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Effects of Goat Manure-Based Vermicompost on Growth and Yield of Garlic (*Allium sativum* L.)

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Abstract— *Garlic, a bulb vegetable used as food and for medicinal purposes, has gained prominence among farmers and consumers in Kenya. Most of consumers increasingly prefer organic agricultural products. But, the farmers are still overutilising chemical fertilizers, which cause adverse effects on the environment. The objective of this study was to evaluate the effects of goat manure-based vermicompost on growth and yield of garlic. The study was conducted at PCEA Nkio secondary school farm and KALRO Embu horticultural field in 2018 to 2019. The experiments were laid out in a Randomized Complete Block Design, replicated 21 times and blocked into three. The treatments consisted of goat manure-based vermicompost at five levels (0, 5, 10, 20 and 30 t ha^{-1}), inorganic fertilizer (NPK 17-17-17) at the rate of 200 kg ha^{-1} and goat manure (30 t ha^{-1}). Data were collected on plant height, stem diameter, leaf length, bulb fresh weight, bulb diameter, number of cloves per bulb and bulb yield. The data obtained were subjected to ANOVA and significantly different means were separated using least significance difference at $\alpha = 0.05$. The results showed statistically significant ($p < 0.05$) effect of application of goat manure-based vermicompost on growth and yield of garlic. Application of goat manure-based vermicompost showed higher performance for plant height, stem diameter and leaf length throughout the growth period, compared to inorganic fertilizer and goat manure. Goat manure-based vermicompost also showed higher performance for bulb fresh weight, bulb diameter, number of cloves per bulb and bulb yield compared to inorganic fertilizer and goat manure. The results of this study demonstrate that application of goat manure-based vermicompost enhanced plant growth and improved garlic yield. Application of goat manure-based vermicompost proved significant for garlic production and its application need to be popularized for sustainable organic garlic production in the area of study. However, there is need to study the long term effect of its application to soil characteristics.*

Keywords— ***Bulb yield, garlic, goat manure, growth, vermicompost.***

I. INTRODUCTION

Garlic (*Allium sativum* L.) belonging to the family Alliaceae is the second most widely used cultivated vegetable bulb crops after onion in the world. It has a wide area of adaptation and cultivation throughout the world[1]. The world production is about three million metric tonnes per annum, with major producers being China, United States of America, Egypt, Korea, Russia and India[2]. In Kenya, garlic is commonly grown in small-scale farms and the annual production average is about 2,000 metric tonnes[2].

Garlic is gaining prominence as a high value horticultural crop in the family Alliaceae in Kenya. This is due to its healthy benefit[3], high returns and the readily available local market[4]. It is cultivated mostly under rain fed conditions in Kenya. However, successful commercial cultivation of this crop greatly relies on many factors such as climate, soil fertility, irrigation systems, fertilizer management, spacing and growing season[5]. The major causes of low yields include depletion of macro and micro-nutrients from the soil, use of low yielding varieties and poor management practices[6].

The growth and yield of garlic crop is greatly influenced by both inorganic and organic nutrients[7]. Studies have indicated application of inorganic fertilizers by small holder farmers have led to increased yield at the expense of product quality and environmental degradation[8]. Hence, the concern on the effects of agrochemicals especially chemical fertilizers on the environment[9]. Consequently,

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the current effort to search for alternative source of nutrients to crops such as organic manures. 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[10].

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[11]. Vermicompost and compost can meet the nutrient demand of greenhouse and field crops and significantly reduce the use of fertilizers[12].

Vermicompost increases soil fertility without polluting the soil, as well as quantity and quality of crops[13]. 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[14].

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[15][16]. Goat manure is readily available on most farms in Kenya. 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 and composting can be done using earthworms to produce vermicompost[15]. Hence, use of organic manures like goat manure-based vermicompost and improved garlic varieties can go a long way towards improving garlic yield, in the study area.

II. MATERIALS AND METHODS

The study was conducted on PCEA Nkio secondary school farm (Site 1), Meru South sub-county and KALRO Embu horticultural field in Manyatta sub-county (Site 2), Eastern Kenya. The experiment was conducted in two sites between December 2018 and March 2019. Site 1 lies at a latitude of 0.338439ºS and longitude 37.699368ºE. The area is classified as upper midlands 2 and 3 (UM2–UM3) agro-ecological zones[17], with an average altitude of approximately 1,281 m above sea level, annual mean temperature of about 18º C and annual rainfall of about 1,500 mm. The rainfall is bimodal, falling in two seasons, the long rains lasting from March through June and short rains from October to February. The soil types are *humic nitisols*[17].

Site 2 lies at a latitude of 0.496804ºS and longitude 37.451477ºE. The area 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. It has an annual mean temperature ranging from 17.4 to 24.5ºC 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[17].

Experimental Design

The experiment was laid out in a Randomized Complete Block Design (RCBD), replicated 21 times and blocked into three. 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 blanket rate of 200 kg ha^{-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 in each study site. 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}.

Preparation and Management of Experimental Plots

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 adequately supplied with water before planting to supplement 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 of 30 cm by 15 cm and a planting depth of 5 cm was adopted. Hence, each experimental plot had a total of one hundred and seven

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plants which translates to 222,453 garlic plants ha^{-1}. Once established, all the 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.

Data Collection Procedure

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 30th, 44th, 58th, 72th and 86th days after emergence (DAE). Data collection was through observations and measurements. Data was collected on plant height, stem diameter, leaf length, bulb fresh weight, bulb diameter, number of cloves per bulb and bulb yield.

Plant height 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). Stem diameter was measured at the middle part of the stem of sampled plants using a Vernier calliper and expressed in centimetres (cm). For 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).

A total of ten sampled plants obtained from the middle row of each experimental plot were used to determine the yield parameters. Fresh weight of 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 was measured at the widest point in the middle portion of the bulb with the help of Vernier calliper and expressed in centimetres (cm). For the number of cloves per bulb, they were determined physically by counting the total number of cloves produced from ten selected samples plants per plot and their number recorded. Bulb yield 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 yield was converted to kilogram per hectare (kg ha-^{1}).

Statistical Analysis

The data on growth and yield parameters of garlic obtained throughout the experimental duration was subjected to analysis of variance (ANOVA) and implemented in the statistical analysis software (SAS) version 9.4. Significant means were separated using Least Significance Difference (LSD) at 5% probability level.

III. RESULTS AND DISCUSSIONS

Effect of Goat Manure-Based Vermicompost on Growth of Garlic

There was significant ($p < 0.05$) effect of different treatments applied on plant height, stem diameter and leaf length at both experimental sites.

On plant height, the treatment K_4 recorded the highest mean plant height (41.80 cm and 41.61 cm, respectively) at Chuka and Embu at 86 DAE (Table 1). The least mean plant height (24.53 cm and 14.07 cm, respectively) at 30 DAE was observed in K_0 treatment at Chuka and Embu (Table 1). The plant height ranged from 24.53 cm to 41.80 cm and 14.07 cm to 41.61 cm at Chuka and Embu respectively (Table 1). The results showed an increasing trend in mean plant height of garlic plants with increase in the number of days after emergence with application of the different treatment combinations.

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Table 1: 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**	27.76^b	29.98^b	32.31^b	35.01^b	36.13^b
	K_5	24.75^c	27.81^c	31.39^b	33.97^b	35.03^b
	K_4	30.26^a	33.11^a	36.45^a	40.34^a	41.80^a
	K_3	30.61^a	33.57^a	36.59^a	40.01^a	41.57^a
	K_2	29.86^a	32.93^a	35.94^a	38.68^a	40.27^a
	K_1	27.50^b	29.53^b	31.47^b	33.39^{bc}	34.19^{bc}
	K_0	24.53^c	27.05^c	29.19^c	31.76^c	32.67^c
	CV (%)	17.34	15.73	16.49	17.42	16.71
	$LSD_{(0.05)}$	1.69	1.68	1.92	2.20	2.18
Embu	**K_6**	19.81^{bc}	22.26^{bc}	24.64^{bc}	26.71^{bc}	29.13^c
	K_5	18.61^c	20.70^c	22.81^c	25.17^c	27.77^c
	K_4	31.67^a	34.09^a	36.43^a	38.84^a	41.61^a
	K_3	31.81^a	34.37^a	36.63^a	38.80^a	41.30^{ab}
	K_2	30.63^a	33.29^a	35.37^a	37.31^a	39.59^b
	K_1	21.39^b	23.78^b	25.84^b	27.64^b	29.53^c
	K_0	14.07^d	14.98^d	15.58^d	16.11^d	16.74^d
	CV (%)	24.95	22.00	19.98	18.32	16.48
	$LSD_{(0.05)}$	2.09	2.02	1.97	1.93	1.86

*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}).

This enhanced garlic plant height 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 is supported by experimental vermicompost and soil analysis results that showed some significant quantity of macronutrients like nitrogen, phosphorous and potassium after experiment[15]. 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[12] where vermicompost application increased plant height of garlic significantly. Degwale[7] 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[7]. 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[18].

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[19]. From the results obtained, it is agreeable that continuous use of chemical fertilizers like NPK in

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Meru south and Manyatta sub-counties, brings about changes in soil parameters thus creates unfavourable conditions for garlic development. Joshi *et al.*[20], Essa *et al.*[21], Ramnarain *et al.*[22] and Yeole *et al.*[23] also made similar findings.

On stem diameter, the treatment K_4 recorded the largest mean stem diameter (0.86 cm and 1.24 cm, respectively) at Chuka and Embu at 86 DAE (Table 2) while the smallest mean stem diameter (0.34 cm and 0.31 cm, respectively) at 30 DAE was observed in K_0 treatment at Chuka and Embu (Table 2). The stem diameter ranged from 0.34 cm to 0.86 cm and 0.31 cm to 1.24 cm at Chuka and Embu respectively (Table 2).

Table 2: 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**	0.46^b	0.55^b	0.62^b	0.69^b	0.72^b
	K_5	0.43^b	0.52^b	0.59^b	0.65^b	0.69^b
	K_4	0.52^a	0.62^a	0.69^a	0.77^a	0.86^a
	K_3	0.54^a	0.63^a	0.69^a	0.76^a	0.83^a
	K_2	0.52^a	0.60^a	0.67^a	0.76^a	0.83^a
	K_1	0.47^b	0.54^b	0.60^b	0.65^b	0.69^b
	K_0	0.34^c	0.46^c	0.52^c	0.58^c	0.61^c
	CV (%)	23.55	18.92	18.71	18.90	18.75
	$LSD_{(0.05)}$	0.03	0.03	0.04	0.04	0.04
Embu	**K_6**	0.35^{cd}	0.40^e	0.47^{de}	0.52^c	0.56^{cd}
	K_5	0.34^d	0.39^e	0.44^{ef}	0.52^c	0.59^c
	K_4	0.54^b	0.67^b	0.84^b	1.03^a	1.24^a
	K_3	0.58^a	0.76^a	0.91^a	1.06^a	1.23^a
	K_2	0.52^b	0.59^c	0.66^c	0.79^b	1.00^b
	K_1	0.38^c	0.44^d	0.50^d	0.57^c	0.63^c
	K_0	0.31^d	0.36^e	0.41^f	0.45^d	0.50^d
	CV (%)	27.00	23.38	21.28	22.29	25.43
	$LSD_{(0.05)}$	0.04	0.04	0.04	0.05	0.07

*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}).

This increased garlic plant stem diameter 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[15]. 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[24][19]. 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[18]. 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[24][19] that indicated maximum

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diameter of stem was found with the treatment that had highest amount of vermicompost. Mavura *et al.*[25] 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[26].

Similarly, Xiang *et al.*[27] 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.*[28], Durak *et al.*[29] and Kumar and Gupta[30] reported that comparison results showed that treatment with vermicompost had significantly greater plant stem diameters compared with other treatments.

For leaf length, the treatment K_4 recorded the highest mean leaf length (31.48 cm and 27.82 cm, respectively) at Chuka and Embu at 86 DAE (Table 3) while the least mean leaf length (15.48 cm and 10.14 cm, respectively) at Chuka and Embu at 30 DAE was observed in K_0 treatment (Table 3). The leaf length ranged from 15.48 cm to 31.48 cm and 10.14 cm to 27.82 cm at Chuka and Embu respectively (Table 3).

Table 3: 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**	21.37^{b}	23.35^{b}	24.33^{b}	25.58^{b}	26.61^{b}
	K_5	17.96^{c}	20.76^{c}	22.28^{c}	25.69^{b}	25.51^{b}
	K_4	22.84^{a}	25.76^{a}	27.20^{a}	28.05^{a}	31.48^{a}
	K_3	23.78^{a}	26.58^{a}	27.66^{a}	28.54^{a}	30.14^{a}
	K_2	22.90^{a}	26.14^{a}	27.33^{a}	28.31^{a}	30.20^{a}
	K_1	20.21^{b}	22.57^{b}	23.52^{bc}	24.86^{b}	25.58^{b}
	K_0	15.48^{d}	17.78d	18.61^{d}	20.76^{c}	21.54^{c}
	CV (%)	18.81	19.94	20.57	25.84	17.56
	$LSD_{(0.05)}$	1.36	1.62	1.75	2.35	1.67
Embu	**K_6**	15.02^{d}	16.03^{c}	16.72^{c}	17.22^{c}	17.73^{c}
	K_5	13.20^{e}	14.10^{d}	14.64^{d}	15.07^{d}	15.51^{d}
	K_4	24.76^{a}	25.59^{a}	26.35^{a}	27.09^{a}	27.82^{a}
	K_3	21.71^{c}	22.70^{b}	23.72^{b}	24.75^{b}	25.73^{b}
	K_2	23.27^{b}	23.97^{b}	24.70^{b}	25.26^{b}	25.87^{b}
	K_1	14.76^{d}	15.21^{cd}	15.63^{cd}	16.20^{cd}	16.63^{cd}
	K_0	10.14^{f}	10.41^{e}	10.63^{e}	10.88^{e}	11.14^{e}
	CV (%)	22.66	20.76	19.55	19.10	18.47
	$LSD_{(0.05)}$	1.39	1.33	1.29	1.30	1.29

*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 enhanced garlic plant leaf length could be attributed to higher nutrient availability as well as better nutrient uptake by the crop[12]. 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[15]. During the processing of various organic wastes by earthworms, many of nutrients it contains are changed to forms which

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are more readily taken by plants such as nitrate, exchangeable phosphorous and soluble potassium[31]. 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[32]. According to Suthar[33], 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[12] reported that the highest length of leaves in garlic was recorded in vermicompost treatment. Kumar *et al.*[19] also found that maximum leaf length in garlic 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[32] promoting more plant vigour in terms of increased leaf length of plants.

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[34]. 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[32]. Kumawat *et al.*[24], Kenea and Gedamu[34] and Kashem *et al.*[32] also made similar findings.

Effect of Goat Manure-Based Vermicompost on Yield of Garlic

There was significant ($p < 0.05$) effect of different treatments applied on bulb fresh weight, bulb diameter, number of cloves and bulb yield per hectare at both experimental sites.

The treatment K_4 recorded the highest mean bulb fresh weight (18.19 gm and 12.66 gm, respectively), bulb diameter (3.92 gm and 3.50 gm, respectively), number of cloves (7.46 and 5.90, respectively) and bulb yield per hectare (4084.24 kg ha^{-1} and 2842.58 kg ha^{-1}, respectively) while K_0 treatment had lowest mean bulb fresh weight (8.51 gm and 7.82 gm, respectively), bulb diameter (2.97 gm and 2.90 gm, respectively), number of cloves (4.80 and 4.56, respectively) and bulb yield per hectare (1945.95 kg ha^{-1} and 1762.37 kg ha^{-1}, respectively) at Chuka and Embu (Table 4).

Table 4: Means of various garlic bulb yield attributes and yield under different treatments at Chuka and Embu

Site	Treatment	Bulb Fresh Weight (gm)	Bulb Diameter (gm)	Number of cloves	Bulb Yield (kg ha^{-1})
Chuka	**K_6**	14.08^{b}	3.63^{bc}	5.80^{cd}	3162.91^{bc}
	K_5	12.60^{b}	3.47^{c}	5.30^{cd}	2829.85^{cd}
	K_4	18.19^{a}	3.92^{a}	7.46^{a}	4084.24^{a}
	K_3	16.99^{a}	3.91^{a}	6.86^{ab}	3816.30^{ab}
	K_2	17.51^{a}	3.83^{ab}	6.00^{bc}	3931.56^{ab}
	K_1	9.62^{c}	3.13^{d}	5.43^{cd}	2160.75^{de}
	K_0	8.51^{c}	2.97^{d}	4.80^{d}	1945.95^{e}
	CV (%)	31.18	12.01	35.00	14.70
	$LSD_{(0.05)}$	2.21	0.21	1.06	819.64
Embu	**K_6**	10.94^{a}	3.28^{a}	5.30^{abc}	2456.38^{abc}
	K_5	8.92^{b}	3.03^{b}	4.96^{bc}	2002.83^{bc}
	K_4	12.66^{a}	3.50^{a}	5.90^{a}	2842.58^{a}
	K_3	11.79^{a}	3.36^{a}	5.66^{ab}	2648.73^{ab}
	K_2	11.45^{a}	3.33^{a}	5.43^{ab}	2486.32^{abc}
	K_1	8.36^{b}	2.96^{b}	5.20^{abc}	1877.83^{bc}

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K_0	7.82^b	2.90^b	4.56^c	1762.37^c
CV (%)	36.30	13.59	29.62	19.15
$LSD_{(0.05)}$	1.89	0.22	0.79	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 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. 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.

Similar to the results of this present study Kenea and Gedamu[34] 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.*[35]. Kumar *et al.*[24][19] 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[24][19]. Abolmaaty and Fawaz[36] and Patidar *et al.*[37] also made similar findings.

The results showed that higher application rates of goat manure-based vermicompost enhanced increased bulb diameter. This can be greatly attributed to fact that during the processing of goat manure-based vermicompost by earthworms, 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 and soluble potassium[31]. 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[24][19]. 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.*[35] 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.*[24][19] 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.*[37], Kumar *et al.*[24][19] and Abolmaaty and Fawaz[36] that application of vermicompost gave the highest garlic bulb diameter in comparison to the control treatments.

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. 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[38]. Also, the enhanced number of cloves 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[7].

Similar to these results, Kenea and Gedamu[34] reported that vermicompost application showed significantly increased garlic cloves number per bulb over the control. Golmohammadzadeh *et al.*[35] reported higher number of bulblets per garlic plant was recorded in vermicompost treatment. The effects of vermicompost showed significant difference on mean clove number[7]. Also Kumar *et al.*[24][19] made similar findings. 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 also 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 treatments.

The results of the present study are similar to the findings of Patidar *et al.*[37] 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.*[24][19] 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[18] and Mbithi *et al.*[8] 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 .

IV. CONCLUSION

The results clearly showed that application of goat manure-based vermicompost enhanced garlic growth. There was significant increase on plant height, stem diameter, leaf length and leaf width of the garlic plants. Therefore, it can be hypothesized 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. Probably the enhanced growth can be attributed to better nutrient uptake, more photosynthesis due to enhanced growth of photosynthetic tissues. Hence, improved synthesis of photo assimilates, which enhanced vegetative growth of garlic plants.

Moreover, the results revealed that application of goat manure-based vermicompost significantly improved garlic yield attributes and yield. Higher bulb fresh weight, bulb diameter, bulb length, number of cloves per bulb and bulb yield was recorded with application of goat manure-based vermicompost compared to application of inorganic fertilizer and goat manure. This can be attributed to more nutrient availability in goat manure-based vermicompost that resulted in enhanced garlic plant growth and development that translated to enhanced garlic yields.

V. RECOMMENDATIONS

The study recommends application of goat manure-based vermicompost since it proved to significant increase garlic production. However, there is need to study the long term effects of its application to soil characteristics.

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