DAE	30DAE	50DAE	70DAE	90DAE
100% NPK	1.6a	6.1a	8.7a	11.9a	3.2c	11.3b	15.9b	21.7b
100% VC	1.4a	4.9c	7.6b	11.1a	3.8a	12.5a	16.8a	24.4a
Control	1.4a	4.6c	6.6c	10.2b	3.3b	11.2b	15.0c	19.6c
50% VC + 50% NPK	1.2a	4.8c	8.1a	12.1a	3.6b	11.0b	14.5c	19.5c
75% NPK + 25% VC	1.5a	5.4b	8.2a	12.1a	2.8c	11.3b	15.0c	19.5c
25% NPK + 75% VC	1.4a	4.6c	6.7c	10.9b	4.2a	13.1a	17.3a	21.9b
100% NPK + 100% VC	1.7a	4.9c	7.0c	11.3a	3.4c	11.8a	16.3b	20.7b
Mean	1.5	5.1	7.6	11.4	3.5	11.8	15.9	21.0
P value	0.460	0.003	0.003	0.036	0.001	0.001	<.001	<.001
LSD	0.5	0.7	1.0	1.2	0.5	0.9	1.0	1.2
CV%	2.1	3.2	2.0	3.2	4.3	1.1	1.3	1.9

VC: vermicompost; NPK: nitrogen, phosphorous and potassium fertilizer; LSD: least significant difference; CV: coefficient of variation. Within a column, means followed by the same letter are not significantly different

3.6.3 Runner formation

3.6.3.1 Number of primary runners

Number of primary runners, runners that are attached to the main strawberry plant, are presented in table 3.3. In both seasons, significant differences (P>0.05) were observed as the crop matured. Treatments with 100% VC consistently produced more runners in the entire experimental period compared to all other treatments in both seasons. Unfertilized control plots had significantly fewer runners with only 15 runners in the first season and 11 runners in the second season. A combination of vermicompost and inorganic NPK at a rate of 75% VC and 25% NPK produced the highest number of runners throughout the sampling period compared to other combinations.

Table 3.3 Mean number of runners grown under different rates of vermicompost and inorganic NPK during two experimental seasons in Kabete farm

Treatment	Season 1				Season 2			
	30DAE	50DAE	70DAE	90DAE	30DAE	50DAE	70DAE	90DAE
100% NPK	3.3a	5.3b	11.0c	17.0b	1.9a	5.6b	11.0b	18.6b
100% VC	5.5a	10.0a	15.4b	22.9a	3.0a	10.3a	15.6a	26.3a
Control	2.0a	9.0b	13.6b	18.2b	1.3a	4.2b	6.3b	11.4b
50% VC + 50% NPK	3.6a	9.2b	15.5b	22.1b	3.2a	9.4a	12.6a	21.3a
75% NPK + 25% VC	3.7a	10.0a	15.0b	20.0b	3.0a	9.3a	13.0a	18.7b
25% NPK + 75% VC	2.5a	12.0a	19.7a	24.3a	1.6a	5.0b	9.3b	17.0b
100% NPK + 100% VC	6.6a	14.6a	22.0a	25.6a	2.9a	11.8a	15.0a	23.0a
Mean	4.0	10.0	16.1	21.4	2.6	8.0	11.8	19.5
P value	0.006	0.004	<.001	<.001	0.19	<.001	0.001	0.006
LSD	2.2	3.6	3.4	2.8	1.8	2.9	3.7	6.2
CV%	17.1	10.3	9.8	8.5	12	9.3	5.9	1.7

VC: vermicompost; NPK: nitrogen, phosphorous and potassium fertilizer; LSD: least significant difference; CV: coefficient of variation. Within a column, means followed by the same letter are not significantly different

3.6.3.2 Number of secondary runners

Results from number of secondary runners, as presented in table 3.4, did not have any significant (P>0.05) difference in the first season. However, significant differences were observed towards end of the second season, with plants that received 100% VC having 61% significantly more secondary runners compared to all other treatments. The different combinations of NPK and VC appeared to give inconsistent results over the sampling period.

3.6.3.3 Runner length

Comparison on the runner length as shown in table 3.5 was done where no significant differences (P>0.05) were observed as the crop matured in the first season. During the second season, differences were measured across the entire sampling period. Results from the second season showed that the addition of 100% VC as well as 75% VC + 25% NPK significantly increased the runner length. Plants that received 100% VC produced the longest runners (34.7cm) at the end of the sampling period while unfertilized control plants produced the shortest runners (16.6cm).

Table 3.4. Mean number secondary runners of strawberry grown under different rates of vermicompost and Inorganic NPK during two experimental seasons in Kabete farm

Treatment	Season 1			Season 2		
	30 DAE	50 DAE	70 DAE	30 DAE	50 DAE	70 DAE
100% NPK	3.7a	4.1a	7.6a	4.7a	7.3b	13.6b
100% VC	2.5a	4.7a	9.3a	10.6a	18.4a	25.9a
Control	2.6a	3.7a	4.1a	6.3a	10.4b	14.3b
50% VC + 50% NPK	1.5a	7.4a	8.2a	8.4a	9.5b	12.2b
75% NPK + 25% VC	2.0a	3.6a	6.0a	9.1a	12.7b	15.6b
25% NPK + 75% VC	2.0a	3.5a	5.0a	7.2a	14.6a	18.5b
100% NPK + 100% VC	2.3a	3.7a	5.3a	9.3a	12.4b	16.1b
Mean	2.3	4.4	6.6	8.0	12.2	16.6
P value	0.84	0.17	0.14	0.2	0.02	0.01
LSD	2.2	3.1	4.1	4.7	5.6	6.5
CV%	7.1	12.3	9.5	5.2	8.3	4.2

VC: vermicompost; NPK: nitrogen, phosphorous and potassium fertilizer; LSD: least significant difference; CV: coefficient of variation. Within a column, means followed by the same letter are not significantly different

Table 3.5. Mean of runner length (cm) of strawberry grown under different rates of vermicompost and inorganic NPK during two experimental seasons in Kabete farm

Treatment	Season 1			Season 2		
	30 DAE	50 DAE	70 DAE	30 DAE	50 DAE	70 DAE
100% NPK	21.3a	24.1a	26.9a	11.3a	19.1c	21.4d
100% VC	20.6a	25.1a	28.1a	12.7a	28.7a	34.7a
Control	15.5a	23.0a	24.7a	6.3b	13.3d	16.6e
50% VC + 50% NPK	15.0b	23.6a	27.1a	14.2a	23.9a	27.4b
75% NPK + 25% VC	17.9a	24.4a	29.3a	13.5a	25.4a	26.3b
25% NPK + 75% VC	16.1a	24.4a	25.0a	14.6a	26.6a	30.1b
100% NPK + 100% VC	10.6b	25.3a	26.6a	11.0a	23.8b	26.0c
Mean	16.7	24.3	26.8	12.0	23.0	26.9
P value	0.02	0.81	0.31	0.02	<.001	<.001
LSD	5.5	3.5	4.4	4.4	4.0	3.7
CV%	11.4	0.7	2.4	3	3.8	2.2

VC: vermicompost; NPK: nitrogen, phosphorous and potassium fertilizer; LSD: least significant difference; CV: coefficient of variation. Within a column, means followed by the same letter are not significantly different

3.6.4 Fruit growth rate

Figure 3.2 shows development of fruit size of strawberry under different combination of vermicompost and inorganic NPK. Addition of vermicompost and inorganic NPK at different proportions had a significant influence on the crop growth rate. In the first season, treatments having 100% NPK had a faster fruit growth rate with plants getting to their maximum size (12.6cm) after 10 days. The reverse was observed in the second season where fruits from treatments having 100% VC had the fastest fruit growth rate, achieving their maximum size (13.2cm) after 11 days.

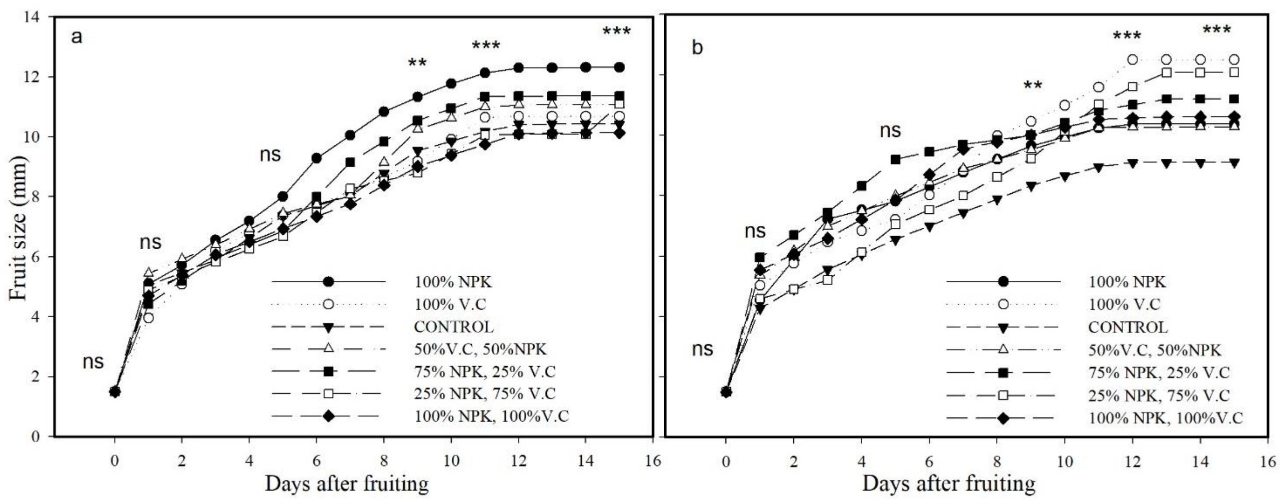

Figure 3.2 Development of fruit size of strawberry grown under different rates of vermicompost and inorganic NPK during two experimental seasons at Kabete farm. **significant at 0.01%; ***significant at 0.001% probability level; ns: not significant at 0.05% probability level

3.6.5 Number of fruiting plants

In the first cycle of experimentation significant differences in the number of fruiting plants (P>0.05) were observed as the crop matured (Table 3.6). At 100 DAE, plants under unfertilized control had the highest number of fruiting plants compared to the other treatments. During the second cycle of experimentation, the reverse was observed where plants that received 100% VC outperformed their counterparts, where they had more fruiting plants across the entire sampling period.

Table 3.6. Mean number of fruiting plants of strawberry grown under different rates of vermicompost and inorganic NPK during two experimental seasons in Kabete farm

Treatment	Season 1				Season 2			
	70DAE	80DAE	90DAE	100DAE	70DAE	80DAE	90DAE	100DAE
100% NPK	3.0a	12.3b	15.5a	29.3a	5.0a	14.1a	28.0a	32.4a
100% VC	1.6a	10.4c	18.6a	22.7a	6.1a	10.4a	20.4b	27.1b
Control	2.5a	15.3a	23.3a	30.6a	2.6b	12.5a	14.7c	19.6c
50% VC + 50% NPK	3.5a	14.7a	18.1a	24.0a	6.7a	13.1a	19.6b	22.3b
75% NPK + 25% VC	4.4a	7.6c	20.1a	22.8a	3.4b	9.7a	11.4c	15.7c
25% NPK + 75% VC	3.1a	15.3a	21.2a	26.6a	6.5a	14.0a	20.7b	23.1b
100% NPK + 100% VC	2.3a	18.0a	22.5a	27.8a	4.7a	11.3a	15.6b	26.1b
Mean	2.9	13.4	19.9	26.3	5.0	12.2	18.6	23.7
P Value	0.210	0.005	0.230	0.440	0.010	0.090	<.001	<.001
LSD	3.0	4.5	6.7	10.2	2.2	5.2	5.1	4.8
CV%	11.9	3.8	4.2	9.63	2.9	2.4	3.4	4.2

VC: vermicompost; NPK: nitrogen, phosphorous and potassium fertilizer; LSD: least significant difference; CV: coefficient of variation. Within a column, means followed by the same letter are not significantly different

3.6.6 Number of fruits

As shown in table 3.7, significant differences in the first season were only observed at 100DAE. Surprisingly, plants under 75% VC + 25% NPK as well as unfertilized control produced the highest number of fruits compared with their counterparts. However, during the second season, differences were measured across the entire sampling period. In the second season, the reverse was observed where addition of 100% VC as well as a combination of 25% VC and 75% NPK significantly increased the number of fruits per plot (59 and 53 respectively) compared with 100% NPK and control. On average, there were significantly more fruits in the second season than the first season.

Table 3.7. Mean number of fruits per square meter of strawberry grown under different rates of vermicompost and inorganic NPK during two experimental seasons in Kabete farm

Treatment	Season 1				Season 2			
	70DAE	80DAE	90DAE	100DAE	70DAE	80DAE	90DAE	100DAE
100% NPK	3.7a	5.3a	7.3a	10.2b	24.3a	31.3b	39.3b	54.1b
100% VC	2.2a	3.7a	6.0a	10.4b	24.7a	42.4a	49.4a	59.0a
Control	2.3a	3.2a	5.5a	17.3a	14.1b	18.0d	36.7b	43.8d
50% VC + 50% NPK	2.0a	2.6a	5.1a	8.1c	16.6b	23.5c	34.5b	46.6c
75% NPK + 25% VC	1.6a	3.0a	3.7a	7.3c	24.1a	32.1b	44.2a	53.2b
25% NPK + 75% VC	3.0a	4.7a	5.6a	12.3b	16.2b	24.2c	33.6b	43.8d
100% NPK + 100% VC	1.6a	3.4a	5.1a	13.6a	18.2b	25.3c	34.4b	49.3c
Mean	2.4	3.7	5.5	11.3	19.7	28.0	38.9	49.9
P value	0.68	0.47	0.54	0.002	<.001	<.001	0.002	<.001
LSD	2.8	2.9	3.7	4.0	6.2	5.4	7.0	3.7
CV%	45.4	39.	23.5	23.5.	6.4	6.6	4.5	3.2

VC: vermicompost; NPK: nitrogen, phosphorous and potassium fertilizer; LSD: least significant difference; CV: coefficient of variation. Within a column, means followed by the same letter are not significantly different

3.6.7 Fruit weight

In both seasons, as presented in table 3.8, significant differences in strawberry fruit weight (P>0.05) were observed as the crop matured. In season one, sole vermicompost fertilized plots as well as plots that received 75% NPK and 25% VC produced fruits with the highest fruit weight (17grams). In the second season, the addition of 100% VC as well as 75% VC + 25% NPK consistently showed significantly higher fruit weight in both seasons (19.4 and 22.8 respectively) compared to their counterparts. On average, Sole vermicompost fertilized plots had the fruits with the higher weight compared to sole NPK fertilized plants.

Table 3.8. Mean of fruit weight (g) per fruit of strawberry grown under different rates of vermicompost and inorganic NPK during two experimental seasons in Kabete farm

Treatment	Season 1			Season 2		
	80DAE	90DAE	100DAE	80DAE	90DAE	100DAE
100% NPK	5.0a	7.3a	10.1b	8.0b	12.9b	14.1b
100% VC	10.1a	14.6a	17.0a	13.4a	16.1a	19.4a
Control	6.4a	9.7a	11.1b	6.6c	8.4c	10.7b
50% VC + 50% NPK	6.3a	7.5a	9.7b	7.7b	10.1b	11.7b
75% NPK + 25% VC	8.6a	13.6a	17.2a	4.3c	8.3c	10.3b
25% NPK + 75% VC	11.4a	12.0a	16.9a	10.1b	16.0a	22.8a
100% NPK + 100% VC	7.7a	10.6a	13.2b	7.8b	10.4b	12.6b
Mean	7.9	10.8	13.6	8.3	11.8	14.5
P value	0.099	0.093	0.031	<.001	0.004	0.002
LSD	4.5	5.6	5.6	2.8	4.2	5.4
CV%	1	8.8	4	4.4	11	9

VC: vermicompost; NPK: nitrogen, phosphorous and potassium fertilizer; LSD: least significant difference; CV: coefficient of variation. Within a column, means followed by the same letter are not significantly different

3.7 Discussion

3.7.1 Crop phenology

Crop development rate is significantly influenced by crop nutrition. In this study, addition of vermicompost at 100% led to early maturity of strawberry crops with only 51 days to crowing, 54 days to runnering and 72 days to fruiting. These results can be attributed to higher accessibility of nutrients and growth promoters to the plants that received sole vermicompost fertilization. Combination of inorganic fertilizers and vermicompost promoted plant height, number of leaves and number of crowns resulting in a faster maturity compared to application of each fertilizer separately (Savita et al., 2023). Faster plant maturity with addition of vermicompost has been linked to presence of plant-available nutrients in vermicompost (Barooah and Datta, 2020). Better plant growth of strawberry is reported when chemical fertilizers are supplemented with vermicompost at equal splits at crowning and fruiting stages due to the presence of humic acid in the vermicompost (Warner et al., 2021). Humic acids aids in root formation therefore promoting nutrient uptake by plants, boosting growth and maturity (Kumar and Tripathi, 2020).

3.7.2 Strawberry plant growth parameters

Addition of vermicompost and inorganic NPK significantly influenced strawberry plant growth promoters compared with the control. While addition of NPK had significantly promoted the growth of strawberry plants in the first season, application of vermicompost improved plant growth parameters such as number of crowns, number of runners and runner length compared to plots treated with 100% NPK in the second season. This delayed performance of vermicompost can be attributed to the time it takes to be broken down in the soil and be accessible to the plants (Kumar and Tripathi, 2020).

3.7.2.1 Crowns and runners

Significant differences were observed in the number of crowns and runners across the entire sampling period. The number of crowns, runners and secondary runners per plant were higher in plots that received vermicompost and inorganic NPK at different rates. The maximum mean number of crowns (24.37) and runners (26.28) were observed in the plots with sole vermicompost fertilization. These findings are comparable to those of Naga et al. (2021), who observed maximum crowns and runners per plant in strawberry fertilized with vermicompost at a rate of 30t/ha. The increase in the number of crown and runners might be attributed to improved growth and development of the strawberry plants. (Kumar and Tripathi, 2020).

3.7.3 Strawberry yield parameters

Addition of vermicompost and Inorganic NPK significantly influenced plant yield parameters such as the number of fruits, fruit size and fruit weight. Fruit per plant (91), individual fruit weight (22.67g), were highest when strawberry plants received 75% VC + 25% NPK. Higher doses of vermicompost leads to improved plant growth consequently resulting in less days to fruit (Kumar and Tripathi, 2020). Maximum number of flowers are achieved when strawberry were fertilized with vermicompost at 30t/ha (Naga et al., 2021).

3.7.3.1 Fruiting plants and fruit growth rate

The maximum number of Fruiting plants per plot were recorded in plants that received 100% NPK (36.0) and plants that received 100% VC (36.7) whereas, the minimum number (24) were observed in the unfertilized control plots. The increase in number of flowers per plant show that vermicompost use fastened the development of inflorescence, resulting in more production of flowers and fruits (Naga et al., 2021). The increased number of flowers might have been as a result of the presence of more crowns per plant. Cabilovski et al (2023) observed similar results in strawberry, where a higher dose of vermicompost increased the number of flowers.

In the first season, fruit growth rate was faster in plants that received 100% NPK compared to other treatments. The reverse was observed in the second season where plants that received 100% VC recorded the fastest fruit growth rate. These results can be attributed to the readily available nutrients from NPK in the first season and the slow release of nutrients from vermicompost in the second season (Singh and Kumar, 2021)

3.7.3.2 Number of fruits and fruit weight

The highest mean number of fruits were recorded in plants that received 100% VC while highest fruit weight was recorded in plants that received a combination of 75% VC and 25% NPK. These results agree with the findings of Kumar and Tripathi. (2020), who documented higher number of fruits and strawberry fruit weight with vermicompost use. This increase in the number of fruits might be due to adequate availability of nitrogen, phosphorus, and potassium from both NPK and vermicompost. Nitrogen increased the overall strawberry crop growth resulting in better yield. Phosphorus improved fruit formation and potassium increased fruit (Cabilovski et al., 2023).

3.8 Conclusions

This study shows that combination of vermicompost with synthetic fertilizers is beneficial in field grown strawberry for improved growth, and yield. In addition to provision of growth promoting hormones, supplementing inorganic fertilizers with vermicompost ensures steady supply of nutrients which is vital for strawberry production. In the first season, plots under sole NPK fertilization performed significantly better than all their counterparts. The reverse was observed in the second season, where crops under sole NPK fertilizations had a lower performance while those under sole vermicompost fertilization outperformed their counterparts. These results imply inorganic fertilizers quickly release nutrients to the crops for a short time, hence the high performance in the first season and slow performance in the second season. Vermicompost takes some time to break down in the soil, but also slowly releases nutrients of the crop for a long time. Vermicompost-NPK combination of 75% VC + 25% NPK had optimal results on growth and yield compared to all other combined counterparts and would be recommended to strawberry farmers. Vermicompost doses below 75% did not significantly improve growth and yield of strawberry and therefore additional research is required to determine optimal rates of vermicompost on strawberry production.

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CHAPTER FOUR: DETERMINATION OF VERMICOMPOST-INORGANIC FERTILIZER NPK COMBINATION ON SELECTED QUALITY ATTRIBUTES OF STRAWBERRY FRUIT AND SOIL PROPERTIES

4.1 Abstract

Strawberry fruit quality is significantly influenced by the amounts of nitrogen, phosphorus, and potassium nutrients available to the plant. This study focused on evaluating the effects of inorganic NPK-vermicompost use of vermicompost on selected strawberry fruit quality and soil parameters. The experimental trials were done for two seasons, season one beginning in October 2021 and season two ending in September 2022. The experiment included seven treatments arranged as randomized complete block design with three replications. Treatments included 100% NPK, 100% vermicompost , 50% NPK + 50% vermicompost, 75% NPK + 25% vermicompost, 25% NPK + 75% vermicompost, 100% NPK + 100% vermicompost, and unfertilized control. A vermicompost-NPK combination of 75% VC + 25% NPK outperformed other treatments in regard to key fruit quality parameters. 75% VC + 25% NPK produced fruits with the highest amount of total soluble solids and lowest titratable acidity. Fruits that received 100% vermicompost in both season one and season two exhibited a redder color (a) compared with their counterparts. Sole vermicompost fertilization significantly improved soil parameters compared to sole NPK fertilization and unfertilized control. Soils in plots that received 100% vermicompost have a lower penetration resistance (3.22), higher infiltration rate (4.20) and higher porosity percentage (58.02%) compared to all other treatments. These results showed that addition of vermicompost in soils improves soil water holding capacity and aeration improving infiltration rate. There was a positive influence of vermicompost on soil microbial activity. Soils that received 100% vermicompost had 160% more earthworms and 90% higher total biodiversity compared to soil that received 100% NPK. Soils with no nutritional amendments also had 53% higher total biodiversity than soils with 100% NPK. These results showed that soil amendment with vermicompost improves fruit quality and soil properties. However, economically optimal inorganic NPK fertilizer-vermicompost rate combinations that improve strawberry fruit quality and soil properties require detailed investigation.

Key words: penetration resistance, vermicompost, soil microbiology, Fruit firmness, Vitamin C

4.2 Introduction

The addition of various nutrient sources is important for quality and profitable fruit production. Different crops require nutrients in varying quantities and ratio to produce satisfactory output. Strawberry is a fibrous shallow rooted plant of which 80% of the root system is located on the upper 30 cm of the soil (Hancock, 2020). Due to fibrous root system of the plant, fluctuations in availability of nutrients and moisture in the topsoil may have undesirable impact on the establishment, growth, and development of the crop. Supplementing chemical fertilizers with organic manures not only supplies the crop with the required nutrients but also improves water holding capacity of the soil. Therefore, a combined use of fertilizers and organic supplements is vital for the growth and yield of fruit crops, especially strawberry (Singh and Kumar, 2021).

The quality parameters that influence choice of strawberry by consumers are fruit appearance and color, size, firmness, taste, and aroma. Nutritionally, strawberry is a low-calorie fruit with high amounts of vitamin A, vitamin C, and fiber (Janurianti et al., 2021; Pinheiro et al., 2021). The concentration of vitamin C content in strawberry fruit depends on strawberry variety used, agronomic practices, climatic conditions, and light intensity.

Vitamin C content is higher with the integration of both chemical fertilizers and organic fertilizers (Kilik et al. 2021). Likewise, a comparison of total phenol and vitamin C content in response to organic and conventional systems revealed that total phenol and vitamin C content in organic system were higher than other treatments (Cabilovski et al., 2023). Anthocyanin are the substances that affect the L value in strawberry and give the fruit its color. Nutritional elements that affect the anthocyanin content are nitrogen, phosphorus, potassium, and iron elements (Bosa et al., 2019; Ruiz et al., 2019).

Organic fertilizers are mostly valued for their contributions to key nutrients and soil fertility (Singh, and Kaur, 2020). Additionally, they can have substantial effects on the microbiological and physical properties of the soil, which are ultimately responsible for promoting crop growth and development (Ramos et al., 2022). Particularly, the biological properties of soils affect soil organic matter and water holding capacity by increasing soil pore space. Scholars have reported improved microbial populations and activity after use of organic fertilizers in the soils (Ahmad et al., 2021; Kilik et al., 2021). Vermicompost, which are products of decomposition of organic waste by earthworms have been shown to promote plant growth and yields of fruit and vegetable crops (Ramos et al., 2022).

Although organic fertilizers such as vermicompost are recommended for strawberry production, their slow release of nutrients to the plant results in delayed crop development. Integration of both organic and inorganic fertilizers is advised for steady supply of nutrients to the crop. The main objective of this study was to evaluate the effects of vermicompost-inorganic NPK combination on quality of strawberry and soil properties. The study hypothesized that use of vermicompost in combination with inorganic NPK would improve quality of strawberry and soil properties.

4.3 Materials and methods

4.3.1 Experiment site

Field experiments were conducted at the University of Nairobi Kabete farm for two seasons. Kabete farm is located 1^{o}14'57'S, 36^{o}44'53'E and 1940 m elevation. The mean minimum temperature in Kabete was 13^{o}C and the maximum temperature was 24^{o}C. There was low rainfall during the October 2020- Feb 2021 season with the average rainfall being 49.6 mm. April 2021 –September 2021 season had heavier rainfall with the average rainfall being 147.3mm.

4.3.2 Treatments and experiment design

The experiment included seven treatments arranged as randomized complete block design with three replications. Each individual trial plot consisted of 36 chandler strawberry plants and the experiment consisted of a total of 21 plots. Treatments consisted of different combinations of inorganic NPK fertilizer and vermicompost. They included 100% NPK, 100% vermicompost , 50% NPK + 50% vermicompost, 75% NPK + 25% vermicompost, 25% NPK + 75% vermicompost, 100% NPK + 100% vermicompost, and control without the supply of nutrients. The inorganic nutrients were sourced from straight fertilizers, of Urea (46% N) for nitrogen, triple super phosphate (44% P) for phosphorus and muriate of potash (60% K) for potassium.

4.4 Data collection

4.4.1 Post experiment soil properties

At the end of the second experimental season, soils were sampled at 0-15cm and 15-30 cm per plot using undisturbed soil cores with a diameter of 7.6 cm and a height of 7.6 cm and analyzed for bulk density, penetration resistance, infiltration rate and porosity. Bulk density was attained by the undisturbed core technique, Tong et al. (2020) while infiltration rate was obtained through saturated hydraulic conductivity (Ksat) (Liao et al., 2020). Soil porosity was achieved by dividing the water in the soil at saturation, the volume of water drained at 60cm of tension by the volume of the cylinder then expressing the results as a percentage. Penetration resistance was determined using a dynamic cone penetrometer with a built-in data logger. Speed penetration was set at 1 cm/s (Elaoud et al., 2023). On each plot, six penetrations were taken to obtain a representative average result per plot automatically.

Soil excavation and manual sorting of monoliths were used to determine soil macro-organism diversity in each plot. Soil monoliths of 25 cm x 25 cm x 20 cm were excavated in each plot (Malo and Nielsen, 1985). The dug soil was placed in plastic trays and large soil clumps were softly broken down. Soil macro invertebrates were sorted and grouped at order/family level as earthworms, termites, ants, millipedes, spiders, and snails.

4.4.2 Fruit quality components

Fruits from three plants per plot were assessed for quality. A Sample of three fruits per plot were used. Firmness was determined from each sampled fruit with texture analyzer (TA-Hdi, Stable Micro Systems, UK) with the 2 mm diameter stainless steel probe and represented in Newton (Narayan et al., 2023).

Flesh fruit color was obtained by determining a single spot at the center using a Minolta color meter (Model CR-200, Osaka, Japan), adjusted with a white sheet of paper. Color readings (*L*, *a*, and *b*) were logged. L value represents lightness, a value represents values from green (-) to red (+) and the b value indicates the degree of yellowness (-) to blueness (+) respectively. The Hue angle was achieved by calculating a, and b as shown in Equation 1

Hue angle (h) = arctan $(\frac{b}{a})$, for + a value and + b values　　Equation 1

Total soluble solids were obtained using an Atago hand refractometer (Model 500, Atago, Tokyo, Japan) on three sampled fruits per plot (Iwanami et al., 2023). On each selected strawberry fruit, 2mL of the fleshly squeezedjuice was poured on the refractometer detecting glass to attain the Brix level.

The total titratable acidity was obtained through titration. Approximately 5 grams of strawberry pulp per plot was grounded and thinned with 50 mL of distilled water. The solution was then mixed with 2-3 droplets of phenolphthalein indicator for titration against 0.1N sodium hydroxide while continuously shaking until the mixture turned purple to show the end point (Kuria et al., 2021). The TTA was calculated as a fraction citric acid content of the fruit using the formula below.

$$\text{TTA} = \frac{\text{volume of the titrant x N x 64.04}}{\text{weight of the sample x 1000}} \text{ x } 100 \qquad \text{Equation 2}$$

Where N is the normality of titrant, and 64.04 is the equivalent weight for citric acid

Vitamin C was obtained by measuring samples of 1 gram of strawberry pulp. 25mL of TCA and 5mL of 4% potassium iodide were then added to each sample. 2-3 drops of starch indicator were then added, and each sample was titrated against N- Bromo while continuously shaking until the mixture turned purple to show the end point (Kuria et al., 2021). Ascorbic acid content was determined as follows:

Ascorbic acid (mg/100g)= y (xz) x (xu) x (100g/sample weight　　Equation 3

Where (y) is the titre value, (xz) is the constant solution and (xu) is the dilution factor

4.5 Data Analysis

The data was analyzed using the GenStat 12th Edition statistical program. Prior to analysis, residuals were checked for normal distribution and necessary transformations were done using Stata Version 15 by Stata Corp LLC. Analysis of variance (ANOVA) was used to test for significant differences and the means compared and separated using Fischer's protected least significant difference (LSD) at 5% probability level.

4.6 Results

4.6.1 Fruit firmness and fruit color

Table 4.1 shows fruit firmness, and fruit color of strawberry grown under different rates of vermicompost and inorganic NPK during the two experimental seasons. In both seasons, plants that received 100% VC produced firmer fruits (8.8N in season 1 and 6.1N in season two) compared to their 100% NPK and control counterparts. Lightness value (L) varied across treatments where plants that received a combination of 75% VC and 25% NPK produced fruits with a lighter external color compared to other treatments. Fruits that received 100% VC in both seasons exhibited a redder color (a) compared with their counterparts. There was no significant difference in hue angle in the first season. However significant differences were observed in the second season where fruits that received 100% NPK had the highest hue angle.

Table 4.1 Mean of firmness (N) and color of strawberry grown under different rates of vermicompost and inorganic NPK during two experimental seasons in Kabete farm

Treatment	Season 1					Season 2				
	Firmness	Color				Firmness	Color			
	N	*L*	A	B	H	N	*L*	A	B	H
100%NPK	5.9b	37.5b	36.2c	21.7a	30.8a	5.3b	24.9a	24.4c	12.3b	40.1a
100%VC	8.8a	36.4b	42.3a	19.9a	25.2a	6.1a	26.2a	38.5a	19.4a	26.7b
Control	4.7b	37.0b	41.5b	20.8a	26.7a	4.7b	24.8a	34.3a	23.3a	26.8b
50% VC + 50% NPK	7.6a	37.9b	43.8a	23.4a	28.2a	6.6a	25.4a	26.1c	22.2a	34.2a
75% NPK + 25% VC	8.2a	39.8a	39.1b	21.3a	28.6a	6.0a	25.2a	35.3a	15.7b	26.7b
25% NPK + 75% VC	6.5b	42.8a	43.2a	24.8a	29.9a	4.2b	27.1a	27.0c	20.0a	23.9b
100% NPK +100% VC	7.2a	34.2c	46.1a	21.2a	24.7a	4.9b	24.8a	32.9b	16.5b	36.3a
Mean	7.0	38.0	41.7	21.9	27.74	5.4	27.2	31.3	18.5	30.67
P value	0.01	0.03	0.01	0.224	0.11	0.01	0.77	<.001	0.01	0.00
LSD	2.0	4.4	4.4	4.1	4.67	1.3	3.6	4.9	5.2	6.56
CV%	16.3	6.5	5.9	10.4	9.50	13	7.9	8.8	15.8	12.00

VC: vermicompost; NPK: nitrogen, phosphorous and potassium fertilizer; LSD: least significant difference; CV: coefficient of variation; N: Newton, L: lightness, a: green to red, b: yellow to blue; h: hue angle, arctan (b/a). Within a column, means followed by the same letter are not significantly different

4.6.2 Total soluble solids, titratable acidity, and vitamin C (ascorbic acid)

Table 4.2 presents total soluble solids, titratable acidity, and vitamin C**.** There were significant differences in the total soluble solids in season one where strawberry fruits from plants that received 100% VC had more soluble solids/sugars (10.2), while no observable differences were observed in the second season. In the first season, Plants that received 100% VC produced fruits with lower acidity (0.7%) and higher ascorbic acid (29 mg/100g). The reverse was observed in the second season where plants from unfertilized control plot produced fruits with lowest and higher ascorbic acid (24.9).

Table 4.2 Mean of selected quality parameters of strawberry grown under different rates of vermicompost and inorganic NPK during two experimental seasons in Kabete farm

Treatment	Season 1			Season 2		
	Soluble solids	Titratable Acidity	Ascorbic Acid	Soluble solids	Titratable Acidity	Ascorbic Acid
	°Brix	Citric acid %	mg/100 (FW)	°Brix	Citric acid %	mg/100g (FW)
100% NPK	9.2a	0.8b	19.2b	12.9a	0.9a	22.0b
100% VC	10.2a	0.7c	29.0a	12.8a	0.8a	14.6b
Control	8.7b	0.9b	12.7c	12.7a	0.9a	24.9a
50% VC + 50% NPK	8.1b	0.8b	25.2a	11.1a	0.8a	17.7b
75% NPK + 25% VC	8.2b	1.0b	25.7a	11.8a	0.7a	36.5a
25% NPK + 75% VC	9.0a	0.8b	21.6b	11.0a	0.8a	20.8b
100% NPK + 100% VC	9.5a	1.2a	12.7c	12.6a	0.9a	15.9b
Mean	8.99	0.89	20.9	12.14	0.84	21.78
P value	0.05	0.01	0.001	0.32	0.31	0.05
LSD	1.4	0.21	6.809	2.23	0.14	13.05
CV%	8.8	12.9	18.3	10.3	9.4	33.7

VC: vermicompost; NPK: nitrogen, phosphorous and potassium fertilizer; LSD: least significant difference; CV: coefficient of variation, F.W: fresh weight. Within a column, means followed by the same letter are not significantly different

4.6.3 Bulk density, penetration force, infiltration rate, and porosity

Table 4.3 presents bulk density, penetration force, infiltration rate and porosity which were done at the end of the experimental period. There were no significant differences in bulk density on all treatments used both at 0-15 centimeters and 15-30 centimeters.

At 0-15 centimeters, there was no significant difference (>0.05) on infiltration rate and porosity. However, at 15-30 centimeters, there were significant differences observed on penetration rate, infiltration rate and porosity. Soils that received 100% VC and control had the lower penetration force. Soils that received 100% VC as well as 75% VC+25% NPK had a higher infiltration rate compared to their 100% NPK and control counterparts. Soils that received 100% VC had a higher porosity percentage (58%) compared to all other treatments tested.

Table 4.3 Mean of selected soil properties of soils under different rates of vermicompost and inorganic NPK during two experimental seasons in Kabete farm

Treatment	0-15 cm			15-30 cm			Penetration resistance
	Bulk density	Infiltration Rate	Porosity%	Bulk density	Infiltration Rate	Porosity%	
100% NPK	1.1a	2.6a	56.7a	1.1a	1.1b	54.6b	3.7a
100% VC	1.2a	1.4a	54.5a	1.1a	4.6a	58.0a	3.2a
Control	1.1a	1.9a	57.7a	1.1a	1.0b	56.3b	4.2c
50% VC + 50% NPK	1.2a	1.3a	55.3a	1.1a	1.6b	54.5b	3.3a
75% NPK + 25% VC	1.2a	3.2a	55.2a	1.2a	1.8a	54.7b	4.0c
25% NPK + 75% VC	1.2a	2.9a	55.9a	1.2a	5.1a	56.4b	4.3c
100% NPK + 100% VC	1.1a	3.8a	57.8a	1.2a	1.2b	54.6b	3.9b
Mean	1.2	2.3	56.2	1.1	2.2	55.6	3.9
P value	0.565	0.691	0.513	0.531	0.036	0.014	0.005
LSD	0.1	3.5	3.4	0.2	3.5	1.9	0.6
CV%	1	35.5	0.8	1.1	39.8	1.7	10.4

VC: vermicompost; NPK: nitrogen, phosphorous and potassium fertilizer; LSD: least significant difference; CV: coefficient of variation. Within a column, means followed by the same letter are not significantly different

4.6.4 Soil macrobial diversity

Table 4.4 presents soil microbial properties done at the end of the experimental period. The biodiversity studied included earthworm, black ants, brown ants, millipede, termites, white beetles, snails, and spiders. There was no significant difference (>0.05) in most of the macro diversity. However, there was a significant difference observed in the number of earthworms, spiders, and the total biodiversity. Treatments that received 100% VC had a significantly higher percentage of earthworms (8.0) and total biodiversity (24.3) compared to their 100% NPK and control counterparts.

Table 4.4 Mean of macro biology of soils growing strawberry under different rates of vermicompost and inorganic NPK during two experimental seasons in Kabete farm

Treatment	Ants	Termites	Millipedes	Snails	Earthworms	Spiders	Total biodiversity
100% NPK	2.0a	1.3a	0.3a	0.7a	3.4b	0.3b	8.7b
100% VC	3.7a	7.0a	1.1a	0.4a	8.0a	3.6a	24.3a
Control	4.0a	2.4a	0.6a	0.4a	3.5b	0.4b	11.34b
50% VC + 50% NPK	2.3a	3.2a	0.7a	1.0a	5.3b	1.7a	16.7a
75% NPK + 25% VC	3.6a	0.7a	0.4a	0.4a	4.3b	0.6b	10.3b
25% NPK + 75% VC	7.0a	1.8a	0.2a	2.4a	4.7b	0.6b	17.2a
100% NPK + 100% VC	6.1a	2.1a	0.3a	1.1a	4.6b	0.4b	14.6b
Mean	4.1	2.6	0.5	0.9	4.8	1.1	14.8
P value	0.22	0.12	0.75	0.22	0.02	0.03	0.04
LSD	4.4	4.4	1.3	1.7	2.3	2.0	9.3
CV%	56.7	71.0	45.8	73.4	6.2	94.4	37.0

VC: vermicompost; NPK: nitrogen, phosphorous and potassium fertilizer; LSD: least significant difference; CV: coefficient of variation. Within a column, means followed by the same letter are not significantly different

4.7 Discussion

4.7.1 Fruit firmness and color

Strawberry has a soft outer peel that is easily damaged during the handling process. A little difference in the firmness of the fruit makes a huge difference in the state that the fruit gets to the consumer (Ruiz et al., 2019). In this study, strawberry plants that received 100% VC produced firmer fruits in both season one and two (8.79N, 6.13N) respectively compared to other treatments. In other previous studies, researchers found that strawberry fertilized with vermicompost produced firmer fruits as compared to inorganic fertilized strawberry (Pinheiro et al., 2021).

Strawberry that received 100% VC displayed higher lightness (L*), green/red (a*) values, than those that received 100% NPK. This difference, though being statistically different, cannot be identified with the naked eye. Organically grown strawberry have a darker red color compared to conventional strawberry (Paparozzi et al., 2018). Other related studies have reported that the L value is higher in organic strawberry than conventional strawberry (Janurianti et al., 2021). Anthocyanin are the substances that affect the L value in strawberry and give the fruit its color (Bosa et al., 2019).

4.7.2 Total soluble solids, titratable acidity, and vitamin C.

Total soluble solids are one of the vital markers for fruit quality (Naga et al., 2022). Soluble solids contents were higher in fruits that received 100% VC (10.18 ºBrix) than in 100% NPK (9.21 ºBrix) and Control (8.77 ºBrix). These findings agree with previous study done by Kilik et al. (2021) for strawberry grown in combined synthetic and organic production systems who found higher soluble sugars in organic strawberry. Studies show that soluble solid contents are higher for organically produced strawberry compared to inorganic strawberry (Temocico et al., 2019).

Titratable acidity is a significant indicator of fruit quality in strawberry due to the influence of organic acids on fruit flavor (Kumar et al., 2020). Plants that received 100% VC had the lowest acidity (0.72%) in the first season. Gunduz and Ozbay (2018) reported a titratable acidity value in the range of 0.54–0.70% in strawberry in their study in which they observed the effects of fertilization on organic acids of different strawberry varieties. Titratable acidity decreased with increase in ripening. This is because the organic acids, after the respiration process, turns into sugar (Janurianti et al., 2021).

Vitamin c results, being in the range of 15.0–36.40 mg 100 g^{-1} of were relatively low in all treatment combinations in both seasons. The reasons why the vitamin C values recorded in this study was lower than in other studies may be attributed to the chandler strawberry variety grown. Chandler strawberry is a species with low phytonutrient content, but higher total soluble sugars compared to other species (Paparozzi et al., 2018). Several scholars suggest that the vitamin C value obtained from vermicompost fertilized strawberry was higher than the conventionally produced strawberry (Kilik et al., 2021; Cabilovski et al., 2023). It has been reported that organic fertilizers, especially vermicompost increase vitamin C content in strawberry, while conventional fertilizers lower vitamin C levels (Paparozzi et al., 2018)

4.7.3 Bulk density, penetration force, infiltration rate, and porosity

There was no significant difference in bulk density. This was a short season experiment while bulk density takes a long time to change. The application of 100% VC had the lowest penetration resistance compared to all other counterparts. The results of this study agree with previous studies carried out on the effects of vermicompost on soil properties (Warner et al., 2021; Vukovi et al., 2021). Addition of organic matter in clay soils improves the soil pore space and can strengthen soil by reducing the formation of hard pans (Akhila and Entoori, 2022).

Although data on porosity was only taken at the end of the experimental period which was a short season study, results showed improvement of soil properties as a result of combining inorganic fertilizers with vermicompost. Warner et al. (2021) and Singh et al. (2020) recorded an improvement in soil porosity and water holding capacity, which are a result of increased soil pore space. In this study, addition of vermicompost improved soil porosity (58.02%) compared to all other treatments.

4.7.4 Soil macrobial properties

Addition of organic manures in soils is vital for the long-term maintenance of soil microbiology. In this study, soils that received 100% VC had the highest number of earthworms and total biodiversity. The amendment of soil with organic sources of nutrients, such as vermicompost, reduces the progressive loss of organic matter in cultivated soils (Ramos et al., 2022). As a result, soil microbiological properties are optimized with the addition of organic matter especially through use of vermicompost (Das et al., 2022). This study confirmed the previous studies, showing positive influence of vermicompost amendment, on soil biodiversity (Huang and He 2023).

4.8 Conclusions

Fruit quality is an important factor of fruit production and profitability. From this study, it was concluded that combination of vermicompost and inorganic NPK at a rate of 25% NPK and 75% VC produced fruits with higher sugars, lower acidity, and high Vitamin C. The results showed that inorganic NPK and vermicompost significantly improved the qualitative yield of strawberry plants in comparison to sole NPK and sole vermicompost fertilization. Soil amendment with vermicompost in strawberry production improved soil porosity and infiltration rate. The increase in pore space, which can be attributed to increase in presence of microorganisms, aids the strawberry plant to developed fibrous roots. These findings explain the superior performance of strawberry plants that received vermicompost compared to those under inorganic NPK treatment. The study therefore concluded that integration of vermicompost with synthetic fertilizers at a rate of 75% VC + 25% NPK improved fruit quality properties tested. Use of organic fertilizers enhanced soil conditions by influencing soil water holding and nutrient characteristics.

CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 General discussion

Application of vermicompost and inorganic NPK increased strawberry growth and yield compared with unfertilized control. In the first cycle of experimentation, addition of 100% NPK outperformed the other treatments in key growth and yield parameters studied. However, the reverse was observed in the second cycle where plants under 100% VC outperformed their counterparts in key growth, yield, and quality parameters studied. At the end of the experimental period, soil parameters including porosity, infiltration rate, penetration resistance and soil macro biology were analyzed. It was observed that soils under sole vermicompost fertilization had a lower penetration resistance, higher infiltration rate and higher number of total biodiversity.

Increase in growth and yield of strawberry was observed with improved soil qualities from soil fertilized with vermicompost. Addition of vermicompost improved key soil properties including soil microbiology, penetration resistance, porosity, and infiltration rate. Vermicompost fertilized soils had significantly higher amount of total biodiversity compared to all its counterparts. This can be used to explain the improved performance of vermicompost fertilized strawberry plants in the second season where these plants had better root formation as a result of the well aerated soils thus resulting in better growth and development. Further, among different vermicompost rates, 100% VC showed superiority in number of crowns and runners indicating that vermicompost increased soil pore space enabling the plant to develop sufficient roots improving growth and development.

Addition of vermicompost resulted in greater nutrient content of strawberry fruit. Application of vermicompost at 100% and in combination with inorganic NPK at a rate of 25% VC and 75% NPK resulted in firmer fruits with higher TSS and vitamin C. These results might be attributed to better growth of plants, higher nutrient content of fruits, which favored the production of firmer fruits Kumar and Tripathi, 2020). Therefore, current study confirms the hypothesis that application of vermicompost alone or in combination with inorganic NPK has a positive effect on the growth, yield, and quality of strawberry.

5.2 Conclusions

This study concluded that combination of vermicompost with inorganic fertilizers is beneficial in field grown strawberry for improved growth, yield, and quality. Vermicompost-NPK combination of 75% VC + 25% NPK had optimal results on growth and yield compared to all other combined counterparts. Improved soil properties with the addition of vermicompost resulted in enhanced growth and yield of strawberry. Soil amendment with vermicompost in strawberry production improved soil porosity and infiltration rate. The increase in pore space, which can be attributed to increase in presence of microorganisms, aids the strawberry plant to develop fibrous roots. These findings explain the superior performance of strawberry plants that received vermicompost compared to those under inorganic NPK treatment.

Despite its various advantages to crop growth, there are a few limitations on vermicompost use. As the present study showed, vermicompost doses below 75% did not have significant improvement in the growth of strawberry plants and thus vermicompost use at low dosage may not fully benefit the farmer. Another limitation of vermicompost is its slow release of nutrient and plant growth stimulators hence may not be beneficial in short season crops and additional research is therefore required to assess the effect of vermicompost on short season crops.

5.3 Recommendations

- Combination that showed significant differences on growth, yield and quality, 75% VC + 25% NPK could be further explored on other strawberry varieties
- Further study on economically optimal rate of vermicompost-NPK combination on strawberry growth and yield is required.
- Long term effects of vermicompost-NPK combination on growth, yield and quality of field grown strawberry are required

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APPENDICES

Appendix 1. Analysis of variance of strawberry crop phenology (crowning) in Kabete 2021 short rains season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blk stratum	2	18.667	9.333	1.17	
Blk.*Units* stratum					
Trt	6	770	128.333	16.04	<.001
Residual	12	96	8		
Total	20	884.667			

Appendix 2. Analysis of variance of strawberry crop phenology (fruiting) in Kabete 2021 long rains season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Blk stratum	2	7.52	3.76	0.2	
Blk.*Units* stratum					
Trt	6	1020	170	9.14	<.001
Residual	12	223.14	18.6		
Total	20	1250.67			

Appendix 3. Analysis of variance of number of runners of strawberry grown in Kabete 2021 long rains season at week 5.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	109.238	54.619	14.02	
BLOCK.*Units* stratum					
TRT	6	1398.952	233.159	59.83	<.001
Residual	12	46.762	3.897		
Total	20	1554.952			

Appendix 4. Analysis of variance of number of runners of strawberry grown in Kabete 2021 short rains season at week 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	1.52	0.76	0.06	
BLOCK.*Units* stratum					
TRT	6	393.9	65.65	5.48	0.006
Residual	12	143.81	11.98		
Total	20	539.24			

Appendix 5. Analysis of variance of fruit weight of strawberry grown in Kabete 2021 long rains season at week 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	4.1	2.05	0.2	
BLOCK.*Units* stratum					
TRT	6	210.57	35.1	3.49	0.031
Residual	12	120.57	10.05		
Total	20	335.24			

Appendix 6. Analysis of variance of fruit weight of strawberry grown in Kabete 2021 long rains season at week 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	24	12	1.33	
BLOCK.*Units* stratum					
TRT	6	400.476	66.746	7.37	0.002
Residual	12	108.667	9.056		
Total	20	533.143			

Appendix 7. Analysis of variance of fruit firmness of strawberry grown in Kabete 2021 short rains season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	16.8608	8.4304	16.84	
BLOCK.*Units* stratum					
TRT	6	13.419	2.2365	4.47	0.013
Residual	12	6.0075	0.5006		
Total	20	36.2873			

Appendix 8. Analysis of variance of total titratable acidity of strawberry grown in Kabete 2021 long rains season

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
BLOCK stratum	2	0.00403	0.00201	0.15	
BLOCK.*Units* stratum					
TRT	6	0.44576	0.07429	5.58	0.006
Residual	12	0.15973	0.01331		
Total	20	0.60951			