Effect of Goat Manure-Based Vermicompost on Soil Chemical Properties under Garlic Production in the Upper Eastern Region of Kenya

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Abstract

Majority of farmers in upper Eastern region of Kenya mainly apply chemical fertilizers to boost crop yields. Continuous use of chemical fertilizers causes several adverse effects such as P-fixation, volatilization of essential nutrients and leaching that affect safety of groundwater and agricultural environment. The effects of goat manure-based vermicompost on soil chemical properties under garlic were evaluated in Chuka University farm, Meru South sub-county and KALRO Embu horticultural field, Manyatta sub-county; from December 2018 to March 2019. The experiment was laid out in a randomized complete block design and replicated thrice. Treatments were; goat manure-based vermicompost applied at five quantities (0, 5, 10, 20 and 30 t ha^{-1}), NPK 17-17-17 at 200 Kg ha^{-1} and goat manure (30 t ha^{-1}). The treatments were randomly assigned to experimental plots. Soil sampling and analysis were done before planting and after harvesting of garlic on each experimental unit. Results showed that application of goat manure-based vermicompost had statistically significant difference ($p \leq 0.05$) on soil chemical properties. Application of 30 tha^{-1} goat manure-based vermicompost showed significantly ($p \leq 0.05$) higher soil pH (8.00), total N (0.606%), available P (21.933 ppm) and exchangeable K (0.863 Cmol Kg^{-1}) than control treatment that had pH (6.59), total N (0.043%), available P (4.67 ppm) and exchangeable K (0.456 Cmol Kg^{-1}) at Chuka. A similar trend was observed in Embu where vermicompost gave significantly higher soil pH (7.91), total N (0.563%), available P (21.053 ppm) and exchangeable K (0.71 Cmol Kg^{-1}) compared to control which had pH (6.54), total N (0.03%), available P (4.6 ppm) and exchangeable K (0.34 Cmol Kg^{-1}). Results of this experiment revealed that addition of goat manure-based vermicompost enhanced soil chemical properties leading to improved garlic productivity.

Keywords: Garlic, Goat Manure-Based Vermicompost, Soil Chemical Properties

Introduction

Agriculture sector is the mainstay in the Kenyan economy contributing 30 percent of the gross domestic product and accounting for 80 percent of the employment (Horticultural Crops Development Authority [HCDA], 2016). Vegetables are a 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). However, soil fertility decline contributes to low and unsustained crop yields in Kenya (Mucheru-Muna *et al.,* 2013). But in particular, the major nutrients, Nitrogen (N) and phosphorous (P), are commonly deficient in the soils (Okalebo *et al.,* 2006).

Garlic (*Allium sativum* L.) 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).

Hence, 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 P-fixation, leaching and volatilization of NO_3 and N_2O, respectively (Rop *et al.,* 2019). Application of 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 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). Use of chemical fertilizers in garlic production also increases the cost of production, cause environmental pollution and associated health problems (Uwah and Eyo, 2014).

A major constraint to 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 for chemical fertilizers (Bhat *et al.,* 2007). Use of organic manures and bio fertilizers to maintain soil health and soil productivity is essential in production of garlic (Bhandari *et al.,* 2012). Thus, 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 nutrient rich, microbiologically active organic amendment which results from interactions between earthworms and micro-organisms during the breakdown of organic matter (Lazcano and Dominguez, 2010). Vermicompost applied soils have high porosity, aeration, drainage, water-holding capacity, enhances cation exchange capacity (CEC) 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).

The application of goat manure significantly increases soil pH, organic matter (OM) content, total N, available P, exchangeable K, calcium, magnesium and the cation exchange capacity (CEC) status of the soil (Uwah and Eyo, 2014). Goat manure is readily available on most farms in Meru south area and Manyatta sub-county. However, its use has received little research attention and hence not effectively used in sustainable agriculture. Driven by the desire to improve productivity while maintaining low cost in garlic production, this study was undertaken to evaluate the utilization of goat manure-based vermicompost in organic production of garlic in Meru south sub-county and Manyatta sub-county of upper eastern Kenya.

Materials and Methods

Study Site

The study was conducted on Chuka university 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 on the eastern slopes of Mount Kenya. Chuka University farm is located along the Nairobi – Meru highway approximately 186 kilometers from Nairobi city. The site lies at a latitude of 0.3229^{0}S and longitude 37.6546^{0}E. 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 1,500 m above 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. Soils are humic nitisols (Jaetzold and Schmidt 1983), which are extremely 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 N, P and Zn (Ogolla *et al.*, 2019).

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 0.6762^{0}S and longitude 37.4702^{0}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 annual mean temperature ranging from 17.4 to 24.5^{o}C and average annual rainfall of 450 mm to 1400 mm. The rainfall is bimodal with long rains (LR) falling from around March to June and short rains (SR) from around October to December. It has *humic nitisols* soils and the prime cropping activity is maize intercropped with beans though livestock keeping is also dominant. Various agricultural activities have been carried out in the region hence the rationale behind its selection (Kisaka *et al.*, 2015).

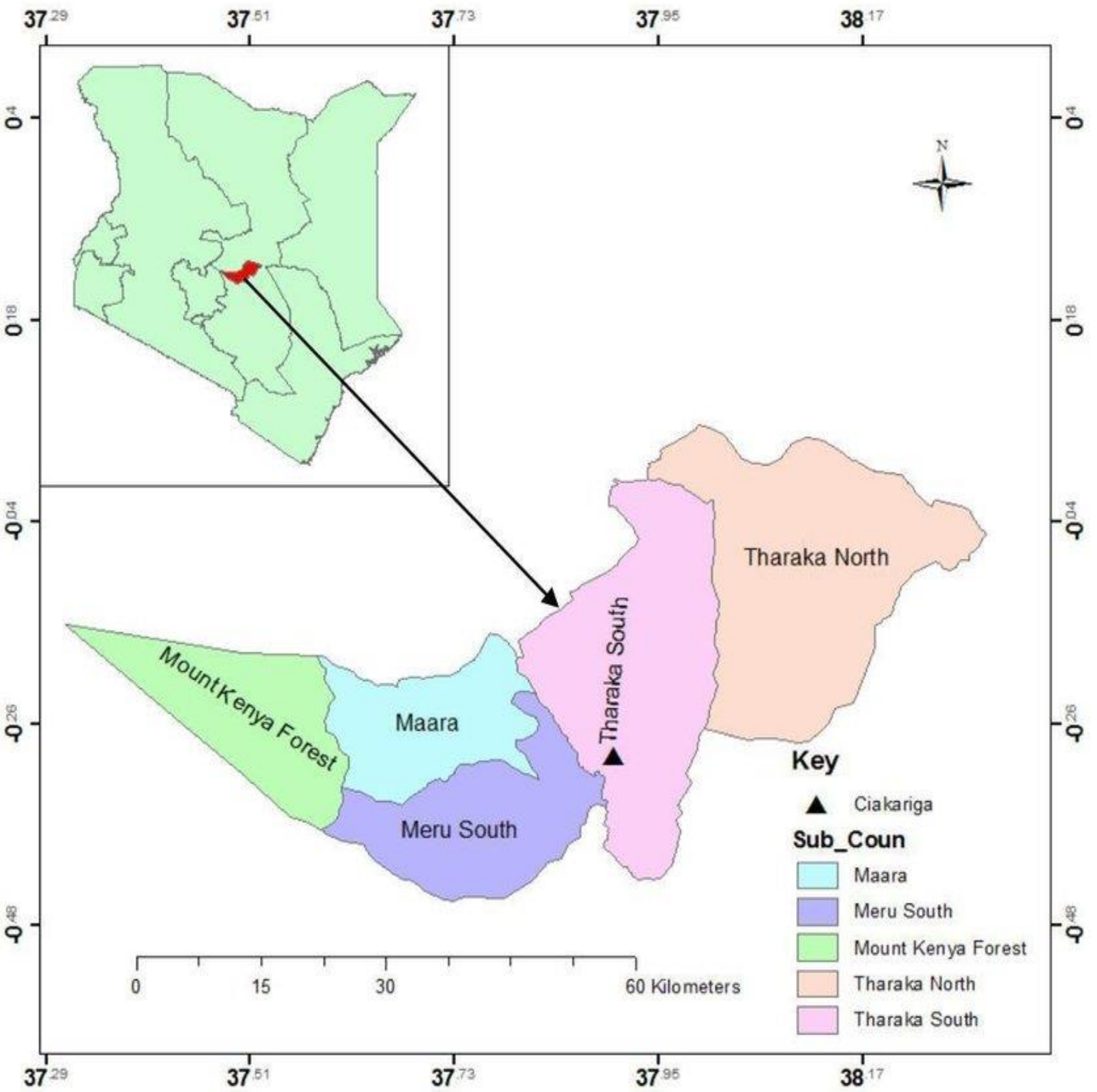

Figure 1: Map of Tharaka Nithi County (Source; Ogolla *et al*., 2019).

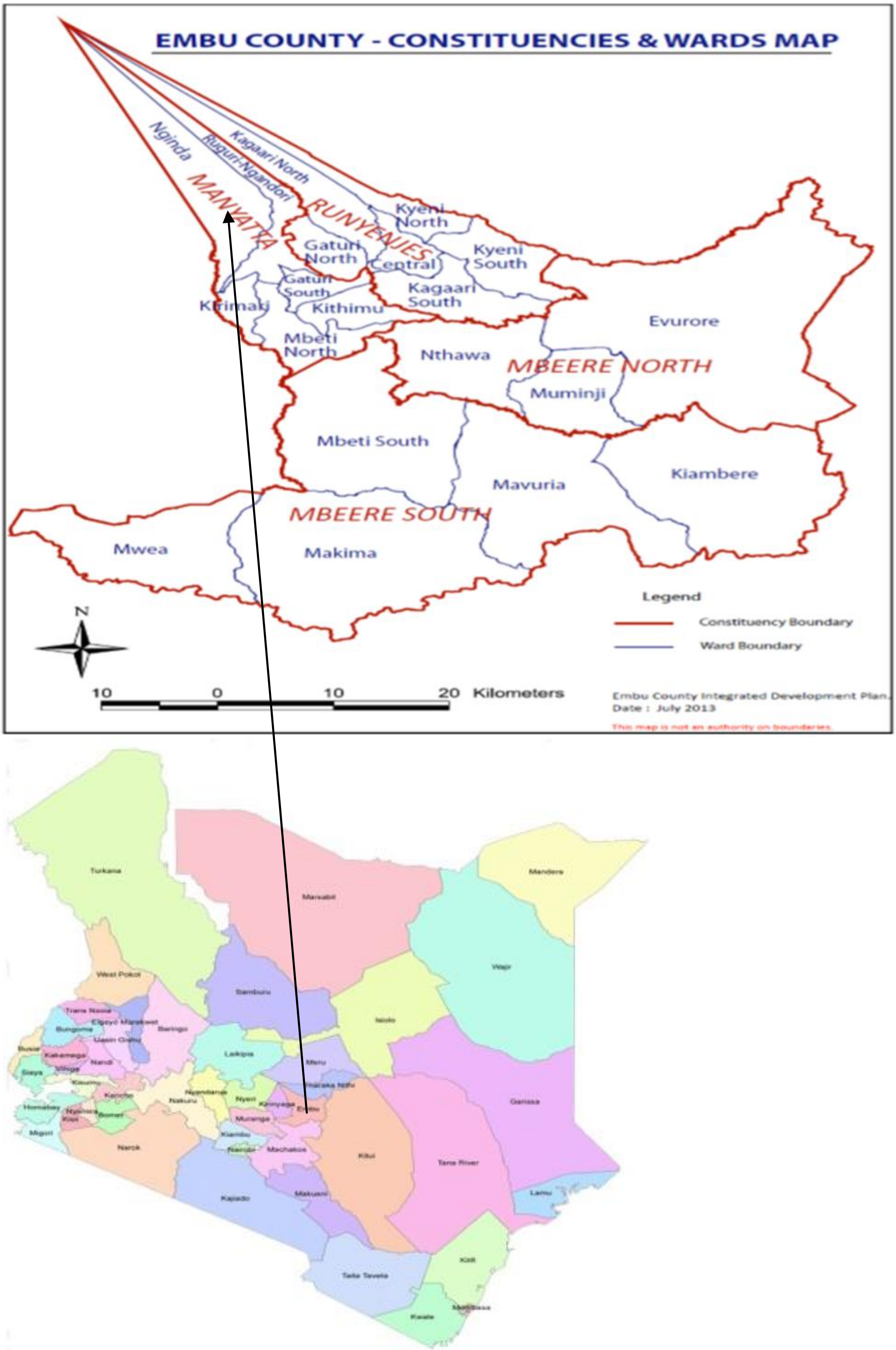

Figure 2: Map of Embu County (Source; Kenya Mpya County Maps, 2012).

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 1 m wide and 1 m high. A shed was erected above the vermicomposting bed to prevent direct sunlight and rain and also fenced round using wire chain link to keep away predators of earthworms like chicken and other birds.

A basal layer composed of broken bricks followed by a layer of coarse sand to a thickness of 7 cm was placed inside this bed to ensure proper drainage and restrict earthworm movement towards the soil layer. A 15 cm layer of loamy soil was placed at the top and moistened. Small lumps of fresh goat manure were scattered over the soil to form an active growing medium for earthworms then, 2,800 red wiggler earthworms (*Eisenia fetida)* species sourced from AAA growers in Naromoru, Laikipia County introduced to facilitate decomposition of the materials as described by Mbithi *et al.,* (2015). This was followed by 10 cm thick layer of dry grass, dry banana leaves and dry bean husks to act as bedding material for the worms. A 10cm thick dry goat manure weighing 100 kg was placed and spread on these materials. The same set of layering was continued till a height of 1 m followed by sprinkling uniformly 5 litres of water to the vermicompost bed to keep the worms moist and facilitate easy earthworm movement in these materials and gunny placed on top to cover the materials.

The vermicompost bed was kept moist by sprinkling 2 litres of water once a week and the process continued to the 7th week. Turning of these materials was gently done once after 15 days to avoid injuring earthworms. Goat manure-based vermicompost was harvested after 120 days when the earthworms were found sticking to the under surface of gunny bags indicating that composting process was complete and spread on a polythene sheet. Adult worms and young ones were handpicked from the manure dried for one day under a shed, 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 and total N estimated using kjeldahl method (Bremner and Mulvaney, 1982), available P using extraction with 0.5 M $NaHCO_3$ as described by Olsen *et al.* (1954) and exchangeable K using Flame photometer (Jackson, 1967). Analysis was done at the University of Nairobi, upper kabete campus soil laboratories.

Experimental Design

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

Plant Establishment and Agronomic Practices

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. The planting beds were thoroughly soaked with water before planting. Goat manure-based vermicompost, NPK and goat manure applied on the experimental plots based on the assigned rates of application and well incorporated into soil in the entire experimental plots. Garlic cloves were planted with the base of the clove down and the tip in upright position and covered with soil. The recommended spacing adopted was 30 cm by 15 cm and a planting depth of 5 cm. Each experimental plot was having a total of 107 plants which translated to 222,453 garlic plants ha^{-1}. Once established, all other necessary maintenance practices were carried out appropriately. Weeding was done through uprooting as weeds emerged. Pests were controlled through regular application of Duduthrin® at the rate of 15 ml 20 $litres^{-1}$ from the second week after garlic emergence at an interval of 14 days and stopped at 86 days after emergence. Diseases were controlled through regular application of Ridomil® fungicide at the rate of 40 gm 20 $litres^{-1}$ from the second week after garlic emergence at an interval of 21 days and stopped at 86 days after emergence. Sprinkler irrigation was done from morning to mid- afternoon after planting twice per week during growth of garlic crop and stopped two weeks to harvesting.

Figure 3: A view of experimental plots layout in Chuka

Data Collection Procedure on Soil Nutrients

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 to a depth of 20 cm of the soil profile from the entire experimental site, broken into small crumbs and thoroughly mixed. From this mixture, a composite sample weighing 1 kg was placed in aplastic bag, air-dried in the laboratory and crushed to pass through < 1mm sieve and chemically analysed. Soil samples were also taken from each polt at the end of the experiment in each growth season and analysed. To determine soil pH, H_2O, was added to soil sample at a ratio of 1:2.5 shaken for 30 min and pH determined using a digital pH meter fitted with a glass electrode. 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, phosphate concentration of solution was measured calorimetrically as described by Olsen *et al.* (1954). Exchangeable K was determined using flame photometer after K was extracted from air dried soil samples by shaking with 0.5M ammonium acetate solution. Potassium content of the filtered extract was then determined as described by Jackson, (1967). Analysis was done at the University of Nairobi, Kabete campus soil laboratories. The soil chemical properties obtained were rated according to ranges given by Hazelton and Murphy, 2007 as shown in Table 1.

Table 1: Soil Chemical Properties Ratings according to Hazelton and Murphy, 2007

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

Statistical Analysis

Data on soil chemical properties obtained during the experimental duration were subjected to analysis of variance (ANOVA) to test the hypothesis of the study. Statistical analysis software (SAS, Version 2008) was used for data analysis. Significant means were separated using the Least Significance Difference test (LSD) at 5% probability level.

Results and Discussions

Soil Characteristics Before the Onset of the Experiment

Samples of each experimental site were analysed for soil chemical properties before planting and results are presented on 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	$Cmolkg^{-1}$	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	$Cmolkg^{-1}$	0.26	0.21-0.30	Low

*The ratings are based according to criteria described in Table 1.

Results showed that 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 were 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% medium and greater than 0.25% is high. Available phosphorous in the two sites was low based on the ranges as described by Hazelton and Murphy (2007). Most vegetables benefit from P fertilization if the soil test is less than 35 – 40 ppm P using the Bray – Kurtz P_1 extraction method (Tadesse, 2015). Exchangeable potassium content of the soil of the two sites was low based on the ranges provided by Hazelton and Murphy (2007). According to Tadesse (2015) if the soil test is less than 85 ppm K, it is categorized as low potassium content. Garlic prefers a fairly neutral pH ranging 6.5 – 7.0. Thus, if the soil is too acidic or too alkalinic it causes slowed growth and late maturity of garlic. Moreover, N decreases as soil acidity increases while it becomes available as soil alkalinity increases (Tadesse, 2015).

Goat Manure-Based Vermicompost and Goat Manure Samples Analysis

A sample of goat manure-based vermicompost and goat manure used in the experiment were analysed for chemical properties and results presented on Table 3.

Table 3: Chemical analysis of goat manure-based vermicompost (GMBV) and goat manure (GM) 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	$Cmolkg^{-1}$	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	$Cmolkg^{-1}$	0.59	0.31-0.60	Medium

*The ratings are based according to criteria described in Table 1.

Chemical analysis of goat manure-based vermicompost used in the study showed very high total N, high available P and exchangeable K and it was moderately alkaline (Table 3) based on the ranges given by Hazelton and Murphy (2007). Goat manure used in the study had high total N, medium available P, medium exchangeable K and moderately alkalinic (Table 3). based on the ranges given by Hazelton and Murphy (2007).

Effect of Different Treatments on Soil Nutrients at Chuka and Embu

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	Exchangeable K
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
	Mean	7.040	0.241	11.825	0.643
	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
	Mean	6.942	0.218	11.391	0.567
	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 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}).

Soil pH

Soil pH was significantly ($p \leq 0.05$) affected by goat manure-based vermicompost treatments. Chuka recorded mean soil pH of 8.00 in K_4 treatment while the lowest mean soil pH (6.58) was recorded in K_0 treatment. Similar to Chuka, at Embu, mean soil pH of 7.91 was recorded in K_4 treatment while the lowest mean soil pH of 6.54 was recorded in K_0 treatment (Table 4). Addition of goat manure-based vermicompost increased soil pH. Among the treatments, the soils blended 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 that increases soil pH and reduces the potential of aluminium and manganese toxicity in soil. The increase in soil pH is also due to the fact that goat manure-based vermicompost had higher pH (7.73) when compared to Chuka soil pH (6.64) and Embu soil pH (6.33). This increase in soil pH (8.00) is not considered to have profound effect on the soil quality since it remains close to neutral. These results are consistent with those of Angelova *et al.* (2013) who reported that application of vermicompost increases soil pH. Contrary to these results, Atiyeh *et al.* (2002) 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.

Total Nitrogen

Total N was significantly ($p \leq 0.05$) affected by goat manure-based vermicompost treatments with Chuka recording highest mean total N (0.606%) in K_4 treatment and the lowest mean total N (0.043%) in K_0 treatment. Similary. Embu, had the highest mean total N (0.563%) in K_4 treatment and the lowest mean total N (0.030%) was recorded in K_0 treatment (Table 4). Addition of goat manure-based vermicompost increased total N. Among the treatments, the soils blended with goat manure –based vermicompost at the rate of 30 t ha $^{-1}$ had the highest total N in comparison to control treatment at the end of harvesting season. This is attributed to higher application of goat manure-based vermicompost that supplied more residual N in soil than the controls. These resuls are also similar to results of Angelova *et al.* (2013) who reported that total N concentration in soil was significantly affected by vermicompost treatments. The soils treated with vermicompost at the rate of 10 g kg^{-1} had more total N compared to soils without vermicompost. This was attributed to organic matter, acidic pH and proper moisture in soil that avails N for plants. Azarmi *et al.* (2008) reported that a decrease in total N in soils without vermicompost application was due to larger amounts of total C and N in vermicompost that could have provided a larger source of N for mineralization.

Available Phosphorous

This results showed that available P was significantly ($p \leq 0.05$) affected by goat manure-based vermicompost treatments. Chuka recorded highest significant mean available P (21.933 ppm) in K_4 treatment while the lowest mean available P (4.670 ppm) was recorded in K_0 treatment. Similar to Chuka, at Embu, highest significant mean available P (21.053 ppm) was recorded in K_4 treatment while the lowest mean available P (4.596 ppm) was recorded in K_0 treatment (Table 4). The addition of goat manure-based vermicompost increased available P. Among the treatments, the soils amended with goat manure-based vermicompost at the rate of 30 t ha^{-1} had highest available P 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 P into the soil even after garlic crop. Also release of P 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 P with the increase of vermicompost doses applied. Soils treated with vermicompost at the rate of 10 g kg^{-1} had significantly more P as compared to control plots. This was attributed to DTPA-extractable P with vermicompost thus release of humic acid during organic matter decomposition resulting in conversion of unavailable soil phosphate into available forms. Also, the enhancement of phosphatase activity and physical breakdown of material resulted in greater mineralization.

Exchangeable Potassium

This results showed that exchangeable potassium was significantly ($p \leq 0.05$) affected by goat manure-based vermicompost treatments. Chuka recorded highest significant mean exchangeable K (0.863 Cmol Kg^{-1}) in K_4 treatment while the lowest mean exchangeable K (0.456 Cmol Kg^{-1}) was recorded in K_0 treatment. Similar to Chuka, at Embu, highest significant mean exchangeable K (0.710 Cmol Kg^{-1}) was recorded in K_4 treatment while the lowest mean exchangeable K (0.343 Cmol Kg^{-1}) was recorded in K_0 treatment (Table 4). This 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 K. Among the treatments, the soils amended with goat manure-based vermicompost at the rate of 30 t ha^{-1} had highest exchangeable K 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 K fixation and consequently increased K availability in the soils even at the end of harvesting season of garlic. Similar to the results obtained, Angelova *et al.* (2013) reported that significantly higher values of available K were obtained after the introduction of vermicompost compared to compost. The DTPA-extractable K were increased by the application of vermicompost. This was attributed to vermicompost which have high amounts of K in organic amendments that increases CEC thus the K amount raises in soil.

Conclusion and Recommendation

Amending soils with goat manure-based vermicompost enhances improved soil chemical properties. Among the different application rates used, the highest rate of 30 t ha^{-1} proved the best in enhancing soil chemical properties in the study area. Even though chemical fertilizer quickly releases mineral elements, goat manure-based vermicompost stimulates microbial growth which promotes synthesis of phosphatase enzymes, it maintains and increases uptake of plant nutrients which leads to faster physiological development hence promotes growth and yield of garlic. Also, application of goat manure-based vermicompost does not result in the immobilization of plant available nutrients but instead it increases nutrient turnover through both increased microbial biomass and activity. Thus, goat manure-based vermicompost when applied in soil improves nutrient availability and also improves physical condition of soil. Hence, a shift to a more sustainable organically production systems that can significantly increase soil fertility and 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.

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