EFFECTS OF GOAT MANURE-BASED VERMICOMPOST ON SOIL CHEMICAL PROPERTIES, GROWTH AND YIELD OF GARLIC IN MERU SOUTH AND MANYATTA SUB COUNTIES, KENYA

VINCENT MAKINI GICHABA

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DECLARATION AND RECOMMENDATIONS

Declaration

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

Signature:..Date: 13/09/2019..........

Vincent Makini Gichaba

NM17/22615/16

Recommendations

This thesis has been examined, passed and submitted with our approval as University supervisors.

Signature:..Date: 13/09/2019..........

Dr. Haggai O. Ndukhu, PhD.

Chuka University

Signature:..Date: 13/9/19..........

Dr. Moses Muraya, PhD.

Chuka University

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DEDICATION

This thesis is dedicated to all my family members, friends and all those who showed me love and gave me moral support towards my academic attainment in my life.

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ABSTRACT

Garlic (*Allium sativum* L.) is a bulb vegetable that is gaining prominence among small-scale and commercial farmers in Eastern Kenya due to its reported high returns and the readily available market. It is used as food and for medicinal purposes. Most of farmers growing garlic in Kenya, apply chemical fertilizers alone during the growth of this crop. Overutilization of chemical fertilizers has caused several adverse effects to the environment and human health, besides being costly hence limiting optimization of garlic production. Moreover, there is increase in the number of customers preferring organically produced agricultural products. This study aimed to determine the effects of different rates of goat manure-based vermicompost on soil chemical properties, growth and yield of garlic. The study was conducted in PCEA Nkio secondary school farm and KALRO Embu horticultural field in 2018 to 2019. The experiment was laid out in a randomized complete block design and replicated three times. The treatments consisted of goat manure-based vermicompost which was applied at five levels (Control treatment (0), 5, 10, 20 and 30 t ha^{-1}), inorganic fertilizer (NPK 17-17-17) at the recommended rate of 200 Kg ha^{-1} and goat manure (30 t ha^{-1}). Data collected included soil pH, total nitrogen, available phosphorous, exchangeable potassium, plant height, number of leaves, stem diameter, leaf length, leaf width, bulb fresh weight, bulb diameter, bulb length, bulb dry weight, number of cloves per bulb and bulb yield per hectare. The data obtained were subjected to ANOVA using SAS and significantly different means were separated using least significance difference at $\alpha = 0.05$. Application of 30 t ha^{-1} goat manure-based vermicompost showed significantly ($p < 0.05$) higher soil pH, total N, available P and exchangeable K compared to control treatment at Chuka and Embu. Application of 30 t ha^{-1} goat manure-based vermicompost showed significantly ($p < 0.05$) higher plant height, number of leaves, stem diameter, leaf length and leaf width than control treatment at Chuka and Embu. Application of 30 t ha^{-1} goat manure-based vermicompost showed significantly ($p < 0.05$) higher bulb fresh weight, bulb diameter, bulb length, number of cloves per bulb, bulb dry weight and bulb yield per hectare than control treatment at Chuka. A similar trend was observed in Embu where goat manure-based vermicompost gave significantly ($p < 0.05$) higher bulb fresh weight, bulb diameter, bulb length, number of cloves per bulb, bulb dry weight and bulb yield per hectare compared to control treatment. Hence the most appropriate recommended rate of application is 30 t ha^{-1} of goat manure-based vermicompost in the organic production of garlic. This study, therefore, provides valuable information on the utilization of goat manure-based vermicompost in organic production of garlic.

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ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
CV	Coefficient of Variance
DAE	Days After Emergence
DAFF	Department of Agriculture, Forestry and Fisheries
DAP	Days After Planting
FAO	Food and Agriculture Organization of the United Nations
FYM	Farm Yard Manure
HCDA	Horticultural Crops Development Authority
IL	Inner Lowland
KALRO	Kenya Agricultural and Livestock Research Organization
KMD	Kenya Meteorological Department
LM	Lower Midland
LR	Long Rains
LSD	Least Significant Difference
NACOSTI	National Commission of Science, Technology and Innovation
SAS	Statistical Analysis Software
SR	Short Rains
UM	Upper Midlands

CHAPTER ONE
INTRODUCTION

1.1 Background to the Study

The agriculture sector is the mainstay in the Kenyan economy contributing 30 percent of the gross domestic product and accounts for 80 percent of the employment (Horticultural Crops Development Authority [HCDA], 2016). Vegetables are recognized source of essential nutrients that lacks in many diets and their production is becoming a source of self-employment and income generation in rural areas leading to rural development and a source of foreign exchange in the country (Kioko *et al.,* 2017). In Kenya, garlic is a leading source of income among herbs and spices (HCDA, 2016).

Garlic is gaining prominence as a high value horticultural crop in the onion family in Kenya. Farmers in upper eastern Kenya are getting interested in growing garlic due to its high returns and the readily available local market (HCDA, 2016). It is cultivated mostly under rain fed conditions in Kenya. Successful commercial cultivation of this crop greatly relies on many factors such as climate, soil fertility, irrigation, fertilizer management, spacing and growing season (Nainwal *et al.,* 2014). Depletion of macro and micro- nutrients from the soil, use of low yielding varieties and poor management practices are major causes of low yields (Tadesse, 2015).

Garlic is mainly grown for its cloves used both as food and for medicinal purposes. The chemical constituents of garlic have been reported to treat cardiovascular diseases, cancer, diabetes, blood pressure, atherosclerosis and hyperlipidemia (Gebreyohannes and Gebreyohannes, 2013). Garlic is also used in the control and treatment of worms, germs, bacterial and fungal diseases, ulcer and rheumatism (Samavatean *et al.,* 2011). It has been successfully used in HIV/AIDS patients to treat cryptosporidium in China (Sovovo and Savo, 2004). Garlic is used in flavouring many types of dishes ranging from vegetable soups, meat, salad, spaghetti, sausages and tomato combination. Green tops are eaten fresh or cooked; mostly in tropical areas, while immature bulbs are consumed as salad (Diriba *et al.,* 2013).

Farmers mainly use mineral fertilizers such as di-ammonium phosphate (DAP), urea and NPK to increase and sustain crop yields. The nutrients in these fertilizers are poorly utilized due to environmental and soil related factors such as phosphorous fixation, leaching and volatilization of nitrates and nitrites, respectively (Rop *et al.,* 2019). The application of the required nutrients through chemical fertilizers alone can have a negative effect on soil health due to high levels of chemical residues in the soil and this can lead to unsustainable yields (Mbithi *et al.,* 2015). Continuous application of most of mineral nitrogenous fertilizers reduces soil pH, microbial populations and activities, organic matter content, buffering capacity and cation exchange capacity of the soils (Olomilua *et al.,* 2007). Besides, use of chemical fertilizers in garlic production also increases the cost of production, cause environmental pollution and associated health problems (Uwah and Eyo, 2014).

The use of organic amendments on soil is an alternative agricultural practice for sustaining economically viable crop production with minimal environmental pollution (Padel *et al.*, 2009). Organic manures are a reservoir for various essential elements, a source of cation exchange capacity and soil buffering, and are a large geochemical reservoir of carbon (Bohn *et al.*, 2001). They also improve the soil physical, chemical and biological properties and increase the efficiency of the applied nutrients especially in light soils (Pandey *et al.*, 2007). In recent time, studies have shown that organically grown fruits and vegetables contain more minerals and vitamins than conventionally grown ones (Citak and Sonmez, 2010).

A major constraint to chemical fertilizer use and profitable farming has been high production cost, a function of a number of variables such as high transport cost, fertilizer unavailability, lack of credit and markets, devaluation of domestic currencies, weak extension services and skewed agricultural policies that favour industrialists but not the farmers (Rop *et al.,* 2019). Thus, indigenously available organic sources of nutrients have enhanced the efficiency of crop performance and reduced the requirements of chemical fertilizers (Bhat *et al.,* 2007). The use of organic manures and bio fertilizers to maintain soil health and soil productivity is essential in production of garlic (Bhandari *et al.,* 2012). Hence, renewable and low cost sources of plant nutrients for supplementing chemical fertilizers and that are affordable to the majority of farming community need to be used (Kokobe *et al.,* 2013). The desire for low cost agricultural production using optimum concentrations of vermicompost is of great importance to farmers today (Moghadam *et al.*, 2012).

Vermicompost is a complex mixture of earthworm faeces, humified organic matter and microorganisms, which when added to the soil or plant growing media, increases germination, growth, flowering, fruit production and accelerates the development of a wide range of plant species (Lazcano and Dominguez, 2011). Vermicompost greatly increases microbial activity and nutrient availability. In addition it contains most nutrients in plant available forms such as nitrates, phosphates, and exchangeable calcium and soluble potassium which are responsible for increased plant growth and crop yield (Arancon *et al.,* 2004). Vermicompost makes soil structure spongy, improves bulk and real density, porosity, increases aggregate's stability and soil structure, and increases the rate of water penetration in the soil and aeration (Ahmadabadi *et al.*, 2011).

Although there have been many studies relating to the benefits of using vermicompost as a fertilizer source (Alsina *et al.,* 2013), there is no available research which has focused on use of goat manure in preparation of vermicompost and on the optimum application rates of vermicompost on garlic in the study area. Mikile (2001) conducted a study which showed that goat manure is one of the richest sources of nutrients that can be used for soil enrichment. The study showed that, in terms of nutrients composition of different manures, cattle manure had the lowest nitrogen, phosphorus and potassium contents followed by sheep manure and goat manure had the highest content of nitrogen, phosphorous and potassium. Composted goat dung was reported to be better in reducing nematode multiplication since it has inhibitory substances which don't encourage growth of nematodes and this improves plant growth. Hence, goat manure can be used to control the growth and development of soil borne pathogenic fungus *S. roffsii* (Ebenezer *et al.,* 2012). This reduces the incidence of disease at the same time enhancing soil with valuable nutrients (nitrogen, phosphorous and potassium) for plant growth.

Ano and Ubochi (2007) reported that goat manure improved nitrogen, phosphorous, potassium, calcium, magnesium and cation exchange capacity status of soil and also reduced the exchangeable acidity of soil. They also reported positive changes in soil contents of sodium, calcium, magnesium and reduction in values of exchangeable acidity which was accompanied by increases in cation exchange capacity upon application of goat manure. Also, Awodun *et al.* (2007) reported that goat dung is an effective source of nitrogen, phosphorous, potassium, calcium, magnesium and organic matter. Hence, this significantly improves nutrient availability in soil. Driven by the desire to improve productivity while maintaining low cost in garlic production, this study was undertaken to determine the utilization of goat manure-based vermicompost in organic production of garlic, in Meru South and Manyatta sub-counties of Eastern Kenya.

1.2 Statement of the Problem

Garlic contributes significantly to the nutrition and health status of people in Kenya. However, its production remains low due to negative changes in the soil related factors contributed by dominant use of chemical fertilizers. Sole use of chemical fertilizers alters soil pH, microbial populations and activities, organic matter content, buffering capacity and cation exchange capacity of the soils. These changes in soil parameters create unfavorable conditions for garlic development. Additionally, chemical fertilizers are costly to the majority of farmers. Hence, it has been challenging to optimize its yields by farmers in Eastern Kenya. This threatens the food security and livelihoods of small-scale farmers. Goat manure is readily available in most farms in Meru South and Manyatta sub-counties. Nonetheless, farmers are using the manure in its raw form, a state that does not fully release the bound nutrients for uptake by garlic from the soil. Nutrient release from raw goat manure can be enhanced through earthworm vermicomposting. Encouraging use of vermicompost in garlic production is environmental friendly, cost effective and provides balanced nutrients in plant available forms for garlic growth. The major setback in use of vermicompost manure is due to scarcity of available research on response of garlic to goat manure-based vermicompost in the study area, hence the study.

1.3 Objectives

1.3.1 General Objective

To determine the effect of different rates of goat manure-based vermicompost on soil chemical properties, growth and yield of garlic in Meru South and Manyatta sub-counties.

1.3.2 Specific Objectives

i. To determine the effect of goat manure-based vermicompost on soil chemical properties in garlic crop.
ii. To determine the effect of goat manure-based vermicompost on garlic growth characteristics.
iii. To determine the effect of goat manure-based vermicompost on garlic yield and yield components.

1.4 Hypotheses

H_{01}: There is no statistically significant effect of goat manure-based vermicompost on soil chemical properties in garlic crop.

H_{02}: There is no statistically significant effect of goat manure-based vermicompost on garlic growth characteristics.

H_{03}: There is no statistically significant effect of goat manure-based vermicompost on garlic yield and yield components.

1.5 Justification of the Study

Garlic is high value horticultural crop in Kenya due to its high returns. Garlic productivity is hindered by lack of available nutrients, lack of improved varieties and inappropriate agronomic practices. To obtain good yields, attention should be given to select land which has high fertility by applying considerable amounts of manure (Degwale, 2016). Also, for increased garlic productivity the quality of garlic cloves is essential and they should be accessible to farmers at affordable prices. Otherwise farmers may opt to use low yielding varieties (HCDA, 2016). Many farmers growing garlic in Meru South sub-county and Manyatta sub-county apply chemical fertilizers alone. Due to escalating costs, environmental and health problems associated with excessive use of inorganic fertilizers like NPK in garlic production (Uwah and Eyo, 2014), many small-scale as well as commercial vegetable growers urgently require information on how to use environmental friendly alternative fertilizers, such as goat manure-based vermicompost. Organic sources of plant nutrients supply sufficient amounts of nutrients for crop growth and development while at the same time improving soil structure, increases soil organic matter and increases soil microbial populations which all have beneficial effects on plant growth and development (Garg and Bahla, 2008). Hence, renewable and low cost sources of plant nutrients for supplementing chemical fertilizers that are affordable to the majority of farming community need to be used (Moghadam *et al.,* 2012). Goat manure is available in most farms in Meru South and Manyatta sub-counties; however, it is rarely used in garlic farming. Goat manure has a lot of nutrients such as nitrogen, phosphorous, potassium, calcium, magnesium and increases cation exchange capacity of soil. Thus, it can be used to prepare vermicompost. Goat manure-based vermicompost is easy to prepare, has excellent properties and is harmless to plants. Soil enriched with vermicompost provides additional substances that are not found in chemical fertilizers (Lazcano and Dominguez, 2011). Vermicompost contains biochemical substances that promote plant growth and fight plant diseases and also improves the soil's ability to hold water (Yeole, 2013). Its use enhances colour, smell, taste, flavour and keeping quality of flowers, fruits, vegetables and food grains (Arancon *et al.,* 2005). The use of goat manure based vermicompost is likely to enhance soil fertility through release of adequate nutrients, alleviate environmental pollution, lower fertilizer costs and thus increase profits obtained from garlic farming in the study area. The information on goat manure-based vermicompost will also be useful as a basis for further research and collaboration among various stakeholders to improve its utilization in organic production of garlic.

CHAPTER TWO
LITERATURE REVIEW

2.1 Garlic Origin and Botany

The origin of garlic (*Allium sativum* L.) is in Central Asia and spread to other parts of the world through trade and colonization (Tadesse, 2015). Garlic has been used in China and India for more than 5000 years for various reasons and Egypt since 2000 B.C. (Kamenetsky and Rabinowitch, 2001). Garlic is a bulb vegetable and it belongs to the family Amaryllidaceae. Garlic is one of the important and widely cultivated spice crops. It is the second main Allium vegetable crops most widely cultivated after onion (Hamma *et al.,* 2013). Other important vegetable crops in this family includes: onions (*Allium cepa*), leek (*Allium ameloprisum*) and shallots (*Allium asacloncum*). Garlic is a diploid species (2n = 2x = 16) of obligated apomixis and propagated vegetatively (Ipek *et al*., 2005). Garlic has a shallow adventitious root system at the bottom of the bulb. The stem is approximately 5.0 to 6.5cm tall. It has flat leaves that are long and grass like. The leaves are blue-green in colour and grow in a form of a dense clump (Department of Agriculture, Forestry and Fisheries [DAFF], 2017). It produces a bulb which consists of bulblets called cloves (Doro, 2012).

2.2 Garlic Production

Garlic has a wide area of adaptation and cultivation throughout the world (Mohd *et al.,* 2011). It is an important vegetable in the world with production reaching about three million metric tonnes per annum, with majority of production occurring in China, United States of America, Egypt, Korea, Russia and India (Kioko *et al.,* 2017). In Kenya, garlic is commonly grown in small-scale farms and the annual production average is about 2000 metric tons (Kioko *et al.,* 2017). Bomet County is the main source of garlic in the country producing 70 tons that earned 57% of the total value (HCDA, 2016). Garlic production in Kenya according to Horticultural Crops Development Authority 2016 is as shown in Table 1.

Table 1: Performance of garlic in selected Kenya counties for the years 2015 - 2016

County	Year 2015			Year 2016			
	Area (Ha)	Vol. (MT)	Value (Million Ksh.)	Area (Ha)	Vol. (MT)	Value (Million Ksh.)	% of Total Value
Bomet	4	40	4	7	70	7	57
Bungoma	2	12	3.6	3	12	3.6	29
Kajiado	2	6	0.65	7	15	1.6	13
Nakuru	-	-	-	1	2	0.06	0.4
Total	8	58	8.25	18	99	12.26	100

Source: HCDA (2016)

Selection of garlic cultivars for growing is based on different characteristics which include adaptability to the climate of the growing area, the market demand of the particular cultivar and the resistance or tolerance of the cultivar to various diseases and pests (DAFF, 2017). Garlic has good production potential on agro-ecological zone UM_1 and LH_{1-2} under rain fed conditions and UM_{2-3} and LH_3 under irrigation (Kenya Agricultural Research Institute [KARI], 2013). Garlic production is suitable in medium to high altitudes ranging 500 – 2000m above sea level and temperatures of 30 ^{0}C are necessary for optimum bulb development. However, cooler temperatures in the early stages of development favours vegetative growth required for proper establishment (Kioko *et al.*, 2017). Long days and high temperature during the growing season encourages bulb formation. Garlic can also survive winter temperature (Tadesse, 2015).

Garlic performs optimally in well-drained soil rich in organic matter. Incorporating manure that is well decomposed into heavy soils, result in the soils being friable and suitable for production. The optimum soil pH for garlic is between 6.0 and 7.0 (DAFF, 2017). Soils should be well tilled to provide a loose growing bed for bulb development. The soil must be kept moist to ensure regular shaped bulbs (FAO, 2007). Garlic is sensitive to moisture stress during the growing season especially during bulbing. The amount of rainfall should range between 600mm to 700mm during its production season. Where enough rainfall is not available, irrigation is a requirement for this crop to provide satisfactory yields. Garlic production requires a growing period of 4 to 6 months (Tadesse, 2015).

The growth and yield of garlic crop is greatly influenced by both inorganic and organic nutrients (Degwale, 2016). Many recent studies have indicated that small holder farmers using inorganic fertilizers have led to increased yield at the expense of product quality and environmental degradation (Mbithi *et al.*, 2015). There is generally a lot of concern on the effects of agrochemicals especially chemical fertilizers on the environment which makes organic manures a better alternative source of nutrients to crops (Hamma *et al.,* 2013). Although organic manures contain plant nutrients in small quantities as compared to the inorganic fertilizers, the presence of growth promoting substances like enzymes and hormones, make them essential for the improvement of soil fertility and productivity (Bhuma, 2001).

The application of goat manure significantly increases soil pH, organic matter content, total nitrogen, available phosphorous, exchangeable potassium, calcium, magnesium and the cation exchange capacity status of the soil (Uwah and Eyo, 2014). Goat manure is readily available on most farms in Meru South and Manyatta sub-counties. However, its use has received little research attention and hence not effectively used in sustainable agriculture. Goat manure is more useful when composted rather than when applied directly. Composting of goat manure can be done using earthworms to produce vermicompost. Hence, the use of organic manures like goat manure-based vermicompost and improved garlic varieties can go a long way towards improving garlic yield, in Meru South and Manyatta sub-counties.

2.3 Vermicompost Utilization in Agriculture

Vermicompost is a nutrient rich, microbiologically active organic amendment which results from the interactions between earthworms and micro-organisms in the breakdown of organic matter (Lazcano and Dominguez, 2010). Vermicompost applied soils have high porosity, aeration, drainage, water-holding capacity, enhances cation exchange capacity and large surface area, providing a strong capacity to hold and retain plant available nutrients such as nitrates, exchangeable phosphorus, soluble potassium, calcium and magnesium (Chaudhuri *et al.,* 2000). The organic carbon in vermicompost releases the nutrients slowly and steadily into the soil and enables the plant to absorb the available nutrients (Lalitha *et al.,* 2000).

A wide range of organic residues, including sewage sludge, animal wastes, crop residues and industrial refuse are increasingly being converted by earthworms to form vermicompost (Pascal *et al.,* 2010). The earthworms breakdown the organic residues, which stimulate greater microbial activity, increase nutrient mineralization rates, and rapidly convert the wastes into a humus-like substance that has a finer structure than ordinary composts while possessing greater and more diverse microbial population (Atiyeh *et al*., 2000). Earthworms have an important influence on soil structure, forming aggregate and improving the physical conditions for plant growth and nutrient uptake. During vermicomposting, earthworms eat, grind, and digest organic wastes with the help of aerobic and some anaerobic micro flora, converting them into a much finer, humified, and microbial active material (Degwale, 2016).

Vermicompost has been reported to contain plant growth regulators and other growth influencing materials produced by micro-organisms which can contribute positively towards better crop yields (Atiyeh *et. al*., 2002). Studies have indicated effect of vermicompost on an improvement in soil physical properties, soil fertility and uptake of mineral nutrient (Azarmi *et al*., 2008). However, the effect of vermicompost on garlic production is not yet fully understood in Kenyan condition. Therefore, the present research focused on studying the effect of goat manure-based vermicompost on the soil chemical properties, growth and yield of garlic in Meru south and Manyatta sub-counties.

2.4 Goat Manure-Based Vermicompost on Soil Chemical Properties, Growth and Yield of Garlic

2.4.1 Goat Manure-Based Vermicompost and Soil Chemical Properties

Vermicompost has been used as a source of nutrients for vegetable crops, as well as improving soil aggregation, increasing soil organic matter, improving soil structure, increases soil microbial population and diversity, improving the moisture holding capacity of soils, increases the soil cation exchange capacity (CEC) which all have beneficial effects on plant growth and development (Kenea and Gedamu, 2018; Arancon *et al.*, 2004). Vermicompost has been shown to have high levels of total and available nitrogen, phosphorous, potassium (NPK) and micronutrients, microbial and enzyme activities and growth regulators (Chaoui *et al.*, 2003).

Continuous and adequate use of vermicompost with proper management increases soil organic carbon, soil water retention and transmission and improvement in other physical properties of soil such as bulk density, penetration resistance, aggregation and other beneficial effect on the growth of plants (Atiyeh *et al.,* 2002). Some studies indicate that farmyard manure and vermicompost enrich soil in terms of major plant nutrients (Doan *et al.,* 2014; Verma *et al*., 2013). However, vermicompost may be considered as better alternative than farmyard manure, especially in terms of organic matter, total nitrogen, available phosphorous and exchangeable calcium contents of soil (Somnmez *et al.,* 2016).

Vermicompost has emerged as an alternative to conventional organic fertilizers due to its addition benefits to the soil. Also, some problems, such as nutrient loss, nutrient toxicity, and salinity that may be associated with organic amendments under certain conditions could also be avoided by vermicompost application especially due to its slow and more release of nutrients to the soil environment (Lazcano *et al.,* 2008). Vermicompost and compost can meet the nutrient demand of greenhouse and field crops and significantly reduce the use of fertilizers (Acharya and Kumar, 2018). Vermicompost increases soil fertility without polluting the soil, as well as quantity and quality of crops (Chanda *et al.,* 2011). These increases in plant productivity have been attributed to enhanced soil structure and soil microbial population that have higher level of activity and greater production of biological metabolites, such as plant growth regulators (Zucco *et al*., 2015).

2.4.2 Goat Manure-Based Vermicompost and Growth of Garlic

Suthar (2009) studied the impact of vermicompost and composted farmyard manure (FYM) on growth and yield of garlic. Plant growth was better in vermicompost treated plots than farmyard manure treated plots. The plot which received vermicompost at the rate of 15 t ha^{-1} along with 50% recommended NPK, showed more root length, shoot length, leaf length and number of leaves per plant than the control recommended NPK. The plot which received farmyard manure at the rate of 15 t ha^{-1} along with 50% recommended NPK, showed less root length, shoot length, leaf length and number of leaves per plant. The observed difference between the plot which received vermicompost at the rate of 15 t ha^{-1} along with 50% recommended NPK and the plot which received farmyard manure at the rate of 15 t ha^{-1} along with

50% recommended NPK clearly indicated the importance of vermicompost in garlic growth than farmyard manure.

Several studies have been done on the effect of vermicompost on growth of garlic. They indicate increased growth due to increased vermicompost application rates. This has been attributed to several plant growth promoters, plant hormone like substances, enzymes, beneficial bacteria and mycorrhizae in vermicompost. Vermicompost supplement increases leaf area index due to the availability of optimum nutrients contained in vermicompost that leads to high leaf area index, increased number of leaves and leaf area per plant through facilitated vegetative growth. Enhanced plant growth characteristics might also be due to higher nutrient availability as well as better nutrient uptake by the crop. This results in better photosynthesis and accumulation of photosynthates leading to more vigour. The other reason for better garlic growth is due to increased concentration of soil enzymes, soil organic matter, rapid mineralization and transformation of plant nutrients in soil resulting in increased plant growth. Vermicompost application brings an excellent biochemical changes in soil structure thus promoting garlic plant growth. Therefore, application of vermicompost provides sufficient nitrogen which is one of the building blocks of amino acids. Amino acids link together and form proteins hence make up metabolic processes required for plant growth (Kumar *et al.,* 2019; Acharya and Kumar, 2018, Reddy and Reddy, 2005 and Manish, 2014).

2.4.3 Goat Manure-Based Vermicompost and Yield of Garlic

Vermicompost increases garlic bulb dry weight by the accumulation of non-structured carbohydrates whole distribution patterns change, thus favouring the metabolism of fructan precursors and accumulating as scorodose. Such reserve substance accumulation in the vermicompost treatment occurs for longer period due to the earlier start of bulbing. The accumulation of scorodose is directly related to the harvest index, translating to increase of the bulb's dry weight, increased size, and therefore, higher quantity and quality and yield at harvest (Juan *et al.,* 2006).

Vermicompost application and sulphur individually produced maximum chlorophyll content in leaves, fresh weight of leaves, neck thickness, number of cloves per bulb, weight of bulb, bulb diameter and bulb yield of garlic. Combined application of 5.0 t

ha^{-1} vermicompost along with 60 kg ha^{-1} sulphur was found to be significantly superior with respect to weight of bulb and bulb yield of garlic (Verma *et al.*, 2013). The significant improvement in yield attributes of garlic with vermicompost may be attributed to plant growth stimulating substances which helps in promoting the overall growth of the plant, thereby increasing the sink size in terms of bulb size (Manish, 2014). Many of nutrients contained in vermicompost are changed to forms that are more readily taken by plants such as nitrate or ammonium nitrate, exchangeable phosphorous and soluble potassium, calcium and magnesium thus increased photosynthesis and resulting to accumulation of carbohydrates in bulbs (Degwale, 2016).

Similar results have revealed that vermicompost contains more exchangeable plant nutrients than those by other plant growth media hence maximum vegetative growth of garlic. This enhances maximum photosynthesis and accumulation of more dry matter (Patidar *et al.*, 2019). Kumar *et al.* (2019) in their studies on garlic reported that the maximum diameter of bulb was due to the application of recommended dose of fertilizer which enhanced the activity of some microbial population in vermicompost and supply of nitrogen, phosphorous and potassium nutrient which resulted in increase to the diameter of the garlic bulb. They also noted that the main reason for increased weight of bulb of garlic was due to humus substances in the vermicompost that mobilized the reserve food materials to the garlic plant through increased activity of hydrolyzing and oxidizing enzymes, hence, more weight of garlic bulbs.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Study Area

The study was conducted on PCEA Nkio secondary school farm, Meru South sub-county and KALRO Embu horticultural field in Manyatta sub-county, upper Eastern Kenya. The crop was planted in one planting season in the two sites; December 2018 – March 2019. Meru South sub-county is found in Tharaka Nithi County which is located on the eastern slopes of Mount Kenya. PCEA Nkio secondary school is located along the Chuka – Kathwana road approximately 5 kilometers from Chuka town. The site lies at a latitude of S00^{o}20.524' and longitude of E037^{o}41.871'. According to Jaetzold and Schmidt (1983), the area is in upper midlands 2 and 3 (UM2–UM3) agro-ecological zones with an average altitude of approximately 1,281 m above local sea level, annual mean temperature of about 18^{o} C and annual rainfall of about 1,500mm. The rainfall is bimodal, falling in two seasons, the long rains (LR) lasting from March through June and short rains (SR) from October to February.

The soil types are humic nitisols (Jaetzold and Schmidt 1983), which are deep, well drained, dusky red to dark reddish brown, friable clay with acidic top soil and moderate to high inherent fertility. However, the soil is deficient in nitrogen, phosphorous and zinc (Ogolla *et al*., 2019). Meru South is a high agricultural potential area and is predominantly characterized by both crop and livestock production mostly on small land holding. Farming accounts for about 80% of employment. The main crops grown in the area include: beans (*Phaseolus vulgaris*), maize (*Zea mays*), cowpeas (*Vigna unguiculata*), cassava (*Manihot esculenta*), pigeon peas (*Cajanus cajan*), sorghum (*Sorghum spp.*), finger millet (*Eleusine coracana*) among others (Ogolla *et al*., 2019). The major livestock reared in the area include: cattle, goats, sheep and poultry. Meru South is potential garlic growing region of eastern Kenya and currently, garlic farming is gaining popularity among farmers.

In Manyatta sub-county, the study was conducted at Kenya Agricultural and Livestock Research Organization station in Embu. The site lies at a latitude of 0.4762^{o}S and longitude 37.4702^{o}E. Manyatta sub-county is located on the eastern slope of Mount Kenya in Embu County. Embu lies in the lower midland 3, 4 and 5 (LM3, LM4 and LM5), upper midlands 1, 2, 3 and 4 (UM1, UM2, UM3 and UM4) and inner lowland 5 (IL 5) at an altitude of approximately 500 m to 1800 m above sea level (a.s.l.). It has an annual mean temperature ranging from 17.4 to 24.5°C and an average annual rainfall of 450 mm to 1400 mm. The rainfall is bimodal with long rains falling from around March to June and short rains from around October to December. It has *humic nitisols* soils. The prime cropping activity is maize intercropped with beans though livestock keeping is also equally dominant. Various agricultural activities have been carried out in the region hence the rationale behind its selection (Kisaka *et al.*, 2015).

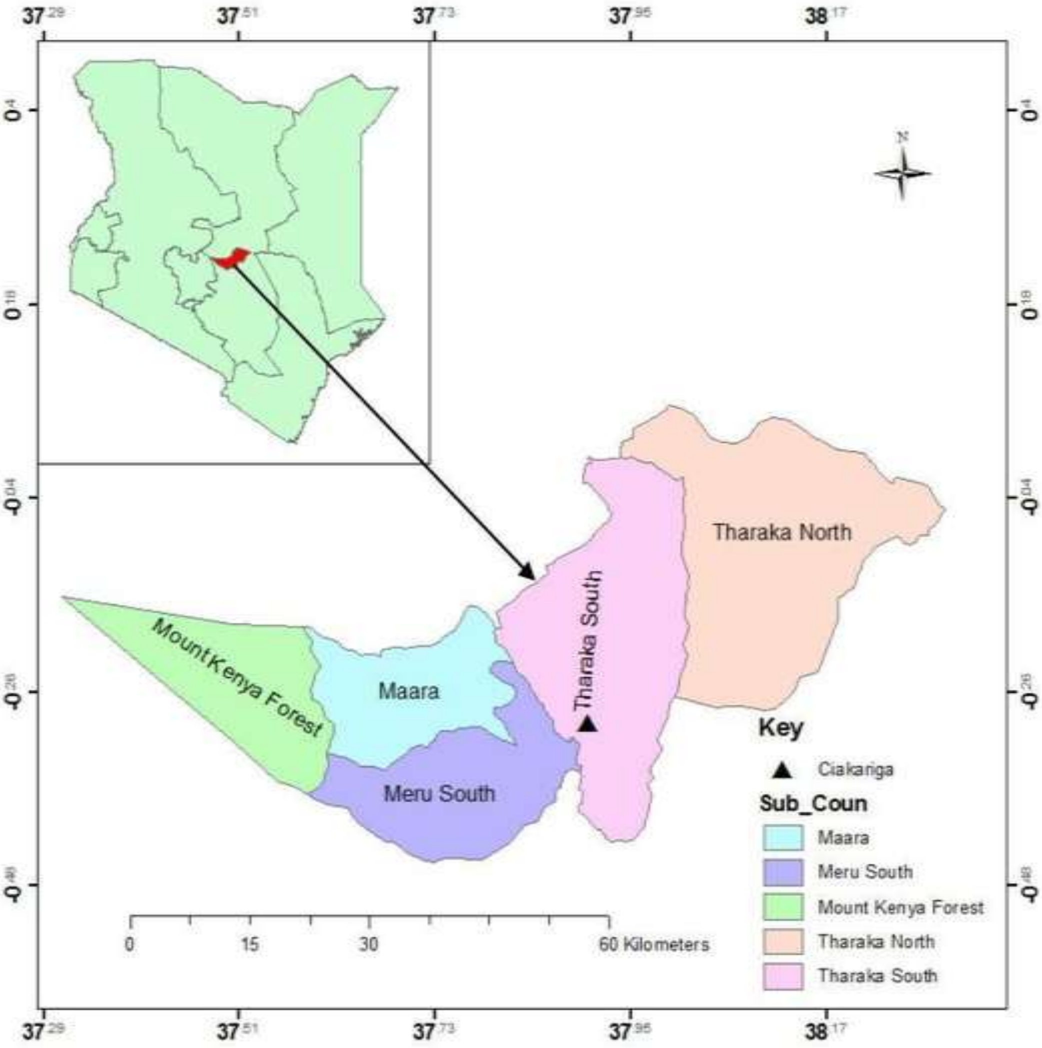

Figure 1: Map of Tharaka Nithi County (Sourced from Kenya mpya county maps, 2012).

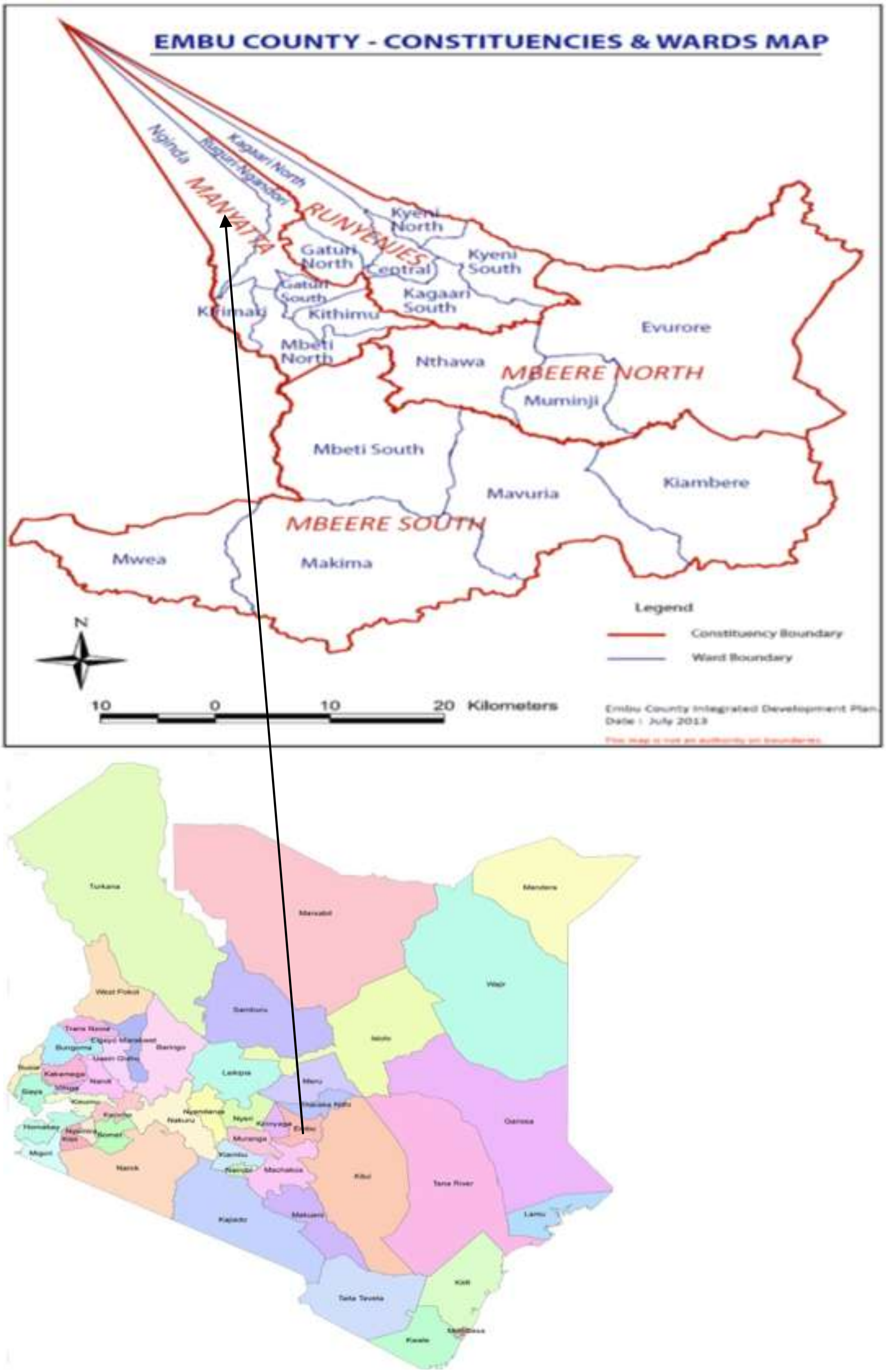

Figure 2: Map of Embu County (Sourced from Kenya mpya county maps, 2012).

3.2 Experimental Design

The experiment was laid out in a Randomized Complete Block Design (RCBD) and replicated three times. The treatments consisted of goat manure-based vermicompost which was applied at five levels (0, 5, 10, 20 and 30 t ha^{-1}), inorganic fertilizer (NPK 17:17:17) which was applied at the recommended rate of 200 $kgha^{-1}$ and goat manure (30 t ha^{1}). The treatments were randomly assigned to the various plots. Seven plots of equal measurements were used in each block giving a total of 21 experimental plots. The distance between the blocks was 1m and distance between experimental plots was 0.5 m. The experimental plots measured 2.60 m by 1.85 m giving a total area of 4.81 m^{-2}.

3.3 Preparation of Goat Manure-Based Vermicompost

Goat manure was used as the main raw material to prepare vermicompost. A vermicompost bed was constructed using bricks and mortar on the walls. The bed measured 3 m long by 1 m wide by 1 m high as per Ansari and Sukhraj (2010). A shed was erected above the vermicomposting bed to prevent direct sunlight and rain and also fenced around using wire chain link to prevent predators of earthworms like chicken and other birds.

A basal layer composed of broken bricks followed by a layer of coarse sand to the thickness of 7 cm was placed inside this bed to ensure proper drainage according to Ramnarain *et al.* (2019) and restrict earthworm movement towards the soil layer. A layer of 15 cm of loamy soil was placed at the top and moistened. Small lumps of fresh goat manure were scattered over the soil. This acted as an active growing medium for earthworms according to Rekha *et al.* (2018). Then, two thousand and eight hundred red wiggler earthworm (*Eisenia fetida)* species were introduced to facilitate decomposition of the materials according to Mbithi *et al.* (2015). The earthworms were sourced from AAA growers in Naromoru, Laikipia County. This was followed by 10 cm thick layer of dry grass, dry banana leaves and dry bean husks which were placed above it to act as bedding material of the worms. Dry goat manure weighing 100 kg was placed and spread on these materials in the bed up to 10 cm thick. The same set of layers was continued till a height of 1 m according to Rekha *et al.* (2018). This was followed by sprinkling uniformly five litres of water to the vermicompost bed in order to keep it moist and facilitate easy earthworm movement in these materials. Water also prevents desiccation of earthworms. Gunny bags were placed on the top to cover the materials.

The vermicompost bed was kept moist by sprinkling two litres of water once a week and this continued up to the seventh week. Turning of these materials was done once after fifteen days and it was done gently to avoid injuring earthworms since they have soft bodies. Goat manure-based vermicompost was harvested after one hundred and twenty days according to Ramnarain *et al.* (2019). This was after the earthworms were found sticking to the under surface of gunny bags indicating that composting process was complete. The goat manure-based vermicompost from the bed was harvested and spread on a polythene sheet. From this harvested goat manure-based vermicompost adult worms and young ones were handpicked and isolated. The goat manure-based vermicompost obtained was dried under a shed for one day, screened and was filled into bags ready for organic growing of garlic.

A sample of goat manure-based vermicompost was analyzed for pH using a digital pH meter (Jones, 2001), total N using kjeldahl method (Bremner and Mulvaney, 1982), available P using extraction with 0.5 M $NaHCO_3$ according to methods of Olsen *et al.* (1954) and exchangeable K using Flame photometer (Jackson, 1967). The analysis was done at the University of Nairobi, upper Kabete campus soil laboratories.

3.4 Preparation and Management of Experimental Field

Land was ploughed to a depth of 15 cm until a good tilth was obtained. Planting beds measuring 2.60 m by 1.85 m and raised 10 cm were prepared with paths of 50 cm apart and 1 m between blocks. Levelling of the beds was done using a rake. Planting cloves of a local garlic variety (moyale) were sourced from AAA growers, Naromoru. Goat manure-based vermicompost, NPK and goat manure were applied on the experimental plots based on the assigned rates of application and then incorporated into soil in the entire experimental plots. The planting beds were thoroughly supplied with water before planting. This was meant to supplement enough soil moisture in order to facilitate faster sprouting of the planted cloves. Garlic cloves were planted with the base of the clove down and the tip in upright position and covered with a thin layer of soil.

The recommended spacing adopted was 30 cm by 15 cm and a planting depth of 5 cm. Hence, each experimental plot had a total of one hundred and seven plants which translates to 222,453 garlic plants ha^{-1}. Once established, all other necessary maintenance practices were carried out appropriately and these included: weeding, which was done through uprooting as weeds emerged. Pests were controlled through regular application of Duduthrin® pesticide that contains the active ingredient Lambdacyhalothrin at the rate of 15 ml 20 $litres^{-1}$ of water from the second week after garlic emergence every fourteen days till eighty six days after emergence. Fungal diseases were controlled using Ridomil® fungicide that contains the active ingredient Metalaxyl-M and S-isomer at the rate of 40 gm 20 $litres^{-1}$ of water from the second week after garlic emergence at an interval of twenty one days and stopped at eight six days after emergence. Sprinkler irrigation was done from morning to mid-afternoon after planting to minimize on soil evaporation losses and this was done twice per week during growth of garlic crop. Two weeks to harvesting, irrigation was stopped.

3.5 Data Collection Procedure

3.5.1 Effect of Goat Manure-Based Vermicompost on Soil Chemical Properties

For soil chemical properties, soil sampling was done before planting and after harvesting of garlic. Before planting, ten soil samples were taken randomly using a soil auger in a zigzag sampling design from the top soil to a depth of 20 cm of the soil profile from the entire experimental site. The soil was broken into small crumbs and thoroughly mixed. From this mixture, a composite sample weighing 1 kg was placed in a plastic bag. The soil samples were taken, air-dried in the University of Nairobi, soil laboratory and crushed to pass through < 1mm sieve. Then, chemical analysis of the soil samples was done.

Also, at the end of the experiment in each experimental site, soil samples from each plot were collected and analysed. For pH, it was determined in soil: H_2O, 1:2.5 extract after shaking the solution for 30 min. by a means of a digital pH meter fitted with a glass electrode (Jones, 2001). Total N was determined by sulphuric acid digestion using $CuSO_4$ and K_2SO_4 as catalyst. Total N in the digest was determined using kjeldahl distillation method (Bremner and Mulvaney, 1982). Available P was determined whereby 5cm^3 soil was extracted for 30 min. with 100cm^3 0.5 $NaHCO_3$ solution (pH adjusted to 8.5). After filtration, the phosphate concentration of the solution was measured calorimetrically by the method of Olsen *et al.*, 1954. Exchangeable K was determined using flame photometer whereby K was extracted from air dried soil samples by shaking with 0.5M ammonium acetate solution. The potassium content of the filtered extract was then determined (Jackson, 1967). The analysis was done at the University of Nairobi, Kabete campus soil laboratories.

3.5.2 Effect of Goat Manure-based Vermicompost on Growth of Garlic

On growth parameters, collection of data was done in the three inner middle rows at different growth stages at an interval of fourteen days. A sample of seven randomly selected plants from each three inner middle rows were tagged, observed and analysed for various parameters. Measurements were taken on the 30^{th}, 44^{th}, 58^{th}, 72^{th} and 86^{th} days after emergence (DAE). Data collection was through observations and measurements. The growth parameters measured included:

Plant Height - This was measured from the soil surface to the tip of the sampled plants using a metre ruler for the entire sample set and expressed in centimetres (cm).

Number of Leaves - On each sampled plant, total number of leaves were physically counted and recorded.

Stem Diameter - This was measured at the middle part of the stem of sampled plants using a Vernier calliper and expressed in centimetres (cm).

Leaf Length – One leaf from the middle part of each sampled plants were measured from the base to the tip of shoot using a ruler and expressed in centimetres (cm).

Leaf Width - This was obtained by measuring the widest part of one leaf that was measured for leaf length from each sampled plants using a ruler and expressed in centimetres (cm).

3.5.3 Effect of Goat Manure-Based Vermicompost on Yield of Garlic

Similarly, a total of ten sampled plants obtained from the middle row of each experimental plot were used to determine the yield parameters. This selection was done during harvest upon physiological maturity. The parameters measured included:

Bulb Fresh Weight - The bulbs of sampled plants were weighed after harvesting using a digital electronic compact scale and their weight expressed in grams $plant^{-1}$ (gm).

Bulb Diameter - The sampled plants were measured at the widest point in the middle portion of the bulb with the help of Vernier calliper and expressed in centimetres (cm).

Bulb Length - This was measured at basal end point from the bottom scar of the bulb to the tip point of bulb using a Vernier calliper and expressed in centimetres (cm).

Bulb Dry Weight - The sampled bulbs were dried under sun for seven days followed by oven drying at temperature of 70^oC for seventy two hours. The dried bulbs were weighed using a digital electronic compact scale. The dry weight obtained for each sampled bulb was recorded in grams (gm).

Number of Cloves per Bulb - This was determined physically by counting the total number of cloves produced from ten selected samples plants per plot and their number recorded.

Bulb Yield per Hectare - This was determined by dividing the total area of one hectare with total area of each plot and then multiplying by the bulb yield obtained from each plot to hectare basis. The yields obtained from each plot were converted to kilogram per hectare ($Kg\ ha\text{-}^1$).

3.6 Data Analysis

Analysis of data on effect of goat manure-based vermicompost on soil chemical properties, growth and yield parameters of garlic involved both descriptive and inferential statistics. The data on soil chemical properties, growth and yield parameters of garlic obtained throughout the experimental duration was subjected to analysis of variance (ANOVA). The statistical analysis software (SAS) was used for data analysis. Significant means were separated using Least Significance Difference (LSD) at 5% probability level.

3.7 Ethical Consideration

Clearance from Chuka University ethics review committee was obtained approving the suitability of the research proposal (Appendix 1). The research permit was acquired from National Commission of Science, Technology and Innovation (NACOSTI) before commencing with the research (Appendix 2) and a research authorization (Appendix 3). The study ensured that research procedures steps described in the document were done in an ethical manner ensuring fidelity and justice. The policy regarding plagiarism was adhered to in the process of data collection, analysis and in document write up. Henceforth, the conclusions and recommendations made from this research study will be shared with farmers and other institutions involved in the study.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Initial Soil Characteristics

The soil samples of each experimental site were analysed for soil chemical properties before planting and the results are presented in Table 2.

Table 2: Soil analysis results of experimental sites before planting

Site	Soil chemical property	Units	Value	Ranges	*Ratings
Chuka	pH (soil:H_2O, 1:2.5)	_	6.64	6.6-6.9	Slightly acidic
	N	%	0.04	< 0.05	Very low
	P	ppm	4.66	0-25	Low
	K	Cmol Kg^{-1}	0.30	0.21-0.30	Low
Embu	pH (soil:H_2O, 1:2.5)	_	6.33	5.6-6.5	Moderately acidic
	N	%	0.03	< 0.05	Very low
	P	ppm	4.57	0-25	Low
	K	Cmol Kg^{-1}	0.26	0.21-0.30	Low

*The ratings are based according to criteria described in Appendix 22.

The results showed that the pH of the soil at Chuka is slightly acidic while that at Embu is moderately acidic based on the ranges by Hazelton and Murphy (2007). The total nitrogen content of the soils at Chuka and Embu are very low (Table 2). Tadesse (2015) reported that nitrogen content of soil of less than 0.05% is very low, between 0.15 – 0.25% is medium and greater than 0.25% is high. Available phosphorous in the two sites was low rated based on the ranges of Hazelton and Murphy (2007). Most vegetables benefit from phosphorous fertilization if the soil test is less than 35 – 40 ppm phosphorous using the Bray – Kurtz P_1 extraction method (Tadesse, 2015). Exchangeable potassium content of the soil of the two sites is low according to ratings based on the ranges of Hazelton and Murphy (2007). According to Tadesse (2015) if the soil test is less than 85 ppm potassium, it is categorized under low potassium content. Garlic prefers a fairly neutral pH ranging 6.5 – 7.0. If the soil is too acidic or too alkaline it causes slowed growth and late maturity in garlic. Moreover, nitrogen decreases as soil acidity increases while it becomes available as soil alkalinity increases (Tadesse 2015).

4.2 Goat Manure Based-Vermicompost and Goat Manure

A sample of goat manure-based vermicompost (GMBV) and goat manure (GM) used in the experiment were analysed for chemical properties and the results are presented in Table 3.

Table 3: Chemical analysis of goat manure-based vermicompost and goat manure samples used in the experiment

Type of manure	Chemical property	Units	Value	Ranges	*Ratings
GMBV	pH (soil:H_2O, 1:2.5)	_	7.73	7.1-8.5	Moderately alkaline
	N	%	1.79	> 0.5	Very high
	P	ppm	52	> 50	High
	K	Cmol Kg^{-1}	1.75	> 0.60	High
GM	pH (soil:H_2O, 1:2.5)	_	8.0	7.1-8.5	Moderately alkaline
	N	%	0.32	0.25-0.50	High
	P	ppm	24	0-25	Medium
	K	Cmol Kg^{-1}	0.59	0.31-0.60	Medium

*The ratings are based according to criteria described in Appendix 22. Where: GMBV is goat manure based vermicompost and GM is goat manure.

The results of chemical analysis of goat manure-based vermicompost used in the study showed that it had very high total nitrogen, high available phosphorous and exchangeable potassium and it was moderately alkaline (Table 3) according to the ratings based on the ranges given by Hazelton and Murphy (2007). For goat manure which was also used in the study, the results showed that it had high total nitrogen, medium available phosphorous and exchangeable potassium and it was moderately alkaline (Table 3). The ratings were based on the ranges given by Hazelton and Murphy (2007). Hence, these results showed that goat manure-based vermicompost had higher nutrient availability (nitrogen, phosphorous and potassium) than goat manure that was used in this experiment.

4.3 Effect of Different Treatments on Soil Nutrients at Chuka and Embu

4.3.1 Soil Nutrients

The results of mean separation on the soil nutrients (soil pH, total nitrogen, available phosphorous and exchangeable potassium) at the end of the experiment are presented in Table 4.

Table 4: Means of various soil nutrients under different treatments at Chuka and Embu at the end of experiment

Site	Treatment	Soil pH	Total N (%)	Available P (ppm)	Exchangeable K (Cmol Kg^{-1})
Chuka	K_6	7.336b	0.230bc	15.240bc	0.676bc
	K_5	6.650de	0.223c	13.380c	0.726ab
	K_4	8.000a	0.606a	21.933a	0.863a
	K_3	7.030c	0.286b	15.906b	0.743ab
	K_2	6.873cd	0.213c	6.920d	0.533cd
	K_1	6.806cde	0.090d	4.726e	0.503cd
	K_0	6.586e	0.043d	4.670e	0.456d
	CV (%)	2.275	13.907	9.129	15.397
	$LSD_{(0.05)}$	0.284	0.059	1.920	0.176
Embu	K_6	7.130b	0.200c	14.316bc	0.650a
	K_5	6.620cd	0.203c	12.873c	0.630ab
	K_4	7.910a	0.563a	21.053a	0.710a
	K_3	6.860bc	0.273b	15.656b	0.683a
	K_2	6.813cd	0.183c	6.546d	0.496bc
	K_1	6.720cd	0.076d	4.700de	0.456cd
	K_0	6.543d	0.030e	4.596e	0.343d
	CV (%)	2.539	11.721	9.432	14.119
	$LSD_{(0.05)}$	0.313	0.045	1.911	1.142

*Means followed by the same letter in the same column are not significantly different from each other at 5% level of significant. Where: K_0 is 0 t ha^{-1}, K_1 is 5 t ha^{-1}, K_2 is 10 t ha^{-1}, K_3 is 20 t ha^{-1}, K_4 is 30 t ha^{-1}, K_5 is NPK (17-17-17) and K_6 is goat manure (30 t ha^{-1}).

The results of soil pH at Chuka and Embu showed that all treatment means were statistically significantly different ($p < 0.05$) but block means not significantly different (Appendix 4**)**. There was significantly interaction ($p < 0.05$) between the two sites (Appendix 5). Chuka recorded higher significant mean soil pH (8.00) in K_4 treatment while the lowest mean soil pH (6.58) was recorded in K_0 treatment. The application of K_5 treatment (NPK) reduced the soil pH after harvesting garlic crop in Chuka site. Thus, the results obtained confirmed that continuous application of chemical fertilizers into the soil reduces soil pH (Olomilua *et al.,* 2007). Similar to

Chuka, at Embu, higher significant mean soil pH (7.91) was recorded in K_4 treatment while the lowest mean soil pH (6.54) was recorded in K_0 treatment (Table 4).

These results of the study area showed that soil pH was significantly ($p < 0.05$) affected by goat manure-based vermicompost treatments. The addition of goat manure-based vermicompost increased soil pH. Among the treatments, the soils amended with goat manure-based vermicompost at the rate of 30 t ha^{-1} had highest soil pH in comparison to the control treatment at the end of harvesting season. This is attributed to higher rates of application of goat manure-based vermicompost that supplied more organic compounds which are mineralized under aerobic conditions to produce ammonium. Ammonium increases the soil pH and also reduces the potential of aluminium and manganese toxicity in soil. Also, the increase in soil pH is due to the fact that goat manure-based vermicompost had higher value of pH (7.73) when compared to Chuka soil pH (6.64) and Embu soil pH (6.33). Thus, the increase in soil pH (8.00 and 7.91) at Chuka and Embu sites respectively is not considered to have profound effect on the soil quality since it remains close to neutral. Similar to these results, Angelova *et al.* (2013) reported that application of vermicompost increased soil pH. Contrary to the results obtained, Atiyeh *et al.* (2001) reported decrease in soil pH as rates of application of vermicompost increased. This was attributed to production of NH^{+4}, CO_2 and organic acids during microbial metabolism in vermicompost.

The results of total nitrogen at Chuka and Embu showed that all treatment means were statistically significantly different ($p < 0.05$) but block means at Chuka were not significantly different (Appendix 4**)**. There was significantly interaction ($p < 0.05$) between the two sites (Appendix 5). Chuka recorded highest significant mean total nitrogen (0.606%) in K_4 treatment while the lowest mean total nitrogen (0.043%) was recorded in K_0 treatment. Similar to Chuka, at Embu, highest significant mean total nitrogen (0.563%) was recorded in K_4 treatment while the lowest mean total nitrogen (0.030%) was recorded in K_0 treatment (Table 4).

This results showed that total nitrogen was significantly ($p < 0.05$) affected by goat manure-based vermicompost treatments. The addition of goat manure-based vermicompost increased total nitrogen in the soils. Among the treatments, the soils amended with goat manure-based vermicompost at the rate of 30 t ha^{-1} had highest total nitrogen in comparison to the NPK treatment, goat manure treatment and the control treatment at the end of harvesting season. This is attributed to higher rates of application of goat manure-based vermicompost that supplied more residual nitrogen in soil than the control treatment. Similar to the results of this study, Angelova *et al.* (2013) reported that the total nitrogen concentration in soil was significantly affected by vermicompost treatments. The soils treated with vermicompost had more total nitrogen compared to soils without vermicompost application. This was attributed to organic matter, acidic pH and proper moisture in soil that avails nitrogen for plants. Azarmi *et al.* (2008) reported a decrease in total nitrogen in soils without vermicompost application was due to larger amounts of total carbon and nitrogen in vermicompost that could have provide a larger source of nitrogen for mineralization.

The results of available phosphorous showed that all treatment means and block means were statistically significantly different ($p < 0.05$) both at Chuka and Embu (Appendix 4**)**. There was significantly interaction ($p < 0.05$) between the two sites (Appendix 5). Chuka recorded highest significant mean available phosphorous (21.933 ppm) in K_4 treatment while the lowest mean available phosphorous (4.670 ppm) was recorded in K_0 treatment. Similar to Chuka, at Embu, highest significant mean available phosphorous (21.053 ppm) was recorded in K_4 treatment while the lowest mean available phosphorous (4.596 ppm) was recorded in K_0 treatment (Table 4).

This results showed that available phosphorous was significantly ($p < 0.05$) affected by goat manure-based vermicompost treatments. The addition of goat manure-based vermicompost increased available phosphorous. Among the treatments, the soils amended with goat manure-based vermicompost at the rate of 30 t ha^{-1} had highest available phosphorous in comparison to the control treatment at the end of harvesting season. This is attributed to higher rates of application of goat manure-based vermicompost that gradually and continuously released more phosphorous due to mineralization into the soil even after garlic crop. Also, release of phosphorous was due to the activity of microorganisms contained in vermicompost (Azarmi *et al.,* 2008). Similar to these results, Angelova *et al.* (2013) reported that there was a significant increase in the soil extractable phosphorous with the increase of vermicompost doses applied. Soils treated with vermicompost had significantly more phosphorous as compared to control plots. This was attributed to vermicompost releasing humic acid during organic matter decomposition resulting in conversion of unavailable soil phosphate into available forms. Also, this was due to enhancement of phosphatase activity and physical breakdown of material that resulted in greater mineralization.

The results of exchangeable potassium showed that all treatment means were statistically significantly different ($p < 0.05$) but blocking was not significantly different both at Chuka and Embu (Appendix 4**)**. There was significantly interaction ($p < 0.05$) between the two sites (Appendix 5). Chuka recorded highest significant mean exchangeable potassium (0.863 Cmol Kg^{-1}) in K_4 treatment while the lowest mean exchangeable potassium (0.456 Cmol Kg^{-1}) was recorded in K_0 treatment. Similar to Chuka, at Embu, highest significant mean exchangeable potassium (0.710 Cmol Kg^{-1}) was recorded in K_4 treatment while the lowest mean exchangeable potassium (0.343 Cmol Kg^{-1}) was recorded in K_0 treatment (Table 4).

These results showed that exchangeable potassium was significantly ($p < 0.05$) affected by goat manure-based vermicompost treatments. The addition of goat manure-based vermicompost increased exchangeable potassium in the soil. Among the treatments, the soils amended with goat manure-based vermicompost at the rate of 30 t ha^{-1} had highest exchangeable potassium in comparison to the control treatment at the end of harvesting season. This is attributed to higher rates of application of goat manure-based vermicompost that resulted in decreased potassium fixation and consequently increased potassium availability in the soils even at the end of harvesting season of garlic. Also, high application of goat manure-based vermicompost supplies a significant higher amount of potassium into the soil. This increases cation exchange capacity of the soil and this contributes to raising the amount of potassium in soil (Angelova *et al.,* 2013). Similar to the results obtained, Angelova *et al.* (2013) reported that significantly higher values of available potassium were obtained after the introduction of vermicompost compared to compost.

4.4 Effect of Goat Manure-Based Vermicompost on Growth of Garlic at Chuka and Embu

4.4.1 Plant Height

The results of mean separation on plant height of garlic plants taken at different days after emergence are presented in Table 5.

Table 5: Means of plant height (cm) under different treatments at different growth days after emergence (DAE) at Chuka and Embu

Site	Treatment	30 DAE	44 DAE	58 DAE	72 DAE	86 DAE
Chuka	K_6	27.769b	29.985b	32.315b	35.017b	36.130b
	K_5	24.754c	27.819c	31.395b	33.979b	35.034b
	K_4	30.263a	33.119a	36.458a	40.349a	41.809a
	K_3	30.611a	33.577a	36.595a	40.014a	41.573a
	K_2	29.865a	32.936a	35.942a	38.682a	40.279a
	K_1	27.506b	29.533b	31.477b	33.395bc	34.190bc
	K_0	24.533c	27.055c	29.196c	31.766c	32.674c
	CV (%)	17.349	15.731	16.494	17.426	16.715
	$LSD_{(0.05)}$	1.695	1.684	1.925	2.207	2.188
Embu	K_6	19.817bc	22.265bc	24.644bc	26.711bc	29.130c
	K_5	18.611c	20.703c	22.812c	25.176c	27.771c
	K_4	31.674a	34.090a	36.439a	38.846a	41.614a
	K_3	31.817a	34.379a	36.636a	38.804a	41.309ab
	K_2	30.634a	33.296a	35.374a	37.315a	39.598b
	K_1	21.396b	23.785b	25.841b	27.641b	29.533c
	K_0	14.071d	14.981d	15.588d	16.111d	16.746d
	CV (%)	24.958	22.004	19.984	18.325	16.480
	$LSD_{(0.05)}$	2.098	2.020	1.973	1.930	1.860

*Means followed by the same letter in the same column are not significantly different from each other at 5% level of significant. Where: K_0 is 0 t ha^{-1}, K_1 is 5 t ha^{-1}, K_2 is 10 t ha^{-1}, K_3 is 20 t ha^{-1}, K_4 is 30 t ha^{-1}, K_5 is NPK (17-17-17) and K_6 is goat manure (30 t ha^{-1}).

The results at Chuka and Embu showed that all treatment means were statistically significantly different ($p < 0.05$) at different stages of growth for the plant height (Appendix 6). At Chuka, the block means were not significant different ($p < 0.05$) for the trait at 30, 44 and 86 DAE. At Embu, the block means were significant different ($p < 0.05$) for the trait across different days (Appendix 6). There was significantly interaction ($p < 0.05$) between the two sites (Appendix 11). The results showed an increasing trend in mean plant height of garlic plants with increase in the number of days after emergence. This meant that the garlic plants increased in size with increase in the number of days after emergence with application of the different treatment combinations (Table 5).

Chuka recorded higher significant plant height during early stages of crop growth at 30, 44 and 58 DAE (30.611 cm, 33.577 cm and 36.595 cm respectively) in K_3 treatment, which was 24.77, 24.11 and 25.34 percent higher over control. End of the season at 72 and 86 DAE, higher significant plant height (40.349 cm and 41.809 cm respectively) was recorded in K_4 treatment, which was 27.02 and 27.96 percent higher over control (Table 5). Similar to Chuka, at Embu, higher significant plant height during early stages of crop growth at 30, 44 and 58 DAE (31.817 cm, 34.379 cm and 36.636 cm respectively) was recorded in K_3 treatment, which was 126.11, 129.49 and 135.02 percent higher over control. End of the season at 72 and 86 DAE, higher significant plant height (38.846 cm and 41.614 cm respectively) was recorded in K_4 treatment, which was 141.11 and 148.50 percent higher over control (Table 5). K_4 treatment recorded the highest mean plant height (41.809 cm and 41.615 cm respectively) at Chuka and Embu at 86 DAE (Table 5). The least mean plant height (24.533 cm and 14.071 cm respectively) at 30 DAE was observed in K_0 treatment at Chuka and Embu (Table 5).

These results indicated a general trend increase in plant height in response to increase in goat manure-based vermicompost application rates from 0 t ha^{-1} to 30 t ha^{-1} at Chuka and Embu respectively. Among the treatments, application of 30 t ha^{-1} produced the tallest garlic plants at 86 DAE in both sites whereas the shortest plants were obtained in 0 t ha^{-1}. This showed that goat manure-based vermicompost is a slow release fertilizer (Lazcano *et al.*, 2008) and hence released nutrients (nitrogen, phosphorous and potassium) to the soil towards the end of the growing season. This is supported by experimental soil analysis results that showed some significant quantity of macronutrients like nitrogen, phosphorous and potassium after experiment. Thus, this significantly was responsible for soil fertility hence very necessary for promoting plant growth.

This enhanced garlic plant height in 30 t ha^{-1} treatment both at Chuka and Embu could be attributed to higher nutrient availability (nitrogen, phosphorous and potassium) in higher rate of application of goat-manure based vermicompost. This promoted increased nutrient uptake by the garlic crop in goat manure-based vermicompost treated soils which facilitated increased plant growth hence taller garlic plants. However, during most of the entire evaluation period data on plant height showed that there was no statistically significant difference for treatments 10 t ha^{-1}, 20 t ha^{-1} and 30 t ha^{-1} which had the highest mean plant heights. In contrast, control treatment, 5 t ha^{-1} of goat manure-based vermicompost treatment, NPK treatment and goat manure treatment produced the lowest mean plant height.

The findings are similar to the results by Acharya and Kumar (2018) where vermicompost application increased plant height of garlic significantly. Degwale (2016) also found that plant height of garlic was affected by vermicompost application. This response to vermicompost is due to the fact that vermicompost supplied sufficient amounts of nitrogen to the soil which is a building block of amino acids ($-NH_2$) that link together to form proteins thus make up metabolic processes required for plant growth (Degwale, 2016). Studies have shown that growth of plants has been associated with humus content excreted by earthworm which contains humic acid. Humic acid increases plant growth hormones and other beneficial symbiotic micro-organisms hence enhanced plant growth (Ali and Kashem, 2019). Also, vermicompost contains some plant growth stimulating substances which promotes vegetative growth in terms of plant height (Manish, 2014).

Application of vermicompost to the soil increases nutrient turnover (Mbithi *et al.,* 2015). Thus, this maintains and increases the uptake of plant nutrients which leads to faster physiological development of the plants. Application of vermicompost has been found to enable the plants to have a good proliferation which leads to improvement in plant growth (Acharya and Kumar, 2018). Similarly, the rapid increase in plant height may be attributed to factors such as beneficial influence of nitrification inhibition properties of vermicompost in the soil and also it may be due to rapid elongation and multiplication of cell in the presence of adequate quantity of nitrogen (Kumawat *et al.,* 2019). From the results obtained, it is agreeable that continuous use of chemical fertilizers like NPK in Meru south and Manyatta sub-counties, brings about changes in soil parameters thus creates unfavourable conditions for garlic development. Joshi *et al.* (2016), Essa *et al.* (2019), Ramnarain *et al.* (2018) and Yeole *et al.* (2013) also made similar findings. Hence the findings of performance of mean plant height in the study area in agreement with results of these previous related experiments.

4.4.2 Number of Leaves

The results of mean separation on the number of leaves of garlic plants taken at different days after emergence are presented in Table 6.

Table 6: Means of number of leaves under different treatments at different growth days after emergence (DAE) at Chuka and Embu

Site	Treatment	30 DAE	44 DAE	58 DAE	72 DAE	86 DAE
Chuka	K_6	4.714bc	5.714cd	6.761c	7.634c	8.650c
	K_5	4.492c	5.603d	6.666c	7.476c	8.476c
	K_4	5.428a	7.031a	8.269a	9.158a	10.365a
	K_3	5.460a	6.650b	7.698b	8.571b	9.650b
	K_2	5.269a	6.523b	7.666b	8.428b	9.539b
	K_1	4.873b	6.031c	6.968c	7.698c	8.619c
	K_0	4.031d	5.111e	6.206d	7.079d	8.095d
	CV (%)	21.769	16.886	14.485	13.444	11.485
	$LSD_{(0.05)}$	0.373	0.360	0.364	0.377	0.364
Embu	K_6	5.000b	6.095b	7.222c	8.301c	9.587c
	K_5	5.063b	6.079b	7.079c	8.095c	9.317c
	K_4	6.539a	8.301a	9.698a	10.904a	12.333a
	K_3	6.571a	8.349a	9.587a	10.603ab	11.746b
	K_2	6.793a	8.031a	9.174b	10.254b	11.444b
	K_1	5.317b	6.349b	7.381c	8.412c	9.682c
	K_0	4.269c	5.365c	6.396d	7.444d	8.523d
	CV (%)	19.617	15.205	13.015	11.238	10.800
	$LSD_{(0.05)}$	0.388	0.369	0.368	0.359	0.392

*Means followed by the same letter in the same column are not significantly different from each other at 5% level of significant. Where: K_0 is 0 t ha^{-1}, K_1 is 5 t ha^{-1}, K_2 is 10 t ha^{-1}, K_3 is 20 t ha^{-1}, K_4 is 30 t ha^{-1}, K_5 is NPK (17-17-17) and K_6 is goat manure (30 t ha^{-1}).

The results at Chuka and Embu showed that all treatment means were statistically significantly different ($p < 0.05$) at different stages of growth for the number of leaves (Appendix 7). At Chuka, the block means were not significant different ($p < 0.05$) for the trait at 30, 44, 58 and 86 DAE. At Embu, the block means were significant different ($p < 0.05$) for the trait across different days (Appendix 7). There was significantly interaction ($p < 0.05$) between the two sites (Appendix 12). The results showed an increasing trend in mean number of leaves of garlic plants with increase in the number of days after emergence in the two sites. These results obtained clearly indicated that the total number of leaves produced by garlic plants increased with increase in the number of days after emergence with application of the different treatment combinations (Table 6).

At Chuka, 30 DAE, higher significant number of leaves (5.460) was recorded in K_3 treatment which was 35.43 percent higher over control. At 44, 58, 72 and 86 DAE, higher significant number of leaves (7.031, 8.269, 9.158 and 10.365 respectively) was recorded in K_4 treatment, which was 37.58, 33.25, 29.37 and 28.04 percent respectively higher over control (Table 6). At Embu, 30 DAE, higher significant number of leaves (6.793) was recorded in K_2 treatment which was 63.33 percent higher over control. At 44 DAE, higher significant number of leaves (8.349) was recorded in K_3 treatment which was 55.62 percent higher over control. At 58, 72 and 86 DAE, higher significant number of leaves (9.698, 10.904, and 12.333 respectively) was recorded in K_4 treatment, which was 51.61, 46.48 and 44.69 percent respectively higher over control (Table 6). K_4 treatment recorded the highest mean number of leaves (10.365 and 12.333 respectively) at 86 DAE while the least mean number of leaves (4.031 and 4.269 respectively) at 30 DAE was observed in K_0 treatment at Chuka and Embu (Table 6).

These results indicated a general trend increase in number of leaves in response to increase in goat manure-based vermicompost application rates from 0 t ha^{-1} to 30 t ha^{-1} at Chuka and Embu respectively. Among the treatments, application of 30 t ha^{-1} produced the highest number of leaves whereas the least number of leaves were obtained in 0 t ha^{-1} treatment in both sites. The higher number of leaves in garlic plants in 30 t ha^{-1} treatment at both Chuka and Embu could be attributed to higher levels of goat manure-based vermicompost which besides supplying nitrogen, phosphorous and potassium also make unavailable form of nutrients into an available form hence facilitated the garlic plants to absorb the nutrients increasing plant vigour hence increased number of leaves per garlic plant. The results revealed that highest number of leaves in 30 t ha^{-1} was due to slow release of nutrients through goat manure-based vermicompost thus enriching available nutrient pool of the soil. This resulted in more number of leaves per plant that was recorded towards the end of the growing season. Hence, due to increased number of leaves and leaf area per plant, this resulted in better photosynthesis and accumulation of photosynthates leading to more plant vigour and more leaves that was recorded in 30 t ha^{-1} treatments in both sites.

This result is supported by the findings of Acharya and Kumar (2018) who reported that vermicompost had significant effect on the number of leaves per garlic plant. Degwale (2016) also reported that vermicompost significantly affected leaf number in garlic. This was due to the fact that vermicompost had higher quantity of nutrients, plant growth promoters, improved the physical properties of soil and increased activities of microbes which improved plant growth significantly hence increased the number of leaves. Similarly, Kumar *et al.* (2019) in his study experiment indicated that maximum number of leaves per garlic plant was due to the higher nitrogen in the vermicompost NPK nutrient thus resulted in the increased number of leaves per plant.

Therefore, the results of experimental analysis of goat manure-based vermicompost showed that it contained higher levels of total nitrogen, available phosphorous and exchangeable potassium that enhanced better plant growth (Essa *et al.,* 2019). This proved that when soils are amended with vermicompost, it provides the required plant nutrients which therefore increases nutrient uptake by plants contributing to maximum growth in vermicompost treated soils when compared to other treatments (Rekha *et al.,* 2018). According to Ali (2018), growth of plants is also associated with humus content excreted by earthworms which contains humic acid that increases plant growth hormones hence better plant growth in terms of leaves.

Suthar (2009) in his field experiment on garlic reported that vermicomposted farmyard manure showed a comparatively high number of leaves which indicates the presence of some growth promoting substances in vermicompost. The findings of Suthar (2009) also showed that vermicomposted farmyard manure contained a considerable amount of some essential plant micronutrients that might be responsible for better plant growth and productivity. Degwale (2016) and Kumawat *et al.* (2019) also made similar findings. Hence, the findings of performance of mean number of leaves in the two study areas are in conformity with results of these previous related experiments.

4.4.3 Stem Diameter

The results of mean separation on stem diameter of garlic plants taken at different days after emergence are presented in Table 7.

Table 7: Means of stem diameter (cm) under different treatments at different growth days after emergence (DAE) at Chuka and Embu

Site	Treatment	30 DAE	44 DAE	58 DAE	72 DAE	86 DAE
Chuka	K_6	0.468b	0.552b	0.626b	0.694b	0.721b
	K_5	0.433b	0.521b	0.592b	0.658b	0.695b
	K_4	0.522a	0.625a	0.692a	0.771a	0.863a
	K_3	0.544a	0.634a	0.697a	0.768a	0.835a
	K_2	0.520a	0.607a	0.678a	0.769a	0.837a
	K_1	0.471b	0.544b	0.603b	0.656b	0.691b
	K_0	0.343c	0.461c	0.524c	0.588c	0.610c
	CV (%)	23.556	18.928	18.713	18.906	18.751
	$LSD_{(0.05)}$	0.038	0.037	0.041	0.046	0.049
Embu	K_6	0.356cd	0.402e	0.473de	0.522c	0.568cd
	K_5	0.341d	0.394e	0.449ef	0.524c	0.591c
	K_4	0.541b	0.679b	0.845b	1.034a	1.241a
	K_3	0.582a	0.761a	0.914a	1.060a	1.235a
	K_2	0.526b	0.594c	0.664c	0.798b	1.006b
	K_1	0.384c	0.446d	0.507d	0.570c	0.630c
	K_0	0.317d	0.363e	0.411f	0.458d	0.506d
	CV (%)	27.000	23.385	21.287	22.291	25.433
	$LSD_{(0.05)}$	0.041	0.042	0.045	0.055	0.073

*Means followed by the same letter in the same column are not significantly different from each other at 5% level of significant. Where: K_0 is 0 t ha^{-1}, K_1 is 5 t ha^{-1}, K_2 is 10 t ha^{-1}, K_3 is 20 t ha^{-1}, K_4 is 30 t ha^{-1}, K_5 is NPK (17-17-17) and K_6 is goat manure (30 t ha^{-1}).

The results at Chuka and Embu showed that all treatment means were statistically significantly different ($p < 0.05$) at different stages of growth for the stem diameter (Appendix 8). At Chuka, the block means were not significant different ($p < 0.05$) for the trait at 44, 58 and 72 DAE while at Embu, the block means were significant different ($p < 0.05$) for the trait across different days (Appendix 8). There was significantly interaction ($p < 0.05$) between the two sites (Appendix 13). The results showed an increasing trend in mean stem diameter of garlic plants with increase in the number of days after emergence in the two sites. These results obtained revealed that the diameter of garlic plants increased with increase in the number of days after emergence with application of the different treatment combinations (Table 7).

At Chuka, higher significant stem diameter during early stages of crop growth at 30, 44 and 58 DAE (0.544 cm, 0.634 cm and 0.697 cm respectively) was recorded in K_3 treatment, which was 58.54, 37.60 and 32.92 percent higher over control. During the end of the season at 72 and 86 DAE, higher significant stem diameter (0.771 cm and 0.863 cm respectively) was recorded in K_4 treatment, which was 31.05 and 41.34

percent higher over control (Table 7). Similar to Chuka, at Embu, higher significant stem diameter at 30, 44, 58 and 72 DAE (0.582 cm, 0.761 cm, 0.914 cm and 1.060 cm respectively) was recorded in K_3 treatment, which was 83.75, 109.43, 122.17 and 131.18 percent higher over control. During the end of the season at 86 DAE, higher significant stem diameter (1.241 cm) was recorded in K_4 treatment, which was 145.19 percent higher over control (Table 7). K_4 treatment recorded the largest mean stem diameter at Chuka and Embu (0.863 cm and 1.241 cm respectively) at 86 DAE while the smallest mean stem diameter (0.343 cm and 0.317 cm respectively) at 30 DAE was observed in K_0 treatment at Chuka and Embu (Table 7).

These results showed that there was an increase in stem diameter of garlic plants in response to increase in goat manure-based vermicompost application rates from 0 t ha^{-1} to 30 t ha^{-1} at Chuka and Embu sites respectively. This increased garlic plant stem diameter in 30 t ha^{-1} treatment at both Chuka and Embu could be attributed to presence of more amount of available nitrogen that was supplied by goat manure-based vermicompost as indicated by the results of the vermicompost analysis. This nitrogen is very essential for the synthesis of structural proteins which are essential in promoting better plant growth in terms of stem diameter.

The other probable reason for maximum diameter of stem was due to increased concentration of soil enzymes, rapid mineralization and transformation of plant nutrients in soil resulting in increased plant growth hence larger stem diameter of garlic plants (Kumar *et al.*, 2019). Equally, the enhanced garlic stem diameter can be explained in terms of increased humic content in goat manure-based vermicompost that is due to processing by earthworms (Ali, 2018). Humic helps availability of plant nutrients by improving soil structure and microbial activities hence increased plant growth in terms of stem diameter.

These results are in agreement with similar studies on diameter of stem by Kumar *et al.* (2019) that indicated maximum diameter of stem was found with the treatment that had highest amount of vermicompost. Mavura *et al.* (2017) reported that vermicompost promotes plant growth and development through the modified nutrition and metabolism that includes the supply of plant growth regulating substances and improvements in soil functions. Some studies have revealed that vermicompost derived from animal manure contain fulvic acids, humic acids and phytohormones which rejuvenate the soil and encourages plant vigour (Abbasi *et al.*, 2017).

Similarly, Xiang *et al.* (2016) reported that the nutrient content in terms of total nitrogen, phosphorous and potassium in *in situ* earthworm breeding was higher providing a better soil nutrient and also plant growth hormones in earthworms' casts stimulated plant growth. The study findings of Borji *et al.* (2014), Durak *et al.* (2017) and Kumar and Gupta (2018) reported that comparison results showed that treatment with vermicompost had significantly greater plant stem diameters compared with other treatments. Hence these results revealed similar findings on garlic plant stem diameter in the two study areas.

4.4.4 Leaf Length

The results of mean separation on leaf length of garlic plants taken at different days after emergence are presented in Table 8.

Table 8: Means of leaf length (cm) under different treatments at different growth days after emergence (DAE) at Chuka and Embu

Site	Treatment	30 DAE	44 DAE	58 DAE	72 DAE	86 DAE
Chuka	K_6	21.379b	23.354b	24.339b	25.582b	26.617b
	K_5	17.968c	20.763c	22.284c	25.693b	25.515b
	K_4	22.849a	25.763a	27.201a	28.052a	31.485a
	K_3	23.785a	26.584a	27.668a	28.544a	30.142a
	K_2	22.901a	26.144a	27.331a	28.312a	30.204a
	K_1	20.211b	22.573b	23.528bc	24.861b	25.587b
	K_0	15.484d	17.788d	18.615d	20.760c	21.549c
	CV (%)	18.817	19.948	20.570	25.846	17.563
	$LSD_{(0.05)}$	1.361	1.626	1.759	2.350	1.679
Embu	K_6	15.023d	16.030c	16.723c	17.227c	17.736c
	K_5	13.203e	14.107d	14.642d	15.073d	15.519d
	K_4	24.760a	25.598a	26.350a	27.090a	27.823a
	K_3	21.715c	22.704b	23.725b	24.754b	25.734b
	K_2	23.277b	23.971b	24.706b	25.269b	25.876b
	K_1	14.760d	15.217cd	15.639cd	16.201cd	16.638cd
	K_0	10.146f	10.412e	10.639e	10.884e	11.147e
	CV (%)	22.660	20.766	19.552	19.108	18.478
	$LSD_{(0.05)}$	1.393	1.330	1.295	1.304	1.298

*Means followed by the same letter in the same column are not significantly different from each other at 5% level of significant. Where: K_0 is 0 t ha^{-1}, K_1 is 5 t ha^{-1}, K_2 is 10 t ha^{-1}, K_3 is 20 t ha^{-1}, K_4 is 30 t ha^{-1}, K_5 is NPK (17-17-17) and K_6 is goat manure (30 t ha^{-1}).

The results at Chuka and Embu showed that all treatment means were statistically significantly different ($p < 0.05$) at different stages of growth for the leaf length (Appendix 9). At Chuka, the blocks were not significant different ($p < 0.05$) for the trait at 30, 44, 58, 72 and 86 DAE. At Embu, the blocks were significant different ($p < 0.05$) for the trait across different days (Appendix 9). There was significantly interaction ($p < 0.05$) between the two sites (Appendix 14). These results showed an increasing trend in mean leaf length of garlic plants with increase in the number of days after emergence in the two sites. These results obtained revealed that the leaf length of garlic plants increased with increase in the number of days after emergence with application of the different treatment combinations (Table 8).

At Chuka, at 30, 44, 58, and 72 DAE, higher significant leaf length (23.785 cm, 26.584 cm, 27.668 cm and 28.544 cm respectively) was recorded in K_3 treatment, which was 53.61, 49.44, 48.62 and 37.50 percent respectively higher over control. During the end of the season at 86 DAE, higher significant leaf length (31.485 cm) was recorded in K_4 treatment which was 46.11 percent higher over control (Table 8). Higher significant leaf length (24.760 cm, 25.598 cm, 26.350 cm, 27.090 cm and 27.823 cm respectively) was recorded in K_4 treatment, which was 144.04, 145.84, 147.66, 148.90 and 149.59 percent respectively higher over control at 30, 44, 58, 72 and 86 DAE respectively at Embu (Table 8). K_4 treatment recorded the highest mean leaf length (31.485 cm and 27.823 cm respectively) at Chuka and Embu at 86 DAE while the least mean leaf length (15.484 cm and 10.146 cm respectively) at Chuka and Embu at 30 DAE was observed in K_0 treatment (Table 8).

The results obtained from the study area indicated a general trend increase in leaf length in response to increase in goat manure-based vermicompost application rates from 0 t ha^{-1} to 30 t ha^{-1} at Chuka and Embu respectively. The enhanced garlic plant leaf length in 30 t ha^{-1} treatment could be attributed to goat manure-based vermicompost that greatly influences growth parameters since it contains plant nutrients in readily available forms. Also, enhanced plant growth characteristics might be due to higher nutrient availability as well as better nutrient uptake by the crop (Acharya and Kumar, 2018). Goat manure-based vermicompost contains more total and exchangeable plant nutrients (nitrogen, phosphorous and potassium) based on the results of the chemical analysis that was carried out. During the processing of various organic wastes by earthworms, many of nutrients it contains are changed to forms which are more readily taken by plants such as nitrate, exchangeable phosphorous and soluble potassium (Arancon *et al.,* 2004).

The increase in the vegetative growth in terms of leaf length might also be due to the effect of nutrients which are exerted by vermicompost (Kenea and Gedamu, 2018). The differential response of plants to different doses of vermicompost may be due to release of variable amounts of available nutrients and growth promoting substances in vermicompost (Kashem *et al.,* 2015). According to Suthar (2009), the maximum range of some plant parameters like leaf length indicated the presence of some growth promoting substances in worm processed material hence responsible for better growth and productivity.

On similar results on leaf length, Acharya and Kumar (2018) reported that the highest length of leaves in garlic was recorded in vermicompost treatment. Kumar *et al.* (2019) also found that maximum leaf length in garlic at 30, 60 and 90 days after sowing was due to earthworm casts that increased the number of tillers and of leaves resulting in increased to the leaf length. Earthworms stimulate microbial activities and metabolism and also they influence microbial populations and hence this enhances more available nutrients and microbial metabolites released into the soil (Kashem *et al.,* 2015) promoting more plant vigour in terms of increased leaf length of plants. Studies have shown that when vermicompost is extensively used as a bedding media, it is very necessary in promoting seedling growth hence longer leaves in plants and productivity of plants (Essa *et al.,* 2019).

Studies have shown that the increase in the vegetative growth in terms of leaf length might also be due to the effect of nutrients which are exerted by vermicompost (Kenea and Gedamu, 2018). Garlic plants responded differently to the rates of application of goat manure based application rates and this can be explained in terms of differences in the leaf length. The differential response of plants to different doses of vermicompost may be due to release of variable amounts of available nutrients and growth promoting substances in vermicompost (Kashem *et al.,* 2015). According to Suthar (2009), the maximum range of some plant parameters like leaf length indicated the presence of some growth promoting substances in worm processed material hence responsible for better growth and productivity. Kumawat *et al.* (2019), Kenea and Gedamu (2018) and Kashem *et al.* (2015) also made similar findings. Hence these results of the present study are in agreement with findings of the other previous studies.

4.4.5 Leaf Width

The results of mean separation on leaf width of garlic plants taken at different days after emergence are presented in Table 9.

Table 9: Means of leaf width (cm) under different treatments at different growth days after emergence (DAE) at Chuka and Embu

Site	Treatment	30 DAE	44 DAE	58 DAE	72 DAE	86 DAE
Chuka	K_6	0.782bc	0.938b	1.044b	1.169b	1.258c
	K_5	0.607d	0.803c	0.925c	1.031c	1.147d
	K_4	0.914a	1.093a	1.234a	1.382a	1.557a
	K_3	0.892a	1.074a	1.212a	1.330a	1.460b
	K_2	0.834b	1.068a	1.211a	1.328a	1.461b
	K_1	0.728c	0.898b	1.004b	1.095bc	1.207cd
	K_0	0.565d	0.681d	0.800d	0.903d	1.015e
	CV (%)	20.818	22.449	21.329	19.274	17.191
	$LSD_{(0.05)}$	0.055	0.073	0.079	0.079	0.078
Embu	K_6	0.727c	0.936c	1.125b	1.292c	1.430d
	K_5	0.625d	0.763e	0.946d	1.127de	1.317e
	K_4	1.023a	1.252a	1.463a	1.661a	1.817a
	K_3	0.988a	1.222a	1.422a	1.588b	1.739b
	K_2	0.860b	1.015b	1.168b	1.320c	1.496c
	K_1	0.738c	0.882d	1.023c	1.163d	1.293ef
	K_0	0.631d	0.798e	0.947d	1.101e	1.250f
	CV (%)	19.345	15.223	13.526	12.135	10.977
	$LSD_{(0.05)}$	0.054	0.052	0.054	0.056	0.056

*Means followed by the same letter in the same column are not significantly different from each other at 5% level of significant. Where: K_0 is 0 t ha^{-1}, K_1 is 5 t ha^{-1}, K_2 is 10 t ha^{-1}, K_3 is 20 t ha^{-1}, K_4 is 30 t ha^{-1}, K_5 is NPK (17-17-17) and K_6 is goat manure (30 t ha^{-1}).

The results showed that all treatment means were statistically significantly different ($p < 0.05$) at different stages of growth for the leaf width at Chuka and Embu respectively (Appendix 10). At Chuka and Embu, the blocks were significant different ($p < 0.05$) for the trait across different days (Appendix 10). There was significantly interaction ($p < 0.05$) between the two sites (Appendix 15). These results showed an increasing trend in mean leaf width of garlic plants with increase in the number of days after emergence in the two sites. These results obtained revealed that the leaf width of garlic plants increased with increase in the number of days after emergence with application of the different treatment combinations (Table 9).

Chuka recorded higher significant leaf width at 30, 44, 58, 72 and 86 DAE (0.914 cm, 1.093 cm, 1.234 cm, 1.382 cm and 1.557 cm respectively) in K_4 treatment, which was 61.79, 60.60, 54.36, 53.07 and 53.27 percent higher over control (Table 9). Similar to Chuka, at Embu, at 30, 44, 58, 72 and 86 DAE higher significant leaf width (1.023 cm, 1.252 cm, 1.463 cm, 1.661 cm and 1.817 cm) was observed in K_4 treatment which was 63.70, 56.86, 54.70, 50.86 and 45.31 percent higher over control (Table 9). K_4 treatment recorded the largest mean leaf width (1.557 cm and 1.817 cm respectively) at 86 DAE while the smallest mean leaf width (0.565 cm and 0.625 cm respectively) at 30 DAE was observed in K_0 treatment at Chuka and Embu (Table 9). At Chuka, K_6, K_2, K_3 and K_4 treatment means were higher than the overall mean of 0.760 cm and 0.936 cm respectively at 30 and 44 DAE.

The results that were obtained revealed a general trend increase in leaf width in response to increase in goat manure-based vermicompost application rates from 0 t ha^{-1} to 30 t ha^{-1} at Chuka and Embu respectively. This enhanced plant growth in terms of leaf width in 30 t ha^{-1} treatment might be due to higher nutrient availability based on the chemical analysis of goat manure-based vermicompost which showed that it contained a considerable amount of nitrogen, phosphorous and potassium. This was also well occasioned by better nutrient uptake by the plants (Mbithi *et al.,* 2015). Hence chlorophyll content of garlic leaf that contributes to leaf width (Acharya and Kumar, 2018) increased significantly with application of 30 t ha^{-1} thus more photosynthesis and formation of photosynthates in the plant. Various growth characters of plants like leaf width determine the vegetative growth of the crop and this greatly influences yield through enhanced dry matter production.

Acharya and Kumar (2018) reported that data on width of leaves in garlic showed a significant increase in leaf width in vermicompost than control treatment. Similarly, Kenea and Gedamu (2018) reported that application of higher rates of vermicompost gave significantly optimum leaf width over the application of lower rates of vermicompost and control treatment. This indicates that vermicompost application brings an excellent biochemical changes in soil structure thus promoting plant growth in terms of leaf width (Kumar *et al.*, 2019). Humic acid in vermicompost stimulates plant growth even in small amounts and also microorganisms including bacteria, fungi, yeasts, actinomycetes and algae are active in vermicompost applied field hence capable of producing plant growth regulators such as auxins, gibberellins, cytokinins, ethylene and abcisic acid in appreciable quantities thus facilitated plant growth (Getnet and Raja, 2013).

4.5 Effect of Goat Manure Based Vermicompost on Yield of Garlic at Chuka and Embu

4.5.1 Garlic Bulb Yield Attributes

The results of mean separation on garlic bulb yield attributes (bulb fresh weight, bulb diameter and bulb length) are presented in Table 10.

Table 10: Means of various garlic bulb yield attributes under different treatments at Chuka and Embu

Site	Treatment	Bulb Fresh Weight (gm)	Bulb Diameter (gm)	Bulb Length (cm)
Chuka	K_6	14.086b	3.632bc	2.710b
	K_5	12.603b	3.478c	2.586bc
	K_4	18.190a	3.928a	3.043a
	K_3	16.996a	3.913a	2.956a
	K_2	17.510a	3.837ab	2.903a
	K_1	9.623c	3.132d	2.430cd
	K_0	8.516c	2.971d	2.363d
	CV (%)	31.186	12.017	11.371
	$LSD_{(0.05)}$	2.212	0.217	0.157
Embu	K_6	10.940a	3.287a	2.676ab
	K_5	8.920b	3.036b	2.520bc
	K_4	12.660a	3.503a	2.846a
	K_3	11.796a	3.367a	2.693a
	K_2	11.450a	3.332a	2.693a
	K_1	8.363b	2.969b	2.473c
	K_0	7.823b	2.905b	2.390c
	CV (%)	36.302	13.592	12.967
	$LSD_{(0.05)}$	1.899	0.221	0.172

*Means followed by the same letter in the same column are not significantly different from each other at 5% level of significant. Where: K_0 is 0 t ha^{-1}, K_1 is 5 t ha^{-1}, K_2 is 10 t ha^{-1}, K_3 is 20 t ha^{-1}, K_4 is 30 t ha^{-1}, K_5 is NPK (17-17-17) and K_6 is goat manure (30 t ha^{-1}).

The results of bulb fresh weight showed that the treatment means were statistically significantly different ($p < 0.05$) at Chuka and Embu (Appendix 16). The blocks were significant different ($p < 0.05$) at Chuka and Embu (Appendix 16). There was significantly interaction ($p < 0.05$) between the two sites (Appendix 18).

At Chuka, K_4 treatment had the highest bulb fresh weight mean of 18.190 gm while K_0 treatment had lowest bulb fresh weight mean of 8.516 gm. K_4 treatment which recorded the highest bulb fresh weight mean was 113.58 percent higher over the control (Table 10). Similar to Chuka, at Embu, treatment K_4 had the highest bulb fresh weight mean of 12.660 gm while K_0 treatment had the lowest bulb fresh weight mean of 7.823 gm. K_4 treatment which recorded the highest bulb fresh weight mean was 61.82 percent higher over the control (Table 10).

The results of bulb diameter showed that the treatment means were statistically significantly different ($p < 0.05$) at Chuka and Embu (Appendix 16). The blocks were significant different ($p < 0.05$) at Chuka and Embu (Appendix 16). There was significantly interaction ($p < 0.05$) between the two sites (Appendix 18). At Chuka, treatment K_4 had the highest bulb diameter mean of 3.928 gm while K_0 treatment had lowest bulb diameter mean of 2.971 gm. K_4 treatment which recorded the highest bulb diameter mean was 32.22 percent higher over the control (Table 10). Similar to Chuka, at Embu, treatment K_4 had the highest bulb diameter mean of 3.503 gm while K_0 treatment had the lowest bulb diameter mean of 2.905 gm. K_4 treatment which recorded the highest bulb diameter mean was 20.56 percent higher over the control (Table 10).

The results of bulb length showed that the treatment means were statistically significantly different ($p < 0.05$) at Chuka and Embu (Appendix 16). The blocks were significant different ($p < 0.05$) at Chuka and Embu (Appendix 16). There was significantly interaction ($p < 0.05$) between the two sites (Appendix 18). At Chuka, treatment K_4 had the highest bulb length mean of 3.043 cm while K_0 treatment had lowest bulb length mean of 2.363 cm. K_4 treatment which recorded the highest bulb length mean was 28.77 percent higher over the control (Table 10). Similar to Chuka, at Embu, treatment K_4 had the highest bulb length mean of 2.846 cm while K_0

treatment had the lowest bulb length mean of 2.390 cm. K_4 treatment which recorded the highest bulb length mean was 19.11 percent higher over the control (Table 12).

Bulb fresh weight of harvested garlic plants was significantly influenced due to effect of goat manure-based vermicompost at Chuka and Embu respectively. The results indicated a general trend increase in bulb fresh weight in response to increase in goat manure-based vermicompost application rates from 0 t ha^{-1} to 30 t ha^{-1} in both sites. Higher mean bulb fresh weight was recorded in 30 t ha^{-1} treatment compared to the control. Although application of 30 t ha^{-1} recorded the highest bulb fresh weight, there was no statistical difference with 10 t ha^{-1} and 20 t ha^{-1} treatment. In contrast, control treatment, 5 t ha^{-1} of goat manure-based vermicompost treatment, NPK treatment and goat manure treatment produced the lowest mean bulb fresh weight. Goat manure-based vermicompost had significant amounts of macro nutrients thus there was better plant growth in 30 t ha^{-1} treatment. This lead to high mean bulb fresh weight by facilitating improved leaf growth and photosynthetic activities in garlic plants. Hence this increased portioning of assimilates to storage organs of garlic plants thus increased bulb fresh weight. Also, this enhanced bulb fresh weight in 30 t ha^{-1} is due to several growth promoters, beneficial bacteria, mycorrhizae and enzymes contained in highest rate of application of goat manure-based vermicompost (Kumar *et al.,* 2019).

Similar to the results of this present study Kenea and Gedamu (2017) reported in their findings that significant maximum mean bulb weight of garlic was obtained from plots treated with vermicompost compared to the rest of the treatments. This was similar to results reported by Golmohammadzadeh *et al.* (2015). Kumar *et al.* (2019) in his study reported that maximum weight of bulb was attributed to vermicompost application in the soil that enhanced the biochemical potential of soil which in turn affected plant production. Studies carried out on garlic have demonstrated that vermicompost contains more exchangeable plant nutrients than those by other plant growth media hence maximum vegetative growth. This enhances maximum photosynthesis and accumulation of more dry matter (Kumar *et al.,* 2019). Abolmaaty and Fawaz (2016) and Patidar *et al.* (2019) also made similar findings.

The effect of goat manure-based vermicompost showed significant difference on mean bulb diameter of harvested garlic plants at Chuka and Embu respectively. The results indicated a general trend increase in mean bulb diameter in response to increase in goat manure-based vermicompost application rates from 0 t ha^{-1} to 30 t ha^{-1} in both sites. Higher mean bulb fresh weight was recorded in 30 t ha^{-1} treatment compared to the control. The results showed that the application of 30 t ha^{-1} recorded the highest mean bulb diameter. However, it was evident in the results obtained that there was no statistical difference with 10 t ha^{-1} and 20 t ha^{-1} treatments in the two sites. Contrary to these results obtained, the control treatment, 5 t ha^{-1} of goat manure-based vermicompost treatment, NPK treatment and goat manure treatment produced the lowest mean bulb diameter.

This enhanced bulb diameter in 30 t ha^{-1} can be greatly attributed to during the processing of goat manure-based vermicompost by earthworms were most of the nutrients it contains are changed to the forms that are more readily taken by garlic plant roots such as nitrates, exchangeable phosphorous, soluble potassium, calcium and magnesium (Arancon *et al.*, 2004). This promotes sink size in terms of bulb size thus enhanced garlic bulb diameter. Equally, enhanced garlic plant growth in goat manure-based vermicompost was possibly due to some plant growth promoters in earthworm casts in the manure (Kumar *et al.*, 2019). Thus size of bulb was directly influenced by the enhanced vegetative growth on the plants which resulted into accumulation of more carbohydrates hence increased diameter of the bulb which is a storage organ.

Similar to the results of this present study, Golmohammadzadeh *et al.* (2015) reported in their study findings that maximum bulb diameter of garlic was obtained in higher vermicompost treatment. In contrast, control treatments, chemical treatment and lower application of vermicompost produced the minimum bulb diameter. According to Kumar *et al.* (2019) in their study reported that the probable reason for the maximum diameter of bulb was due to the application of vermicompost which enhanced the activity of some microbial population and also the supply of nitrogen, phosphorous and potassium nutrient which resulted in increase to the diameter of the garlic bulb. The findings agree with those of Patidar *et al.* (2019), Kumar *et al.* (2019) and

Abolmaaty and Fawaz (2016) that application of vermicompost gave the highest garlic bulb diameter in comparison to the control treatments.

The effect of goat manure-based vermicompost showed significant difference on mean bulb length of harvested garlic plants at Chuka and Embu respectively. The results indicated a general trend increase in mean bulb length in response to increase in goat manure-based vermicompost application rates from 0 t ha^{-1} to 30 t ha^{-1} in both sites. The highest mean bulb length was recorded in 30 t ha^{-1} treatment both in Chuka and Embu as compared to the control. Though the application of 30 t ha^{-1} recorded the highest mean bulb length, it however showed that there was no statistical difference with 10 t ha^{-1} treatments and 20 t ha^{-1} treatments both at Chuka and Embu sites. This was in contrast to the control treatment, 5 t ha^{-1} of goat manure-based vermicompost treatment, NPK treatment and goat manure treatment that produced the lowest mean bulb length.

This increased bulb length in 30 t ha^{-1} might be due to the fact that high rates of goat manure-based vermicompost supplies nitrogen, phosphorous and potassium as indicated by the results of the chemical analysis of the vermicompost. Nitrogen is necessary in forming amino acids in a plant that link to form proteins thus make metabolic processes required for plant growth (Degwale, 2016). Phosphorous is very important in facilitating cell division, enhancing photosynthesis and metabolism of carbohydrates in garlic plants. Potash is required also in regulating proper translocation of photosynthates and stimulated enzyme activities in garlic plants. This contributed to higher rates of growth and in turn rapid development in yield characters like bulb length leading to facilitated high bulb yield of garlic.

Similar to these results, Kumar *et al.* (2019) reported maximum clove length under treatment of vermicompost while minimum clove length in control treatment. These results of Kumar *et al.* (2019) revealed that length of cloves show positive response of good yields in garlic. Highest garlic bulb length was achieved from plots that received vermicompost and recommended dose of fertilizer while the control plot gave the lowest bulb length. These results revealed that organic vermicompost supplied the necessary requirements for the proper vegetative growth of plant that helps in obtaining the highest bulb size (Gebremichael *et al.*, 2017). This showed that the results of the present study are in agreement with findings of the other previous studies.

4.5.2 Garlic Bulb Yield Components and Yield

The results of mean separation on garlic bulb yield components and yield (number of cloves per bulb, bulb dry weight and bulb yield per hectare) are presented in Table 11.

Table 11: Means of various garlic bulb yield components and yield under different treatments at Chuka and Embu

Site	Treatment	Number of cloves	Bulb Dry Weight(gm)	Bulb Yield (kg ha^{-1})
Chuka	K_6	5.800cd	12.496bc	3162.91bc
	K_5	5.300cd	8.606d	2829.85cd
	K_4	7.466a	15.963a	4084.24a
	K_3	6.866ab	15.153a	3816.30ab
	K_2	6.000bc	14.453ab	3931.56ab
	K_1	5.433cd	11.353c	2160.75de
	K_0	4.800d	7.270d	1945.95e
	CV (%)	35.001	31.847	14.705
	$LSD_{(0.05)}$	1.060	1.975	819.64
Embu	K_6	5.300abc	9.906ab	2456.38abc
	K_5	4.966bc	8.273bc	2002.83bc
	K_4	5.900a	11.296a	2842.58a
	K_3	5.666ab	10.606a	2648.73ab
	K_2	5.433ab	10.213a	2486.32abc
	K_1	5.200abc	7.823c	1877.83bc
	K_0	4.566c	7.036c	1762.37c
	CV (%)	29.628	35.390	19.157
	$LSD_{(0.05)}$	0.798	1.677	782.73

*Means followed by the same letter in the same column are not significantly different from each other at 5% level of significant. Where: K_0 is 0 t ha^{-1}, K_1 is 5 t ha^{-1}, K_2 is 10 t ha^{-1}, K_3 is 20 t ha^{-1}, K_4 is 30 t ha^{-1}, K_5 is NPK (17-17-17) and K_6 is goat manure (30 t ha^{-1}).

The results of number of cloves per bulb showed that the treatment means were statistically significantly different ($p < 0.05$) at Chuka and Embu (Appendix 17). The blocks were not significant different ($p < 0.05$) at Chuka and Embu (Appendix 17). There was significantly interaction ($p < 0.05$) between the two sites (Appendix 19). At Chuka, treatment K_4 had the highest number of cloves mean of 7.466 while K_0 treatment had lowest number of cloves mean of 4.800. K_4 treatment which recorded the highest mean number of cloves was 55.56 percent higher over the control (Table 11). Similar to Chuka, at Embu, treatment K_4 had the highest number of cloves mean of 5.900 while K_0 treatment had the lowest number of cloves mean of 4.566. K_4 treatment which recorded the highest number of cloves mean was 29.19 percent higher over the control (Table 11).

The results of bulb dry weight showed that the treatment means were statistically significantly different ($p < 0.05$) at Chuka and Embu (Appendix 17). The blocks were significant different ($p < 0.05$) at Chuka and Embu (Appendix 17). There was significantly interaction ($p < 0.05$) between the two sites (Appendix 19). At Chuka, treatment K_4 had the highest bulb dry weight mean of 15.963 gm while K_0 treatment had lowest bulb dry weight mean of 7.270 gm. K_4 treatment which recorded the highest mean bulb dry weight was 119.57 percent higher over the control (Table 13). Similar to Chuka, at Embu, treatment K_4 had the highest bulb dry weight mean of 11.296 gm while K_0 treatment had the lowest bulb dry weigh mean of 7.036 gm. K_4 treatment which recorded the highest bulb dry weight mean was 60.54 percent higher over the control (Table 13).

The results of bulb yield per hectare showed that the treatment and block means were statistically significantly different ($p < 0.05$) at Chuka while at Embu treatment and block means were not statistically significant (Appendix 17). There was significantly interaction ($p < 0.05$) between the two sites (Appendix 19). At Chuka, treatment K_4 had the highest mean bulb yield per hectare of 4084.24 Kg ha^{-1} while K_0 treatment had lowest mean bulb yield per hectare of 1945.95 Kg ha^{-1}. K_4 treatment which recorded the highest mean bulb yield per hectare was 109.88 percent higher over the control treatment (Table 11). Similar to Chuka, at Embu, treatment K_4 had the highest mean bulb yield per hectare of 2842.58 Kg ha^{-1} while K_0 treatment had the lowest mean bulb yield per hectare of 1762.37 Kg ha^{-1}. K_4 treatment which recorded the highest bulb yield per hectare mean was 61.29 percent higher over the control treatment (Table 11).

Number of cloves of harvested garlic bulbs was significantly influenced due to effect of goat manure-based vermicompost at Chuka and Embu respectively. The results indicated a general trend increase in mean number of cloves per bulb in response to increase in goat manure-based vermicompost application rates from 0 t ha^{-1} to 30 t ha^{-1} in both sites. Higher mean bulb length was recorded in 30 t ha^{-1} treatment compared to the control but there was no statistical difference with 20 t ha^{-1} treatment at Chuka and Embu sites. This is in contrast with control treatment, 5 t ha^{-1} of goat manure-based vermicompost treatment, NPK treatment and goat manure treatment that produced the lowest mean bulb length.

Goat manure-based vermicompost is a nutritive organic fertilizer rich in macronutrients, mycorrhizae fungi and beneficial soil microbes. The enzymes in goat manure-based vermicompost like amylase, lipase, cellulose and chitinase continued to breakdown organic matter in the soil to release the various nutrients and made it available to the garlic plant roots hence promoted sink size in terms of bulb size (Rekha *et al.,* 2018). Also, the enhanced bulb length in 30 t ha^{-1} treatment might be due to goat manure-based vermicompost that increased the budget of essential soil micronutrients and promoted microbial population which promoted the plant growth and also production at sustainable basis (Degwale, 2016).

Similar to these results, Kenea and Gedamu (2017) reported that vermicompost application showed significantly increased garlic cloves number per bulb over the control. Golmohammadzadeh *et al.* (2015) reported higher number of bulblets per garlic plant was recorded in vermicompost treatment. The effects of vermicompost showed significant difference on mean clove number (Degwale 2016). Also Kumar *et al.* (2019) made similar findings.

Different rates of application of goat manure-based vermicompost had significant influence on mean bulb dry weight of harvested garlic bulbs in both sites. The results showed a general trend increase in mean bulb dry weight in response to increase in goat manure-based vermicompost application rates from 0 t ha^{-1} to 30 t ha^{-1} with the highest mean bulb dry weight being recorded in 30 t ha^{-1} treatment compared to the control. The application of 30 t ha^{-1} which recorded the highest mean bulb dry weight clearly showed that there was no statistical difference with 10 t ha^{-1} and 20 t ha^{-1} treatments at Chuka and Embu sites. This was in contrast with the control treatment, 5 t ha^{-1} of goat manure-based vermicompost treatment, NPK treatment and goat manure treatment produced the recorded the lowest mean bulb dry weight.

This enhanced bulb dry weight in treatment 30 t ha^{-1} could be due to the role of goat manure-based vermicompost which contains macronutrients nitrogen, phosphorous and potassium. Hence, this enhanced nutrient supply that facilitated better plant growth which resulted in increased garlic yield that translated to more bulb dry weight. The other probable reason for increased weight of bulb was due to humus substances that mobilized the reserve food materials to the plant through increased activity of hydrolyzing and oxidizing enzymes (Patidar *et al.,* 2019). Vermicompost contains several plant growth promoters, enzymes, beneficial bacteria and mycorrhizae (Degwale, 2016) thus better plant growth and more garlic yields.

Similar to these results, Kumar *et al.* (2019) reported maximum average dry weight of garlic bulb in vermicompost treated plots. Patidar *et al.* (2019) reported significantly maximum bulb weight of bulb was exhibited in the treatment with vermicompost whereas the minimum weight of bulb was observed in absolute control. In other studies, Degwale *et al.* (2016) reported that application of vermicompost increased mean bulb weight as compared to the control treatments.

The yield of any crop is the final index of the experiment which indicates the success or failure of any treatment. With this view the bulb yield of garlic per hectare was recorded. The results revealed that bulb yield per hectare of harvested garlic bulbs was significantly influenced due to effect of goat manure-based vermicompost at Chuka and Embu respectively. The results indicated a general trend increase in mean bulb yield per hectare in response to increase in goat manure-based vermicompost application rates from 0 t ha^{-1} to 30 t ha^{-1} in both sites. The results of this experiment showed that there was no statistical difference with 10 t ha^{-1} and 20 t ha^{-1} treatments at Chuka and Embu sites. This was in contrast with control treatment, 5 t ha^{-1} of goat manure-based vermicompost treatment, NPK treatment and goat manure treatment produced the lowest mean bulb yield per plot. These results clearly demonstrated and affirmed of the need to use organic manures over chemical fertilizers in garlic farming.

There was enhanced bulb yield in plots which had treatment of 30 t ha^{-1}. This can be accounted due to availability of optimum nutrients contained in goat manure-based vermicompost that may have led to high leaf index through improved leaf growth and photosynthesis. Maximum vegetative growth of garlic enhances maximum photosynthesis and accumulation of more dry matter. Carbohydrate accumulation resulted into increased size of garlic bulbs as indicated by bulb diameter, number of cloves per bulb and bulb weight hence enhanced the overall yield of garlic. During the processing of the various organic wastes by earthworms, many of the nutrients it contains are converted to forms that are more readily taken by plants such as nitrate, exchangeable phosphorous, soluble potassium, calcium and magnesium (Degwale, 2016).

Similar to these results, Albolmaaty and Fawaz (2016) in their study reported that the most effective treatment in increasing bulb yield was vermicompost hence there was a proportional increase of onion bulb yield with vermicompost concentration. Patidar *et al.* (2019) reported that vermicompost treatment recorded the maximum total bulb yield and the lowest total bulb yield was recorded in control treatment. Kumar *et al.* (2019) and Degwale (2016) reported marketable yield of garlic was increased by with increased application rates of vermicompost.

The enhanced bulb yields obtained from each plot with the highest rate of goat manure-based vermicompost resulted into enhanced bulb yield per hectare. This can be attributed to the fact that higher rates of application of goat manure-based vermicompost contributed to increased plant height, number of leaves and yield attributes like bulb fresh weight, number of cloves per bulb, bulb length and bulb diameter. This is due to the higher availability of the nutrients in readily available form in goat manure-based vermicompost and also the C: N was high over control.

The results of the present study are similar to the findings of Patidar *et al.* (2019) who reported in their research study findings that highest total bulb yield of onion was recorded in vermicompost treatment and the lowest total bulb yield was recorded in control treatment. Kumar *et al.* (2019) reported maximum garlic bulb yield per hectare was recorded in treatment with vermicompost hence these results revealed that vermicompost application increased micro nutrients in the soil and supply to the plant increasing with the result.

Ali and Kashem (2018) and Mbithi *et al.* (2015) reported in their studies that highest yields were obtained from the crop which was planted in treatment that had vermicompost application even though they used different crops other than the garlic plant. Hence, the results of these previous studies are in agreement with the findings of this study.

CHAPTER FIVE

SUMMARY OF FINDING, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

The present study reveals that application of goat manure-based vermicompost is of greater importance in organic garlic production. All soil chemical properties, growth and yield traits of garlic were significantly influenced by different rates of application of goat manure-based vermicompost. This is attributed to enhanced significant higher soil pH, total nitrogen, available phosphorous and exchangeable potassium on the soils of the study area. There was significant higher plant height, number of leaves, stem diameter, leaf length and leaf width on garlic growth characteristics. Also, significant higher bulb fresh weight, bulb diameter, bulb length, bulb dry weight, number of cloves per bulb, bulb yield per plot and bulb yield per hectare on garlic yield and yield components were recorded during the study.

On soil chemical properties, significant higher soil pH (8.00) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least soil pH (6.58) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant total nitrogen (0.606%) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rates and least total nitrogen (0.043%) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant available phosphorous (21.933 ppm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rates and least available phosphorous (4.670 ppm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant exchangeable potassium (0.863 Cmol Kg^{-1}) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least exchangeable potassium (0.456 Cmol Kg^{-1}) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate at Chuka.

At Embu, significant higher soil pH (7.91) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least soil pH (6.54) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant total nitrogen (0.563%) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least total nitrogen (0.030%) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant available phosphorous (21.053

ppm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least available phosphorous (4.596 ppm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant exchangeable potassium (0.710 Cmol Kg^{-1}) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least exchangeable potassium (0.343 Cmol Kg^{-1}) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate.

On growth parameters, significant higher plant height (41.809 cm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and smallest plant height (24.533 cm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant number of leaves (10.365) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least number of leaves (4.031) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant stem diameter (0.863 cm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and smallest stem diameter (0.343 cm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant leaf length (31.485 cm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least leaf length (15.484 cm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant leaf width (1.557 cm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least leaf width (0.565 cm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate at Chuka.

At Embu, significant higher plant height (41.614 cm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and smallest plant height (14.071 cm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant number of leaves (12.333) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least number of leaves (4.269) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant stem diameter (1.241 cm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and smallest stem diameter (0.317 cm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant leaf length (27.823 cm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least leaf length (10.146 cm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant leaf width (1.817 cm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least leaf width (0.631 cm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate.

On garlic bulb yield attributes, significant higher bulb fresh weight (18.190 gm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and lowest bulb fresh weight (8.516 gm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant bulb diameter (3.928 cm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least bulb diameter (2.971 cm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant bulb length (3.043 cm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least bulb length (2.363 cm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate at Chuka.

At Embu, significant higher bulb fresh weight (12.660 gm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and lowest bulb fresh weight (7.823 gm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant bulb diameter (3.503 cm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least bulb diameter (2.905 cm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant bulb length (2.846 cm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least bulb length (2.390 cm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate.

On garlic bulb yield components and yield, higher significant number of cloves per bulb (7.466) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least number of cloves per bulb (4.800) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant bulb dry weight (15.963 gm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and lowest bulb dry weight (7.270 gm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant bulb yield per hectare (4084.24 Kg ha^{-1}) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and lowest bulb yield per hectare (1945.95 Kg ha^{-1}) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate at Chuka.

At Embu, higher significant number of cloves per bulb (5.900) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and least number of cloves per bulb (4.566) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant bulb dry weight (11.296 gm) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and lowest bulb dry weight (7.036 gm) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate. Higher significant bulb yield per hectare (2842.58 Kg ha^{-1}) was recorded in 30 t ha^{-1} goat manure-based vermicompost application rate and lowest bulb yield per hectare (1762.37 Kg ha^{-1}) was recorded in 0 t ha^{-1} goat manure-based vermicompost application rate.

5.2 Conclusion

Amending soils with goat manure-based vermicompost enhances improved soil chemical properties, vegetative growth and yield traits of garlic. The highest rate of application of 30 t ha^{-1} proved the best in enhancing soil chemical properties in the study area. The higher application rate of goat manure-based vermicompost increased soil pH, total nitrogen, available phosphorous and exchangeable potassium as recorded at the end of the growing season in the study area. Increased soil pH helps to prevent immobilization of certain macronutrients at low pH hence they are availed in the soil for better plant uptake by garlic plants. An improved level of nitrogen, phosphorous and potassium in the soil by addition of goat manure-based vermicompost is important in enhancing better garlic plant growth and development.

The chemical analysis of goat manure-based vermicompost results showed that it contained higher levels of macronutrients nitrogen, phosphorous and potassium. Hence, if prepared well and applied using the appropriate rates it can sustain higher garlic plant growth by providing the macronutrients nitrogen, phosphorous and potassium. Goat manure-based vermicompost is a better organic fertilizer in comparison to the chemical fertilizer used and goat manure in garlic production based on the results obtained. Thus, the results of this experiment revealed that its application in garlic farming increases uptake of nutrients by plants which leads to faster physiological development and this promotes growth and yield of garlic.

Goat manure-based vermicompost has a more varied chemical composition than the chemical fertilizer applied (NPK) during the study. Even though the chemical fertilizer quickly releases mineral elements, the results that were obtained from this experiment proved that goat manure-based vermicompost used in this particular study releases nutrients slowly into the soil over time. This was exhibited by significantly higher growth parameters and also soil parameters that were recorded towards the end of the growing season in the study area in the vermicompost treated plots.

The results recorded showed that application of higher rates of goat manure-based vermicompost increased garlic growth characteristics in the study area at the end of the growing season. This was in terms of plant height, number of leaves per plant, stem diameter, leaf length and leaf width of the garlic plants. It can be argued that the application of goat manure-based vermicompost does not result in the immobilization of plant available nutrients in comparison to the chemical fertilizer applied during the study. Hence there was better nutrient uptake, more photosynthesis and formation of photosynthates which enhanced vegetative growth of garlic plants in the study area.

Based on the third objective of this study, the results of the study showed that application of higher rates of goat manure-based vermicompost increased significantly garlic yield components and yield. Higher bulb fresh weight, bulb diameter, bulb length, number of cloves per bulb, bulb dry weight, bulb yield obtained in each plot and total yield of bulbs per hectare was recorded in 30 t ha^{-1} treatment. This can be attributed to more nutrient availability in goat manure-based vermicompost that contributed to better garlic plant growth and development that translated to enhanced garlic yields in the study area.

The soil analysis report of the experimental sites before planting revealed that the soils of the study area have low inherent soil fertility in terms of nitrogen, phosphorous and potassium. Hence, there is need to supply organic manures like goat manure-based vermicompost to enhance soil fertility for improved garlic productivity. The soil analysis report also confirmed that the soil pH of the sites is within the ranges of 6.5 – 7.0 that is optimum for garlic production.

Therefore, the application of goat manure-based vermicompost in the soil improves nutrient availability and it can also improve the physical condition of the soil. Goat manure-based vermicompost proved to be of benefit even when only a small portion was applied to garlic plants in the study area compared to the total amount of chemical fertilizer which was supplied to the soil. Hence, there is need to shift to a more sustainable organically production system to increase soil fertility and also maintain garlic crop yield at levels comparable to those of chemically fertilized garlic. Thus, application of 30 t ha^{-1} goat manure-based vermicompost is an efficient quality yield and economy enhancer in organic garlic production for sustainable agriculture.

5.3 Recommendations

The current study puts forward the following two recommendations:

i. Farmer education on preparation and utilization of goat manure-based vermicompost since there is scanty of scientific knowledge in the Eastern region of Kenya. This information will enable the farmers to be able to utilize this organic fertilizer that is a cheaper alternative on sustainable basis.

ii. The study recommends that for optimum garlic productivity, there is need to use the recommended application rates of goat manure-based vermicompost in the organic production of garlic.

5.4 Suggested Further Research

More research to be carried on:

i. Different rates of goat manure-based vermicompost under different soils types. This is to come up with specific rates suitable for the different soils types.

ii. Different rates of goat manure-based vermicompost on various soil micronutrients in upper Eastern Kenya. This will bring an understanding on the effect of goat manure-based vermicompost on availability of various micronutrients in soils.

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APPENDICES

Appendix 1: Chuka ethical committee clearance letter

CHUKA UNIVERSITY

Telephones: 020 2310512
020 2310518

P.O. Box 109
Chuka

CHUKA UNIVERSITY

OFFICE OF THE CHAIRMAN
INSTITUTIONAL ETHICS REVIEW COMMITTEE

Our Ref: CU/IERC/NCST/18/6 6th March, 2018

THE CHIEF EXECUTIVE OFFICER
NATIONAL COMMISION FOR SCIENCE, TECHNOLOGY AND INNOVATION
P.O. BOX 30623-00100
NAIROBI

Dear Sir/Madam,

RE: RESEARCH CLEARANCE AND AUTHORIZATION FOR VINCENT MAKINI GICHABA. REG NO NM17/22615/16

The above matter refers:

The Institutional Ethics Review Committee of Chuka University met and reviewed the above MSC Research Proposal titled **Effect of Goat Manure based Vermicompost on Soil Chemical Properties, Growth and Yield of Garlic (*Allium sativum L.*)** The Supervisors are **Dr. Moses Muraya and Dr. Haggai O. Ndukhu**

The committee recommended that after candidate amends the issues highlighted in the Attached research clearance and authorization check list, the permit be issued.

Attached please find copies of the minutes, research clearance and authorization check list for your perusal. Kindly assist the student get the research permit.

Yours faithfully,

Prof. Adiel Magana
CHAIR
INSTITUTIONAL ETHICS REVIEW COMMITTEE
cc: BPGS

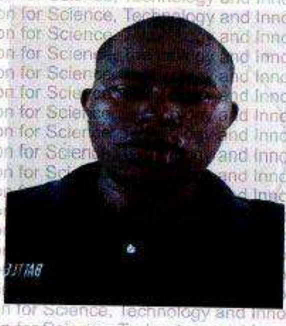
Appendix 2: NACOSTI research permit

THIS IS TO CERTIFY THAT:
MR. VINCENT MAKINI GICHABA
of CHUKA UNIVERSITY, 569-60400
CHUKA,has been permitted to conduct
research in *Tharaka-Nithi County*

on the topic: *EFFECT OF GOAT MANURE BASED VERMICOMPOST ON SOIL CHEMICAL PROPERTIES,GROWTH AND YIELD OF GARLIC (ALLIUM SATIVUM L.)IN MERU SOUTH SUB-COUNTY,KENYA*

for the period ending:
13th September,2019

Permit No : NACOSTI/P/18/47369/24839
Date Of Issue : 15th September,2018
Fee Recieved :Ksh 1000



....
Applicant's Signature

....
Director General
National Commission for Science, Technology & Innovation

Appendix 3: NACOSTI research authorization

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

Telephone:+254-20-2213471,
2241349,3310571,2219420
Fax:+254-20-318245,318249
Email: dg@nacosti.go.ke
Website : www.nacosti.go.ke
When replying please quote

NACOSTI, Upper Kabete
Off Waiyaki Way
P.O. Box 30623-00100
NAIROBI-KENYA

Ref: No. **NACOSTI/P/18/47369/24839**

Date: **15th September, 2018**

Vincent Makini Gichaba
Chuka University,
P. O. Box 109-60400
CHUKA.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Effect of goat manure based vermicompost on soil chemical properties, growth and yield of garlic (Allium Sativum L.)in Meru South Sub-County, Kenya"*** I am pleased to inform you that you have been authorized to undertake research in **Tharaka Nithi County** for the period ending **13th September, 2019.**

You are advised to report to **the County Commissioner and the County Director of Education, Tharaka Nithi County** before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

BONIFACE WANYAMA
FOR: DIRECTOR-GENERAL/CEO

COUNTY COMMISSIONER RECEIVED 27 SEP 2018 THARAKA NITHI COUNTY

Copy to:

The County Commissioner
Tharaka Nithi County.

The County Director of Education
Tharaka Nithi County.

Appendix 4: Analysis of variance for effect of treatments on various soil elements at Chuka and Embu

Site	Variable	Source	DF	SS	MS	F	Pr > F
Chuka	pH	Block	2	0.10440952	0.05220476	2.03	0.1734
		Treatment	6	4.34862857	0.72477143	28.25	<.0001
	N	Block	2	0.00735238	0.00367619	3.25	0.0746
		Treatment	6	0.59659048	0.09943175	87.86	<.0001
	P	Block	2	14.0166952	7.0083476	6.01	0.0155
		Treatment	6	775.6741238	129.2790206	110.91	<.0001
	K	Block	2	0.00172381	0.00086190	0.09	0.9165
		Treatment	6	0.39900000	0.06650000	6.78	0.0025
Embu	pH	Block	2	0.03615238	0.01807619	0.58	0.5740
		Treatment	6	3.92264762	0.65377460	21.03	<.0001
	N	Block	2	0.00925714	0.00462857	7.05	0.0094
		Treatment	6	0.53812381	0.08968730	136.65	<.0001
	P	Block	2	17.0609238	8.5304619	7.39	0.0081
		Treatment	6	710.1403238	118.3567206	102.50	<.0001
	K	Block	2	0.00111429	0.00055714	0.09	0.9174
		Treatment	6	0.33596190	0.05599365	8.73	0.0008

Appendix 5: Combined analysis of variance for effect of treatments on various soil elements at Chuka and Embu

Variable	Source	DF	SS	MS	F	Pr > F
pH	Block	2	0.12232857	0.06116429	2.27	0.1229
	Treatment	13	8.37231429	0.64402418	23.95	<.0001
	Site					
N	Block	2	0.01653333	0.00826667	9.98	0.0006
	Treatment	13	1.14043095	0.08772546	105.92	<.0001
	Site					
P	Block	2	30.922300	15.461150	14.36	<.0001
	Treatment	13	1487.786114	114.445086	106.27	<.0001
	Site					
K	Block	2	0.00280476	0.00140238	0.19	0.8303
	Treatment	13	0.79591429	0.06122418	8.17	<.0001
	Site					

Appendix 6: Analysis of variance for effect of treatments on plant height at Chuka and Embu

Site	Variable	Source	DF	SS	MS	F	Pr > F
Chuka	30 DAE	Block	2	122.168889	61.084444	2.61	0.0749
		Treatment	6	2406.701814	401.116969	17.12	<.0001
	44 DAE	Block	2	55.721134	27.860567	1.20	0.3009
		Treatment	6	2676.218685	446.036447	19.28	<.0001
	58 DAE	Block	2	185.083039	92.541519	3.06	0.0479
		Treatment	6	3311.445034	551.907506	18.25	<.0001
	72 DAE	Block	2	310.429524	155.214762	3.91	0.0208
		Treatment	6	4521.699002	753.616500	18.97	<.0001
	86 DAE	Block	2	235.197596	117.598798	3.01	0.0503
		Treatment	6	5353.964036	892.327339	22.85	<.0001
Embu	30 DAE	Block	2	973.23469	486.61735	13.56	<.0001
		Treatment	6	19903.03061	3317.17177	92.42	<.0001
	44 DAE	Block	2	926.33977	463.16989	13.92	<.0001
		Treatment	6	22485.93347	3747.65558	112.63	<.0001
	58 DAE	Block	2	858.35810	429.17905	13.52	<.0001
		Treatment	6	24999.03900	4166.50650	131.27	<.0001
	72 DAE	Block	2	758.21501	379.10751	12.47	<.0001
		Treatment	6	27833.17043	4638.86174	152.61	<.0001
	86 DAE	Block	2	505.07515	252.53757	8.94	0.0002
		Treatment	6	31582.40372	5263.73395	186.41	<.0001

Appendix 7: Analysis of variance for effect of treatments on number of leaves at Chuka and Embu

Site	Variable	Source	DF	SS	MS	F	Pr > F
Chuka	30 DAE	Block	2	0.3038549	0.1519274	0.13	0.8748
		Treatment	6	106.1859410	17.6976568	15.58	<.0001
	44 DAE	Block	2	4.4217687	2.2108844	2.09	0.1253
		Treatment	6	171.9365079	28.6560847	27.05	<.0001
	58 DAE	Block	2	6.4625850	3.2312925	2.99	0.0513
		Treatment	6	196.8390023	32.8065004	30.35	<.0001
	72 DAE	Block	2	8.8571429	4.4285714	3.82	0.0226
		Treatment	6	201.5192744	33.5865457	28.98	<.0001
	86 DAE	Block	2	3.4331066	1.7165533	1.59	0.2059
		Treatment	6	246.6938776	41.1156463	38.00	<.0001
Embu	30 DAE	Block	2	146.3582766	73.1791383	59.55	<.0001
		Treatment	6	361.0158730	60.1693122	48.97	<.0001
	44 DAE	Block	2	133.5646259	66.7823129	59.99	<.0001
		Treatment	6	586.8707483	97.8117914	87.86	<.0001
	58 DAE	Block	2	145.6099773	72.8049887	65.88	<.0001
		Treatment	6	702.3310658	117.0551776	105.92	<.0001
	72 DAE	Block	2	135.6780045	67.8390023	64.23	<.0001
		Treatment	6	736.7437642	122.7906274	116.25	<.0001
	86 DAE	Block	2	101.2426304	50.6213152	40.31	<.0001
		Treatment	6	787.7369615	131.2894936	104.54	<.0001

Appendix 8: Analysis of variance for effect of treatments on stem diameter at Chuka and Embu

Site	Variable	Source	DF	SS	MS	F	Pr > F
Chuka	30 DAE	Block	2	0.14684626	0.07342313	5.94	0.0029
		Treatment	6	1.77715828	0.29619305	23.96	<.0001
	44 DAE	Block	2	0.01122041	0.00561020	0.49	0.6115
		Treatment	6	1.48242041	0.24707007	21.68	<.0001
	58 DAE	Block	2	0.00510794	0.00255397	0.18	0.8326
		Treatment	6	1.51661587	0.25276931	18.14	<.0001
	72 DAE	Block	2	0.09975692	0.04987846	2.84	0.0595
		Treatment	6	1.92928798	0.32154800	18.31	<.0001
	86 DAE	Block	2	0.21597596	0.10798798	5.45	0.0046
		Treatment	6	3.43801179	0.57300197	28.91	<.0001
Embu	30 DAE	Block	2	0.96837959	0.48418980	35.02	<.0001
		Treatment	6	4.58566259	0.76427710	55.27	<.0001
	44 DAE	Block	2	0.90275556	0.45137778	30.49	<.0001
		Treatment	6	9.36534921	1.56089153	105.42	<.0001
	58 DAE	Block	2	0.64837324	0.32418662	19.26	<.0001
		Treatment	6	15.43762449	2.57293741	152.88	<.0001
	72 DAE	Block	2	0.60574195	0.30287098	12.10	<.0001
		Treatment	6	24.44748571	4.07458095	162.81	<.0001
	86 DAE	Block	2	1.23490113	0.61745057	14.00	<.0001
		Treatment	6	40.00479002	6.66746500	151.15	<.0001

Appendix 9: Analysis of variance for effect of treatments on leaf length at Chuka and Embu

Site	Variable	Source	DF	SS	MS	F	Pr > F
Chuka	30 DAE	Block	2	66.237324	33.118662	2.19	0.1129
		Treatment	6	3423.504263	570.584044	37.77	<.0001
	44 DAE	Block	2	25.153878	12.576939	0.58	0.5586
		Treatment	6	3923.666621	653.944437	30.32	<.0001
	58 DAE	Block	2	29.143175	14.571587	0.58	0.5619
		Treatment	6	4146.499909	691.083318	27.38	<.0001
	72 DAE	Block	2	148.955147	74.477574	1.65	0.1927
		Treatment	6	2837.987846	472.997974	10.50	<.0001
	86 DAE	Block	2	2.827256	1.413628	0.06	0.9404
		Treatment	6	4642.697687	773.782948	33.66	<.0001
Embu	30 DAE	Block	2	1091.00481	545.50240	34.47	<.0001
		Treatment	6	11971.76522	1995.29420	126.08	<.0001
	44 DAE	Block	2	905.20694	452.60347	31.37	<.0001
		Treatment	6	12554.04426	2092.34071	145.00	<.0001
	58 DAE	Block	2	848.10054	424.05027	30.99	<.0001
		Treatment	6	13496.59678	2249.43280	164.40	<.0001
	72 DAE	Block	2	850.33728	425.16864	30.62	<.0001
		Treatment	6	14388.45429	2398.07571	172.71	<.0001
	86 DAE	Block	2	855.66095	427.83048	31.11	<.0001
		Treatment	6	15338.47855	2556.41309	185.90	<.0001

Appendix 10: Analysis of variance for effect of treatments on leaf width at Chuka and Embu

Site	Variable	Source	DF	SS	MS	F	Pr > F
Chuka	30 DAE	Block	2	0.93882086	0.46941043	18.71	<.0001
		Treatment	6	6.89641723	1.14940287	45.82	<.0001
	44 DAE	Block	2	0.36340136	0.18170068	4.11	0.0171
		Treatment	6	9.17664399	1.52944067	34.58	<.0001
	58 DAE	Block	2	0.51591837	0.25795918	5.03	0.0069
		Treatment	6	10.44126984	1.74021164	33.92	<.0001
	72 DAE	Block	2	0.56217687	0.28108844	5.47	0.0045
		Treatment	6	12.07492063	2.01248677	39.16	<.0001
	86 DAE	Block	2	0.67034014	0.33517007	6.70	0.0014
		Treatment	6	14.62553288	2.43758881	48.70	<.0001
Embu	30 DAE	Block	2	0.82653061	0.41326531	17.28	<.0001
		Treatment	6	9.91392290	1.65232048	69.10	<.0001
	44 DAE	Block	2	1.19510204	0.59755102	29.76	<.0001
		Treatment	6	14.19836735	2.36639456	105.96	<.0001
	58 DAE	Block	2	1.66317460	0.83158730	33.97	<.0001
		Treatment	6	17.10403628	2.85067271	116.45	<.0001
	72 DAE	Block	2	1.33664399	0.66832200	25.96	<.0001
		Treatment	6	18.86222222	3.14370370	122.09	<.0001
	86 DAE	Block	2	0.96725624	0.48362812	18.37	<.0001
		Treatment	6	18.75727891	3.12621315	118.76	<.0001

Appendix 11: Combined analysis of variance for effect of treatments on plant height

Variable	Source	DF	SS	MS	F	Pr > F
30 DAE	Block	2	806.833764	403.416882	13.48	<.0001
	Treatment Site	7	7957.542698	1136.791814	37.99	<.0001
44 DAE	Block	2	569.641429	284.820714	9.95	<.0001
	Treatment Site	7	9169.045476	1309.863639	45.77	<.0001
58 DAE	Block	2	671.63948	335.81974	10.71	<.0001
	Treatment Site	7	11063.59857	1580.51408	50.42	<.0001
72 DAE	Block	2	547.64254	273.82127	7.69	0.0005
	Treatment Site	7	13714.68040	1959.24006	55.06	<.0001
86 DAE	Block	2	399.59190	199.79595	5.88	0.0029
	Treatment Site	7	12093.07484	1727.58212	50.87	<.0001

Appendix 12: Combined analysis of variance for effect of treatments on number of leaves

Variable	Source	DF	SS	MS	F	Pr > F
30 DAE	Block	2	74.4920635	37.2460317	29.49	<.0001
	Treatment Site	7	171.8492063	24.5498866	19.44	<.0001
44 DAE	Block	2	93.1088435	46.5544218	41.00	<.0001
	Treatment Site	7	229.0634921	32.7233560	28.82	<.0001
58 DAE	Block	2	104.9138322	52.4569161	45.82	<.0001
	Treatment Site	7	270.8492063	38.6927438	33.80	<.0001
72 DAE	Block	2	106.8049887	53.4024943	46.50	<.0001
	Treatment Site	7	388.5238095	55.5034014	48.33	<.0001
86 DAE	Block	2	70.0022676	35.0011338	29.02	<.0001
	Treatment Site	7	492.3650794	70.3378685	58.31	<.0001

Appendix 13: Combined analysis of variance for effect of treatments on stem diameter

Variable	Source	DF	SS	MS	F	Pr > F
30 DAE	Block	2	0.83566599	0.41783299	31.21	<.0001
	Treatment Site	7	0.97873968	0.13981995	10.44	<.0001
44 DAE	Block	2	0.46592404	0.23296202	17.14	<.0001
	Treatment Site	7	2.42468254	0.34638322	25.49	<.0001
58 DAE	Block	2	0.37140680	0.18570340	11.85	<.0001
	Treatment Site	7	4.29178810	0.61311259	39.12	<.0001
72 DAE	Block	2	0.59826825	0.29913413	14.00	<.0001
	Treatment Site	7	7.15864683	1.02266383	47.86	<.0001
86 DAE	Block	2	1.24182948	0.62091474	19.32	<.0001
	Treatment Site	7	11.97581429	1.71083061	53.24	<.0001

Appendix 14: Combined analysis of variance for effect of treatments on leaf length

Variable	**Source**	**DF**	**SS**	**MS**	**F**	**Pr > F**
30 DAE	Block	2	376.722925	188.361463	11.53	<.0001
	Treatment Site	7	3895.960794	556.565828	34.08	<.0001
44 DAE	Block	2	378.518571	189.259286	10.18	<.0001
	Treatment Site	7	6977.138175	996.734025	53.60	<.0001
58 DAE	Block	2	300.633220	150.316610	7.48	0.0006
	Treatment Site	7	8283.146111	1183.306587	58.92	<.0001
72 DAE	Block	2	296.75404	148.37702	4.91	0.0076
	Treatment Site	7	11888.28778	1698.32683	56.20	<.0001
86 DAE	Block	2	395.66955	197.83477	10.49	<.0001
	Treatment Site	7	13364.67151	1909.23879	101.21	<.0001

Appendix 15: Combined analysis of variance for effect of treatments on leaf width

Variable	**Source**	**DF**	**SS**	**MS**	**F**	**Pr > F**
30 DAE	Block	2	0.20002268	0.10001134	3.81	0.0225
	Treatment Site	7	0.94317460	0.13473923	5.13	<.0001
44 DAE	Block	2	0.68210884	0.34105442	9.97	<.0001
	Treatment Site	7	23.81950113	1.83226932	53.55	<.0001
58 DAE	Block	2	0.88519274	0.44259637	11.26	<.0001
	Treatment Site	7	4.00412698	0.57201814	14.56	<.0001
72 DAE	Block	2	0.42696145	0.21348073	5.31	0.0051
	Treatment Site	7	6.77523810	0.96789116	24.09	<.0001
86 DAE	Block	2	0.37553288	0.18776644	4.75	0.0089
	Treatment Site	7	8.43563492	1.20509070	30.46	<.0001

Appendix 16: Analysis of variance for effect of treatments on garlic bulb yield attributes at Chuka and Embu

Site	Variable	Source	DF	SS	MS	F	Pr > F
Chuka	Fresh weight	Block	2	367.546952	183.773476	9.73	<.0001
		Treatment	6	2700.136476	450.022746	23.84	<.0001
	Diameter	Block	2	3.62426000	1.81213000	9.92	<.0001
		Treatment	6	26.34741905	4.39123651	24.04	<.0001
	Length	Block	2	2.03609524	1.01804762	10.69	<.0001
		Treatment	6	12.69133333	2.11522222	22.22	<.0001
Embu	Fresh weight	Block	2	156.7120952	78.3560476	5.63	0.0042
		Treatment	6	639.8278095	106.6379683	7.66	<.0001
	Diameter	Block	2	1.85357429	0.92678714	4.90	0.0084
		Treatment	6	9.36892952	1.56148825	8.25	<.0001
	Length	Block	2	1.01552381	0.50776190	4.42	0.0132
		Treatment	6	4.48333333	0.74722222	6.51	<.0001

Appendix 17: Analysis of variance for effect of treatments on garlic bulb yield components and yield at Chuka and Embu

Site	Variable	Source	DF	SS	MS	F	Pr > F
Chuka	Number of cloves	Block	2	25.7238095	12.8619048	2.96	0.0539
		Treatment	6	155.3238095	25.8873016	5.96	<.0001
	Dry weight	Block	2	169.656381	84.828190	5.63	0.0042
		Treatment	6	1979.479238	329.913206	21.91	<.0001
	Yield $hectare^{-1}$	Block	2	1797446.81	898723.40	4.23	0.0406
		Treatment	6	13369814.19	2228302.37	10.50	0.0004
Embu	Number of cloves	Block	2	8.29523810	4.14761905	1.69	0.1875
		Treatment	6	35.11428571	5.85238095	2.38	0.0303
	Dry weight	Block	2	115.8720952	57.9360476	5.34	0.0055
		Treatment	6	457.5925714	76.2654286	7.03	<.0001
	Yield $hectare^{-1}$	Block	2	765993.258	382996.629	1.98	0.1809
		Treatment	6	3092034.017	515339.003	2.66	0.0703

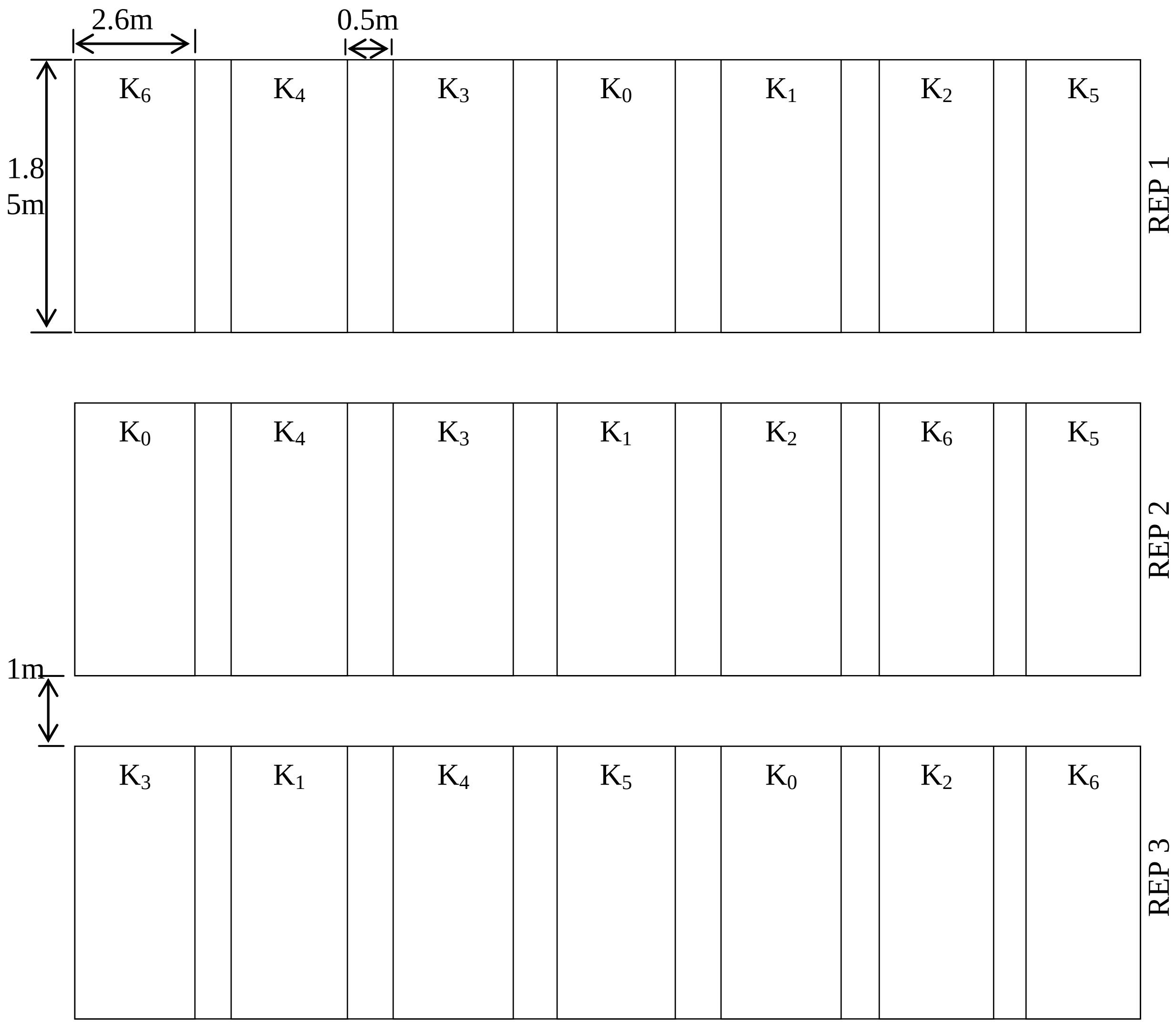
Appendix 18: Combined analysis of variance for effect of treatments on garlic bulb yield attributes

Variable	**Source**	**DF**	**SS**	**MS**	**F**	**Pr > F**
Fresh weight	Block	2	414.081000	207.040500	12.48	<.0001
	Treatment Site	13	4741.382952	364.721766	21.98	<.0001
Diameter	Block	2	5.03421857	2.51710929	13.52	<.0001
	Treatment Site	13	49.01295071	3.77022698	20.26	<.0001
Length	Block	2	2.48919048	1.24459524	11.75	<.0001
	Treatment Site	13	18.22466667	1.40189744	13.24	<.0001

Appendix 19: Combined analysis of variance for effect of treatments on garlic bulb yield components and yield

Variable	Source	DF	SS	MS	F	Pr > F
Number of cloves	Block	2	31.6000000	15.8000000	4.66	0.0099
	Treatment Site	13	236.4404762	18.1877289	5.37	<.0001
Dry weight	Block	2	225.258333	112.629167	8.64	0.0002
	Treatment Site	13	3306.256667	254.327436	19.50	<.0001
Yield hectare^{-1}	Block	2	2118237.33	1059118.66	5.18	0.0128
	Treatment Site	13	23806544.27	1831272.64	8.96	<.0001

Appendix 20: Experimental plot layout after randomization



KEY

K_0 – 0 t ha^{-1}; K_1 – 5 t ha^{-1}; K_2 – 10 t ha^{-1}; K_3 – 20 t ha^{-1}; K_4 – 30 t ha^{-1}; K_5 – N-P-K (200 kg ha^{-1}) and K_6 – Goat manure (30 t ha^{-1}).

Appendix 21: Monthly rainfall and average temperature of Meru south and Manyatta sub-counties during 2018 – 2019 seasons

Site	Months	Monthly Rainfall (mm)	Average Temp (^oC)
Chuka	March 2018	0.4	22.5
	April 2018	164	21.4
	May 2018	105	19.6
	June 2018	62.5	19.8
	July 2018	0.0	18.1
	August 2018	5.8	18.3
	September 2018	0.2	19.4
	October 2018	0.4	21.7
	November 2018	209.5	19.9
	December 2018	35.6	21.6
	January 2019	0.0	21.5
	February 2019	21.5	21.8
Embu	March 2018	87	22.7
	April 2018	268	21.3
	May 2018	45	19.8
	June 2018	8	18.9
	July 2018	3	18.1
	August 2018	3	18.6
	September 2018	11	18.7
	October 2018	81	21.2
	November 2018	221	19.5
	December 2018	68	19.3
	January 2019	6	20.1
	February 2019	31	20.6

Source: Kenya meteorological department (KMD) stations in Tharaka Nithi and Embu Counties

Appendix 22: Soil chemical properties ratings

Parameter	Units	Values	Ratings
Soil pH(soil:H_2O, 1:2.5)	_	< 4.6	Extremely acidic
		4.6 - 5.5	Strongly acidic
		5.6 - 6.5	Moderately acidic
		6.6 - 6.9	Slightly acidic
		7.0	Neutral
		7.1 - 8.5	Moderately alkaline
		> 8.5	Strongly alkaline
N	%	< 0.05	Very low
		0.05 - 0.15	Low
		0.15 - 0.25	Medium
		0.25 - 0.50	High
		> 0.5	Very high
P	ppm	0 – 25	Low
		25 – 50	Medium
		> 50	High
K	$Cmolkg^{-1}$	< 0.20	Very low
		0.21 - 0.30	Low
		0.31 - 0.60	Medium
		> 0.60	High

Source: Hazelton and Murphy (2007).