

Full Length Research Paper

Soil properties and maize (*Zea mays* L.) growth and yield response to water hyacinth (*Eichhornia crassipes*) compost application in Lake Victoria Basin, Kenya

Kevin Obondo*, Joyce J. Lelei and Samuel M. Mwonga

Department of Crops, Horticulture and Soils, Faculty of Agriculture, Egerton University,
P.O. Box 536-20115 Egerton Njoro Kenya.

Received 15 December, 2020; Accepted 8 February, 2021

The decline in organic matter (OM) content and fertility of soils often contribute to losses in agricultural production. This research determined the effects of water hyacinth compost application on selected soil properties and maize growth and yield during a field experiment conducted between February 2020 and August 2020 in Lake Victoria basin, Kenya. The experiment was conducted in a randomized complete block design (RCBD) with five fertilizer treatments. The treatments were vermicompost, thermophilic compost, effective microorganisms (EM) compost, positive control (inorganic fertilizer) and negative control (no fertilizer) replicated three times. Vermicompost application significantly increased the soil pH. Fertilizer treatments and the environment significantly affected maize growth and yield parameters. The percent crop emergence was above the threshold level (88%) for plots treated with organic amendments and no fertilizer treatment and those below the threshold level for the plots treated with inorganic fertilizer. The duration to 50% tasseling was significantly reduced by vermicompost application when compared to other treatments. Higher plant height (239.4 cm), nitrogen uptake (130.8 kg/Ha), and grain yield (5580 kg/Ha) was also recorded under vermicompost treatment. This suggests that vermicompost could be a promising substrate for amending acidic soils and improving crop productivity.

Key words: EM compost, Thermophilic compost, vermicompost, Water hyacinth

INTRODUCTION

Soil organic matter (SOM) is the basis of soil fertility (Srivastava et al., 2016). Compost manure is one of the main sources of organic matter in the soil which is rich in plant nutrients and also improves the physico-chemical and biological properties of the soil (Van Haute, 2014). Owing to these improvements, the soil becomes more resistant to stresses such as drought, diseases and

toxicity. It helps the crops in improved uptake of plant nutrients because of vigorous microbial activity. These advantages manifest themselves in reduced cropping risks, higher yields and lower reliance on inorganic fertilizers for economic crop production (Sharma et al., 2017).

SOM depletion is one of the major factors causing

*Corresponding author. E-mail: kevinobondo@yahoo.com.

degradation of ecosystem services and loss of ecosystem resilience in Sub-Saharan Africa (Feller et al., 2012). As a result, numerous studies have suggested organic soil amendments as alternative for sustaining economically viable crop production with minimal environmental pollution. However, a major limitation of organic amendment is its smaller impact on plant yield than chemical fertilizers, although this difference is contextual and depends on the system and site characteristics (Seufert et al., 2012). Therefore, more research is needed to improve knowledge on the potential of organic amendments, as well as to improve their effectiveness. Two alternative and emerging organic fertilizers are vermicompost and effective microorganisms (EM) compost.

Vermicomposting is the enzymatic degradation of organic materials as they pass through the digestive system of earthworms. Worms such as *Eisenia fetida*, *Perionyx escavatus*, *Eudrilus eugeniae* and *Lumbricus rubellus* (Gupta et al., 2007) are used for transforming organic wastes into a useful product termed as vermicast. In this process, the nutrients contained in the organic matter are converted to more bioavailable forms. Vermicompost is rich in nutrients and contains enzymes and hormones that stimulate plant growth and help them resist pathogens (Gajalakshmi and Abbasi, 2004). The EM based composting process uses effective microorganisms as activator to expedite the decomposition process. The EM consists of species of photosynthetic bacteria (*Rhodospseudomonas* spp), lactic acid bacteria (*Lactobacillus* spp), yeast (*Saccharomyces* spp), and or fermenting fungi like *Aspergillus* and *Penicillium* collected from natural environment (Javaid and Shah, 2010).

Maize is one of the main staple foods cultivated by over 80% of the population in Lake Victoria basin, Kenya in almost all the agro-ecological zones during the first and second cropping season of the year (NAAIAP, 2014). It is majorly grown by small-scale farmers and contributes significantly towards food security of the households (GoK, 2015). The average maize yield obtained per unit area is low. This can be attributed to several challenges including inadequate use of recommended certified seeds and fertilizers, the striga weed menace and erratic and unreliable rainfall (NAAIAP, 2014). The dominant soil types in the Lake Victoria basin are acrisols and ferralsols (Jaetzold et al., 2010). They are highly leached acidic soils with low fertility (ISRIC, 2007).

The use of water hyacinth (*Eichhornia crassipes*) as a substrate in vermicompost and EM based compost preparation and effects of their application on soil fertility and maize yield improvement has not been realized in Kenya. Water hyacinth is a good substrate for composting because it absorbs nutrient elements present in aquatic environment (Patil et al., 2012). Water hyacinth causes economic and environmental losses in many countries and is regarded as an invasive species with serious threat to biodiversity (Téllez et al., 2008). The objective

of this study was to determine effect of water hyacinth compost application on selected soil properties and maize growth and yield. This will also contribute in development of environmentally sound methods for the management and control of the invasive water hyacinth weed.

METHODOLOGY

Description of the study area

The field experiment was conducted between February 2020 and August 2020 within two regions (Kisii and Siaya) of Lake Victoria basin, Western Kenya. The study site in Siaya region (Asembo) lies on longitude 34°23'0" E, latitude 0°11'0" S, and an altitude of 1137 M above the sea level. The area lies in Lower midland 3 agro-ecological zone. The site receives mean annual rainfall of approximately 1079 mm. The distribution is bimodal with long rains occurring between March and June and short rains between September and December. The average annual temperature in the area is about 22.0°C (Jaetzold et al., 2010). The predominant soil type at Asembo is orthic and chromic acrisols with argillic endopendon (FAO, 2014). The soils are well drained with moderate gravelly sand clay to clay over petrophlinthite or rock. Continuous cultivation without any fallow periods coupled with removal of crop residues is a common practice on cultivated fields. Over 70% of the farmers in this region use diammonium phosphate (DAP-(NH₄)₂HPO₄), urea (CO(NH₂)₂), and NPK as sources of fertilizers (GoK, 2015). The main food crops grown in the area include maize, beans, sorghum, millet, cassava, cowpeas, soybean, sweat potatoes, chili and groundnuts. Cereal crops are mainly grown during the long rain season (MoALF, 2016).

The study site in Kisii region (Kisii National Polytechnic) lies on longitude 34°45'59" E, latitude 0°40'54" S, and an altitude of 1631 M above the sea level. The area lies in Upper midland 1 agro-ecological zone with medium to long growing period (155-174 days). The site receives mean annual rainfall of approximately 1922 mm. The distribution is bimodal with long rains occurring between March and June and short rains between September and December. The average annual temperature in the area is about 19.6°C (Jaetzold et al., 2010). The predominant soil type at Kisii National Polytechnic is nito-rhodic ferralsols (FAO, 2014). The soils are well drained, deep, reddish brown with friable sandy clay. Continuous cultivation without any fallow periods coupled with removal of crop residues is a common practice on cultivated fields. Over 80% of the farmers in the study area rely on inorganic fertilizers (GoK, 2015). The main food crops grown in the area include maize, bananas, beans, sorghum, millet, kales, carrots and tomatoes.

Treatments, experimental design, and procedures

The experiment consisted of five fertilizer treatments; vermicompost, thermophilic compost, EM compost, positive control (inorganic fertilizer) and negative control (no fertilizer), laid out in randomized complete block design (RCBD) with three replications. Land preparation took place well in advance before planting to allow for incubation period of organic amendments in the soil. Plot size was 3 by 3 m and the total area used for the experiment was 216 m² (18 m by 12 m) including border areas. The experimental field was prepared following the conventional farmers' practices. Hybrid maize variety (H517) was used as a test crop. An inter-row spacing of 75 cm and intra-row spacing of 30 cm was used giving a plant population of 44,444 plants Ha⁻¹. Organic fertilizer (compost) and inorganic fertilizer (NPK 14:29:8 + Ca + S + Mg + TE) were applied

Table 1. Treatments description.

Treatment	Description	Amount of organic fertilizer (t Ha ⁻¹)	Amount of inorganic fertilizer (kg Ha ⁻¹)
T1	Water hyacinth vermicompost	5	0
T2	Water hyacinth EM compost	5	0
T3	Water hyacinth Ordinary compost	5	0
T4	Positive control (NPK 14:29:8 + Ca + S + Mg + TE)	0	200
T5	Negative control (No fertilizer)	0	0

Table 2. Initial Soil physical and chemical properties of the study sites.

Fertility results	Kisii		Siaya	
	Value	Class	Value	Class
Soil pH	4.15	extremely acidic	5.2	Strongly acidic
Exch. Acidity me%	1.4	High	1.1	High
Total Nitrogen%	0.12	Low	0.18	Low
Total Org. Carbon%	1.40	Moderate	0.96	Low
Phosphorus ppm	32	Adequate	43	Adequate
Potassium me%	0.34	Adequate	0.72	Adequate
Calcium me%	0.2	Low	0.4	Low
Magnesium me%	3.12	High	0.83	Adequate
Manganese me%	0.60	Adequate	0.33	Adequate
Copper ppm	5.09	Adequate	3.5	Adequate
Iron ppm	57.3	Adequate	63.6	Adequate
Zinc ppm	6.20	Adequate	11.2	Adequate
Sodium me%	0.21	Adequate	0.15	Adequate
Elect. Cond. mS/cm	0.11	Adequate	0.32	Adequate
Sand%	50	-	56	-
Silt%	8	-	17	-
Clay%	42	-	27	-
Texture Class	SC	sandy clay	SCL	Sandy clay loam
Bulk density (g/cm ³)	1.22	Favourable	1.27	Favourable
Cat. Exch. Cap. me%	24.5	Medium	28.4	Medium
Base saturation%	28	Low	32	Low
ESP	3.3	Adequate	2.7	Adequate

at the recommended rate of 5 t Ha⁻¹ and 200 kg Ha⁻¹ (NO₃⁻ = 28, P₂O₅ = 56, K₂O = 16, Ca²⁺ = 8, S²⁻ = 8, Mg²⁺ = 2, Zn²⁺ = 0.2 and BO₃⁻ = 0.2 kg) respectively. Calcium ammonium nitrate (CAN) was applied at the recommended rate of 200 kg Ha⁻¹ in two splits as a top dress for all treatments receiving inorganic fertilizer. All agronomic practices including ploughing, weeding, irrigation and pest management (fall armyworm) were undertaken uniformly in all plots (Table 1).

Analysis of soil physical and chemical properties

Soils were obtained from the fields with acrisols and ferralsols as the predominant soil type in the study fields. Soils (0-20 cm depth)

were sampled from twenty spots in each field using the random sampling method and composited. The physiochemical and biological properties of the composite samples were analyzed for initial soil characterization at NARL, Nairobi (Table 2). Soil water holding capacity was determined by capillary action technique and bulk density by water displacement method (Estefan et al., 2013). Soil texture was determined by Bouyoucos hydrometer method and the textural class determined using the soil textural triangle as described by Okalebo et al. (2002). Total organic carbon (TOC) was extracted by the potassium dichromate oxidation method and determined by titration of unreduced dichromate with ferrous ammonium sulfate as described by Estefan et al., 2013. Soil pH and electrical conductivity (EC) was measured potentiometrically in 1:2.5 soils: water (H₂O) solution using a combined glass electrode

pH meter and EC meter respectively (Okalebo et al., 2002). Total exchangeable acidity was determined by saturating the soil samples with 1 M potassium chloride (KCl) solution as described by Okalebo et al. (2002). From the same extract, exchangeable aluminium (Al) in the soil samples was determined by application of 0.1 M NaOH. Acid saturation (AS) was calculated from exchangeable acidity and cation exchange capacity (Okalebo et al., 2002). Total nitrogen content of the soil was determined by wet-oxidation procedure of the Kjeldahl distillation method as described by Haluschak (2006). Available phosphorus was extracted by Mehlich III method and the determination by UV-VIS spectrophotometry as described by Kovar and Pierzynski (2009).

Exchangeable basic cations (Ca, Mg, K, and Na) were determined by saturating the soil samples with 1M NH₄OAc solution at pH 7.0. Then Ca and Mg were determined by using atomic absorption spectrophotometry (AAS), while exchangeable Na and K were measured by flame photometer from the same extract. The cation exchange capacity (CEC) of the soil was determined from the NH₄⁺ saturated samples that were subsequently replaced by K⁺ from KCl solution (Estefan et al., 2013). The extractable micronutrients (Fe, Mn, Zn, and Cu) were extracted by diethylene triamine pentaacetic acid (DTPA) as described by Okalebo et al. (2002). At the end of the field study, composite top soil (0-20 cm) samples were collected from each experimental unit and were analyzed to determine the changes in selected soil properties (pH and EC) using the methods described above.

Analysis of maize growth and yield parameters

Data on crop emergence (%) was taken two weeks after planting. Plant height was measured in cm from the soil surface to most recent mature leaf of 16 randomly taken plants from the net plot area during the first nine weeks at an interval of three weeks after planting (Hernandez et al., 2010). Data on days to tasseling was taken when 50% of the sampled plants have tasseled. Nutrient uptake (%) was determined through plant tissue analysis, where the most recent mature leaf material was sampled at mid tasseling, washed with distilled water, air dried and then oven dried at 65°C for 24 h. It was grounded with a Wiley mill to quantify total N, P and K by means of the standard laboratory procedures as described by Estefan et al. (2013). Grain yield (GY) per plot was weighed in kg/plot, adjusted to 13% moisture content then converted to kg Ha⁻¹ (Kannan et al., 2013). Total above ground dry biomass yield (kg Ha⁻¹) for each plot were recorded after harvesting and air drying the samples to constant weight. Harvest index (Equation ii) was determined according to He et al. (2012).

$$\text{Harvest Index (HI)} = \frac{\text{Economic (grain) yield}}{\text{Total above ground biomass at maturity}} \quad (1)$$

Nutrient use efficiency were computed for N, P and K according to Burzaco et al. (2014) as follows:

$$\text{Apparent Crop Nutrient Recovery Efficiency (NRE) (\%)} = \frac{(U - U_0)}{F} \times 100 \quad (2)$$

$$\text{Partial Nutrient Balance (PNB)} = \frac{U_H}{F} \quad (3)$$

$$\text{Agronomic Efficiency of Applied Nutrient (AE) (\%)} = \frac{Y - Y_0}{F} \quad (4)$$

Where, F = amount of nutrient applied (as fertilizer or manure), Y = yield of the harvested portion of the crop with applied N,

Y₀ = yield of control with no applied nutrient, U_H = nutrient content of harvested portion of the crop, U = the total nutrient uptake in aboveground crop biomass with applied N and U₀ = the total nutrient uptake in aboveground crop biomass with no N applied.

Statistical analysis of data

All statistical analyses were conducted using SAS computer software version 9.2 (SAS, 2004) for Windows. The measured parameters were tested for normality by Shapiro-Wilk procedure prior to analysis of variance (ANOVA). Since the variation between sites was significant, the data was subjected to single site analysis of variance to determine the effect of fertilizer application on soil properties, maize growth and yield (Gomez and Gomez, 1984). Least significant difference (LSD) test was employed to test the significant difference between treatments means.

RESULTS

Selected soil properties (pH and EC)

Vermicompost significantly increased the soil pH by 0.5 units in Siaya and 1.2 units in Kisii site within 5 months (Table 3). Therefore, the ferralsol was more responsive to pH change compared to the acrisol. Vermicompost was in particular a better remedy for amending extremely acidic soils of Kisii. EM compost and thermophilic compost also performed sparingly well in amending extremely acidic soils; pH increased by 0.1 and 0.9 units, respectively. In Kisii, there was a 0.1 unit increase in soil pH under inorganic fertilizer (NPK 14:29:8 + Ca + S + Mg + TE). Under negative control, there was 0.5 units decrease in soil pH for extremely acidic soils. In Siaya, both the negative and positive control resulted in a decrease in soil pH (0.4 and 0.6 units respectively).

The highest soil EC was observed under inorganic fertilizer treatment; 0.46 in Siaya and 0.51 in Kisii. This was 0.14 units increase in EC from 0.32 mS/cm in Siaya and 0.4 units increase in soil EC from 0.11 mS/cm in Kisii within 5 months respectively. Therefore, the ferralsol was also more responsive to EC change compared to the acrisol. EM compost in particular increased soil EC by 0.1 mS/cm in Siaya and 0.36 mS/cm in Kisii. Vermicompost and thermophilic compost sparingly increased soil EC (0.03 and 0.1 units increase in soil EC in Siaya, 0.3 and 0.23 units increase in soil EC in Kisii respectively). Under negative control, there was 0.03 units increase in soil EC for acrisols and 0.21 units increase in soil EC for ferralsols (Table 3).

Maize growth and yield

Growth parameters

The effect of fertilizer treatments on maize growth parameters (crop emergence, plant height and days to 50% tasseling) was significant at P<0.05 (Table 4 and

Table 3. Mean soil pH and EC as affected by fertilizer application for two regions in Lake Victoria basin.

Fertilizer	Siaya		Kisii	
	pH	EC (mS/cm)	pH	EC (mS/cm)
Vermicompost	5.7 ^a	0.35 ^b	5.3 ^a	0.41 ^b
EM Compost	5.3 ^b	0.42 ^a	5.1 ^{ab}	0.47 ^a
Thermophilic Compost	5.3 ^b	0.42 ^a	5.0 ^b	0.34 ^c
Inorganic Fertilizer	4.6 ^c	0.46 ^a	4.2 ^c	0.51 ^a
No Fertilizer	4.8 ^c	0.35 ^b	4.1 ^c	0.32 ^c
LSD	0.3*	0.05*	0.3*	0.05*

*LSD at 0.05 **LSD at 0.01 ns-not significant. Means followed by the same letter are not significantly different at 5% probability by LSD.

Table 4. LSD mean separation for maize growth parameters as affected by fertilizer application.

Fertilizer	Crop emergence (%)		Days to 50% tasseling	
	Siaya	Kisii	Siaya	Kisii
Vermicompost	92.5 ^a	90.0 ^a	66 ^c	75 ^c
EM compost	90.8 ^a	88.3 ^a	69 ^{bc}	78 ^{bc}
Thermophilic compost	90.8 ^a	88.3 ^a	67 ^{bc}	76 ^{bc}
Inorganic fertilizer	85.0 ^b	81.7 ^b	70 ^b	79 ^{bc}
No fertilizer	92.5 ^a	90.8 ^a	82 ^a	93 ^a
LSD	5.57*	5.89*	3*	3*

*LSD at 0.05 **LSD at 0.01 ns-not significant. Means followed by the same letter are not significantly different at 5% probability by LSD.

Figure 1). A mean crop emergence of 92.5 and 90.8% in Siaya and Kisii respectively was recorded as the highest, two weeks after planting from the plots with no fertilizer treatment and vermicompost treatment; while the lowest crop emergence was recorded under inorganic fertilizer treatment. A mean plant height of 208.4 and 239.4 cm in Siaya and Kisii respectively were recorded as the highest on week nine after planting from the plots treated with vermicompost. This was significantly different from the rest of the treatments. The negative control (no fertilizer treatment) had a significantly lower plant height as compared to organic amendments and inorganic fertilizer. A mean of 66 days and 75 days in Siaya and Kisii, respectively was recorded as the shortest days to 50% tasseling from the plots treated with vermicompost. The longest duration (82 days in Siaya and 93 days in Kisii) to 50% tasseling was recorded under no fertilizer treatment, which was also significantly different from organic amendments and inorganic fertilizer.

Yield parameters

The results of ANOVA showed that the effect of fertilizer treatments on maize yield parameters (total aboveground

biomass, grain yield, harvest index and nutrient use efficiency) was significant at $P < 0.05$ (Table 5 to 7 and Figures 2 to 3).

Total aboveground biomass (TAB)

The highest mean total aboveground biomass (TAB) was recorded in plots treated with vermicompost in both regions. TAB for maize under thermophilic compost and inorganic fertilizer was not significantly different in both regions. The negative control (no fertilizer treatment) had a significantly lower mean TAB as compared to organic amendments and inorganic fertilizer (Table 5).

Grain yield (GY)

The highest mean grain yield (5580 kg Ha⁻¹ in Kisii and 4428 kg Ha⁻¹ in Siaya) was recorded in plots treated with vermicompost, while the lowest (1260 kg Ha⁻¹ in Kisii and 1094.78 kg Ha⁻¹ in Siaya) was recorded under no fertilizer treatment. Maize grain yield under EM compost and thermophilic compost treatments was not significantly different in both regions. Inorganic fertilizer performed

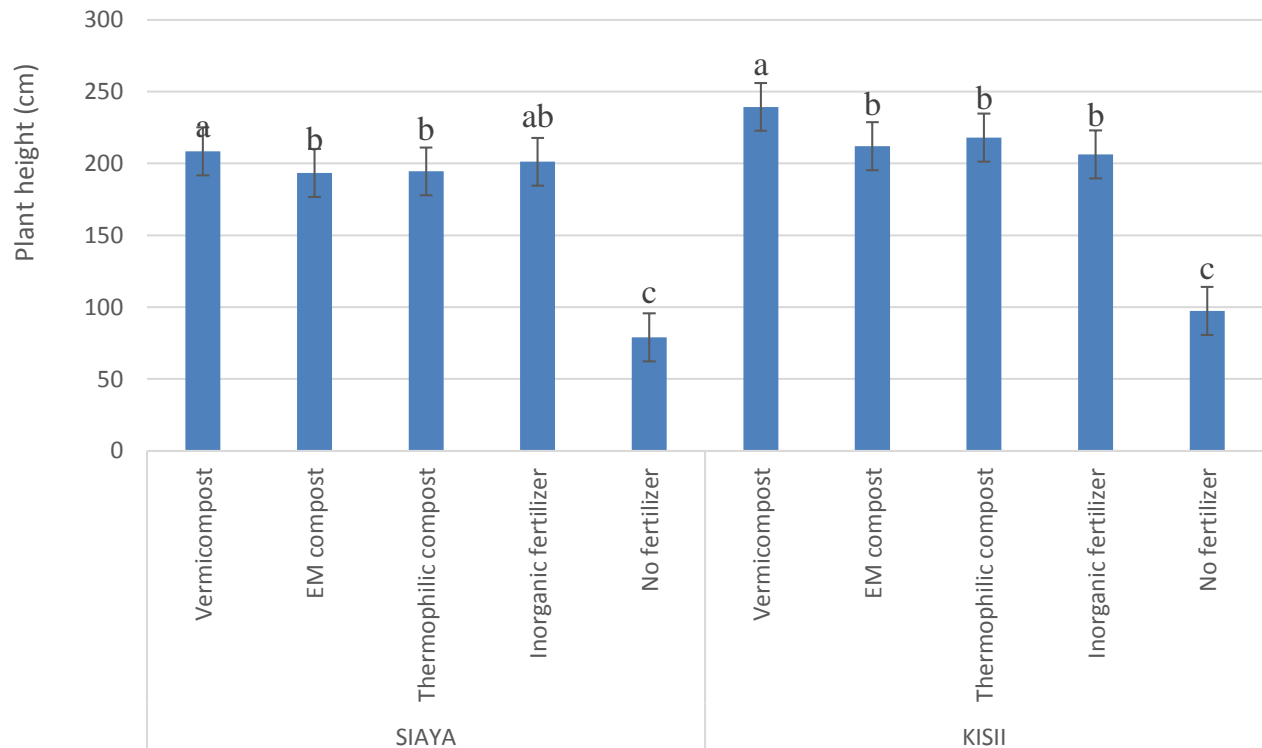


Figure 1. Mean maize plant height on week nine after planting in two regions of Lake Victoria basin as affected by fertilizer application. The error bars represent the standard errors (SE). The letters a, b and c represent the means separations using the LSD. Means represented by different letters are significantly different at $P \leq 0.05$.

Table 5. LSD mean separation for maize yield parameters as affected by fertilizer application.

Fertilizer	Total Aboveground Biomass (kg Ha ⁻¹)		Harvest Index (%)	
	Siaya	Kisii	Siaya	Kisii
Vermicompost	17696.3 ^a	22566.0 ^a	25.03 ^a	24.74 ^a
EM compost	15208.4 ^a	18703.5 ^c	24.10 ^b	24.45 ^{ab}
Thermophilic compost	15266.5 ^b	20556.8 ^b	22.90 ^c	22.67 ^c
Inorganic fertilizer	16796.9 ^b	19193.7 ^{bc}	24.71 ^{ab}	23.60 ^{bc}
No fertilizer	6831.9 ^c	8240.9 ^d	16.03 ^d	15.33 ^d
LSD	1080.7*	1807.6*	0.85**	1.09*

*LSD at 0.05 **LSD at 0.01 ns-not significant. Means followed by the same letter are not significantly different at 5% probability by LSD.

Table 6. LSD mean separation for nutrient uptake (kgHa⁻¹) as affected by fertilizer application.

Fertilizer	P Uptake		K Uptake	
	Siaya	Kisii	Siaya	Kisii
Vermicompost	41.72 ^a	21.94 ^b	63.73 ^a	63.18 ^a
EM compost	33.57 ^b	23.01 ^b	52.44 ^b	64.05 ^a
Thermophilic compost	33.90 ^b	20.61 ^b	52.23 ^b	59.52 ^a
Inorganic fertilizer	39.60 ^a	27.12 ^a	51.01 ^b	44.87 ^b
No fertilizer	11.67 ^c	14.17 ^d	15.92 ^c	28.11 ^c
LSD	4.17*	3.23*	9.94*	5.51*

*LSD at 0.05 **LSD at 0.01 ns-not significant. Means followed by the same letter are not significantly different at 5% probability by LSD.

Table 7. Agronomic efficiency (AE), nutrient recovery efficiency (NRE) and partial nutrient balance (PNB) for applied nitrogen in two environment.

Fertilizer Type	Environment					
	Siaya			Kisii		
	AE	NRE (%)	PNB	AE	NRE (%)	PNB
VC	24.51	71.84	0.9395	31.77	70.99	0.9618
EMC	23.57	63.72	0.9130	30.40	68.24	0.9967
TC	21.53	61.36	0.8833	30.46	66.95	0.9754
IF	38.18	99.25	1.3683	40.88	62.08	1.0491

VC- vermicompost, EMC-effective microorganisms compost, TC-thermophilic compost, IF-inorganic fertilizer.

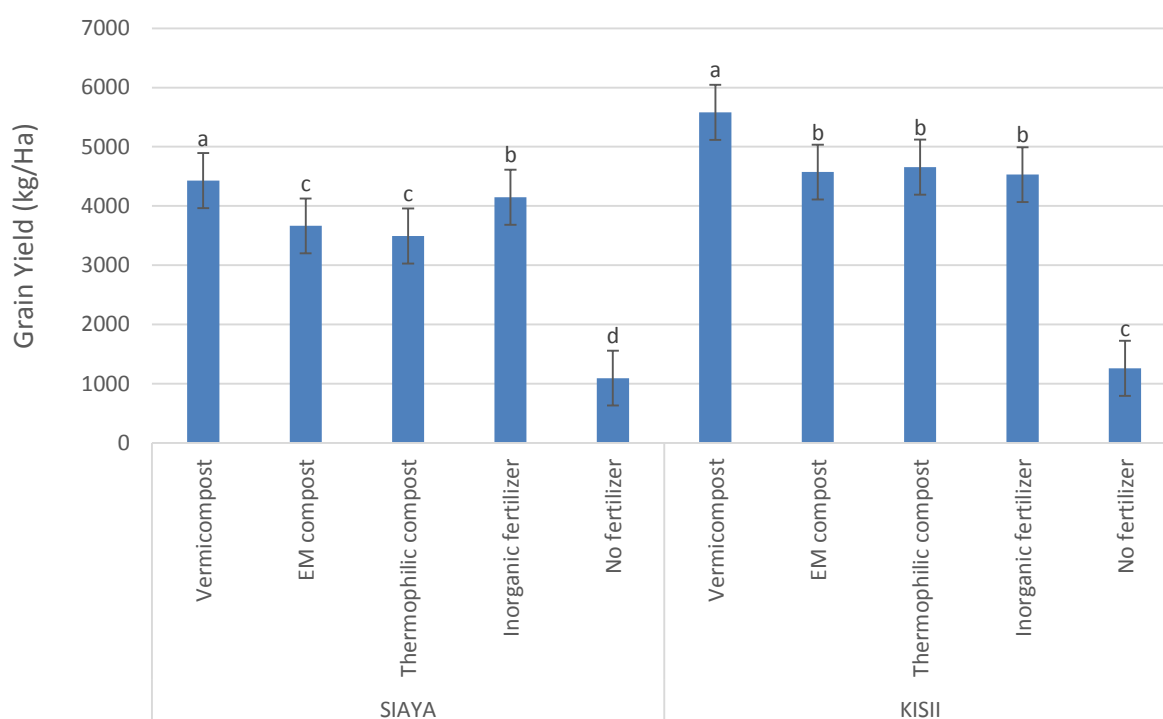


Figure 2. Maize grain yield in two regions of Lake Victoria basin as affected by fertilizer application. The error bars represent the standard errors (SE). The letters a, b, c and d represent the means separations using the LSD. Means represented by different letters are significantly different at $P \leq 0.05$.

fairly well in Siaya as compared to EM compost and thermophilic compost treatments. However, in Kisii, the treatments were not significantly different (Figure 2).

Harvest index (HI)

The highest mean grain HI (25.03% in Siaya and 24.74% in Kisii) was observed in plots treated with vermicompost, while the lowest (16.03% in Siaya and 15.33% in Kisii) was observed when no fertilizer was applied (Table 5). Harvest index for maize under EM compost and thermophilic compost was also significantly different in both regions. In Siaya region, there was no significant

difference between maize grain harvest index under vermicompost and inorganic fertilizer. However, the two were significantly different in Kisii region, with the latter (inorganic fertilizer) being insignificantly different from EM compost.

Nutrient uptake

Maize nutrient uptake was significantly affected by fertilizer treatment (Table 6 and Figure 3). The highest mean nitrogen (N) uptake was recorded under vermicompost treatment. The amount obtained under no fertilizer treatment in both sites was four fold. Higher

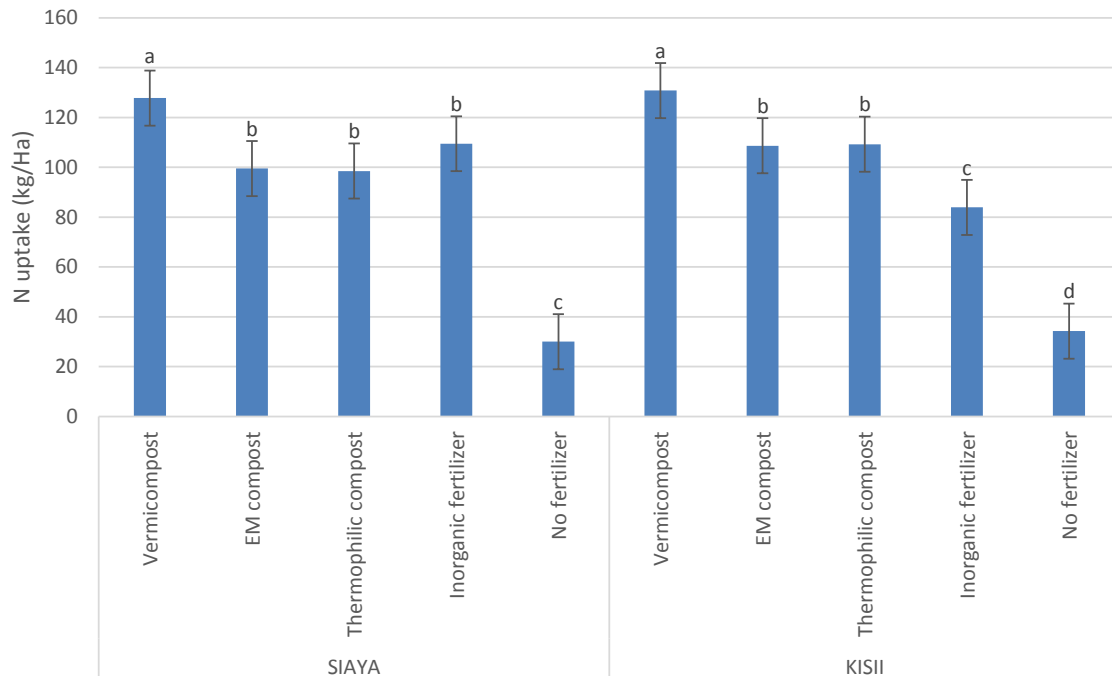


Figure 3. Maize nitrogen uptake in two regions of Lake Victoria basin as affected by fertilizer application. The error bars represent the standard errors (SE). The letters a, b, c and d represent the means separations using the LSD. Means represented by different letters are significantly different at $P \leq 0.05$.

mean phosphorus (P) uptake was recorded under vermicompost in Siaya and inorganic fertilizer in Kisii region. P uptake under EM compost and thermophilic compost was not significantly different in both regions. The highest mean potassium (K) uptake was recorded under Vermicompost and EM compost in Siaya and Kisii respectively. As expected, low nutrient uptake was observed in no fertilizer treatment as compared to other treatments.

Nutrient use efficiency (NUE)

The highest agronomic efficiency (AE) was recorded under inorganic fertilizer followed by vermicompost treatment as shown in Table 7. The highest nitrogen recovery efficiency (NRE) was also recorded under inorganic fertilizer treatment (99.25% at Siaya) and vermicompost (70.99% at Kisii). Higher mean partial nitrogen balance (PNB) was achieved through inorganic fertilizer (Table 7) in both regions.

DISCUSSION

Selected soil properties

The addition of organic amendments regulated soil acidity in both sites. This indicates adsorption of exchangeable Al and Fe onto the composts causing an increase in soil pH (Seufert et al., 2012). A higher rise in

soil pH occurred under vermicompost as compared to other fertilizer treatments. This is in line with a study by Liu et al. (2019) on remediation effectiveness of vermicompost for a potentially toxic metal contaminated tropical acidic soil, where vermicompost amendment increased soil pH by 0.7 to 1.5 units. The Kisii site was previously forested and soils were extremely acidic. Inorganic fertilizer treatments fairly maintained initial soil pH in Kisii region (Figure 1). However, this was not the same case in Siaya as application of inorganic fertilizer resulted in 0.6 units decrease in soil pH. Low availability of basic cations in the soil may have resulted to soil mining of basic cations by plants, thus replaced by acidic cations in the soil exchange complex. This is in line with Singh et al. (2016) who also reported that application of inorganic fertilizer especially acidifying fertilizers might result into soil degradation over time. Higher soil electrical conductivity reported under inorganic fertilizer treatment as compared to the initial soil EC may have been due to additional salts from the fertilizer (Table 3). Organic amendments also increased soil EC and this may be due to high salt content of poultry litter (Dhal et al., 2012).

Maize growth and yield parameters

Crop emergence

The ideal crop emergence of $\geq 88\%$ (Mburu et al., 2011)

was obtained with organic amendments and no fertilizer treatment. Inorganic fertilizer recorded low crop emergence especially in Kisii station (Table 4). Application of inorganic fertilizer may have induced fertilizer scorching effect in some planting hills, impeding germination process and thus the statistical difference with the rest of the treatments. According to Hernandez et al. (2010), seedling emergence in the soil is a factor of germination index and prevailing soil conditions.

Plant height (cm)

The higher mean plant height obtained on plots treated with water hyacinth compost and inorganic fertilizer as compared to no fertilizer treatment may be attributed to the role of essential plant nutrients in improving plant growth vigour. This is in harmony with the findings of Kannan et al. (2013) and Abera et al. (2019) who reported that integrated nutrient management has positive effect on maize height. Manish et al. (2017) also reported that the tallest plant height was observed on the plots treated by VC and cattle manure, whereas the shortest was in the control. Similarly, Atarzadeh et al. (2013) also described that VC contains many humic acids which improve morphological traits of the crop and, thus, increase plant height. According to Mburu et al. (2011) and Kannan et al. (2013), chemical fertilizers offer soluble nutrients which are instantly availed to the maize plants hence perform significantly better compared to the control.

Organic amendments provides the nutrients slowly but steadily and improve the soil's physical properties over time and thus enhancing better uptake of nutrients by the crop (Amitava et al., 2008). The significant difference among the fertilizer treatments on maize plant height in both regions could probably have been due to the variations in soil pH and physical conditions like soil structure, texture, bulk density and water holding capacity that favoured microbial action releasing the nutrients from the soil (Chukwuka and Omotayo, 2009). Inorganic fertilizer significantly increased the maize plant height in both regions compared to no fertilizer treatment due to the availability of plant nutrients in soluble form that require low energy utilization by the plants for uptake to build up their dry biomass hence improving plant growth vigour (Achieng et al., 2010; Mohsin et al., 2012). The highest plant height reported in maize plots amended with vermicompost as compared to the rest of the treatments may be due to the efficacy of red worms in turning organic matter into more bioavailable forms for plant uptake (Gupta et al., 2007).

Days to 50% tasseling

The environment significantly affected the number of days taken by maize plant to attain 50% tasseling in

addition to fertilizer treatment. This may be due to variation in soil temperature and relative humidity which affects the rate of photosynthesis and transpiration (Canatoy, 2018). Phosphorylation is directly affected by air humidity which is a factor of temperature and moisture content variation (Atarzadeh et al., 2013). Early transition in maize growth stages (including days to 50% tasseling) reported in plots treated with vermicompost as compared to the rest of the treatments in both regions (Table 4) may be attributed to increase in plant growth vigour as a result of favourable soil conditions created by vermicompost (Van Haute, 2014).

Total aboveground biomass

Application of water hyacinth compost and inorganic fertilizer led to a higher mean total aboveground biomass (TAB) of maize as compared to no fertilizer treatment probably due to the release of considerable amounts of essential plant nutrients during mineralization that were utilized for plant development (Kamau et al., 2012; Biswasi et al., 2020). The higher TAB recorded for maize plants grown on soil amended with vermicompost (Table 5) compared to the rest of the treatments in both regions could be attributed to the availability of plant macronutrients more readily in vermicompost (Munroe, 2007). NPK also readily provided phosphorus that probably enhanced root development thus the higher TAB in maize. These results are in line with that of Makinde and Ayoola (2010), who demonstrated that the application of organic manure as fertilizers provides growth-regulating substances and improves physicochemical and microbial properties of soils. The total aboveground biomass weight after harvest was higher in maize plants grown in soil amended with vermicompost compared to the rest of organic amendments (EM compost and thermophilic compost) probably due to the release of considerable amounts of nutrients, especially nitrogen, to the plant during mineralization that were utilized for photosynthesis hence better plant development (Sharma et al., 2017).

Grain yield

The application of water hyacinth compost and inorganic fertilizer led to higher grain yield compared to no fertilizer treatment probably due to considerable release of essential plant nutrients during mineralization that were utilized for photosynthesis hence better plant growth and grain setup (Figure 2). The result is in agreement with Adrien et al. (2010), who reported that the application of composted paper sludge as organic soil amendment led to high maize yields. Babbu et al. (2015) also reported that the highest maize grain yield was in treatment having NPK with FYM, whereas the lowest was in non-treated plots showing the beneficial effects of manure on crop

performance. The maximum grain yield might be due to the higher association among plant height, cob length, grain numbers per cob, and aboveground biomass. This is in consent with the reports of Negasi (2014), who stated that organic manure plays a significant role in plant nutrition through its positive effects on nutrient supply to plant roots, in improving soil structure, water holding capacity, and other soil properties.

Grain yield potential for Kisii region was higher than that of Siaya possibly due to variation in other environmental factors other than soil fertility during the growing period. The plots treated with vermicompost had a higher maize grain yield in both regions compared to the rest of the treatments probably due to the higher amount of N, K and Ca in bioavailable forms which are essential for grain development (Pandit et al., 2019). Continuous application of compost over time has been reported to produce significantly better results compared to inorganic fertilizer due to its slow but steady release of nutrients over time (Yagoub et al., 2012). The lowest grain yield reported under no fertilizer treatment in both sites might be due to the deficiency of essential plant nutrients (Jagwe et al., 2019). Water hyacinth compost effectively regulated the soil acidity probably by binding the exchangeable aluminium ions in the acidic soils besides releasing plant nutrients slowly hence equally improved plant growth vigour and higher maize grain yield compared to the negative control in both regions (Seufert et al., 2012).

Harvest index

Fertilizer application significantly improved maize harvest index as compared to no fertilizer treatment. This might be due to the increment of the availability of essential nutrients for crops when the acidic soils were treated with organic amendments and inorganic fertilizer (Mburu et al., 2011; Abera et al., 2019). According to Hamidia et al. (2010), mineral P plays great role for maximum utilization of nutrients in acidified soils. The highest mean harvest index obtained with vermicompost as compared to the rest of the treatments could be attributed to the role of earthworms in converting plant nutrients in organic matter into more bioavailable form for plant uptake and the role of organic amendments in improving soil physical properties (Dominguez and Edwards, 2011). The results showed that harvest index directly correlates with grain yield and total above ground biomass of the crop as supported by Burzaco et al. (2014) equation. For instance, despite the fact that mean grain yield under EM compost and thermophilic compost were not significantly different, the harvest index obtained with EM compost was slightly higher compared to the later due to the variation in aboveground biomass. The presence of effective microbes in EM compost might have increased microbial action hence faster release and absorption of

nutrients especially micronutrients from the compost required for grain development (Sharma et al., 2017). Therefore, thermophilic compost favoured more vegetative growth in maize resulting into higher plant biomass yield as opposed to grain yield.

Nutrient uptake and nutrient use efficiency

Improvement in nutrient concentration of maize plant tissue reported in plots treated with water hyacinth compost and inorganic fertilizer, in comparison to no fertilizer treatment can be attributed to increased availability of essential plant nutrients concentration in the soil (Table 6). Water hyacinth compost contains high amounts of organic matter which could have increased the moisture retention of soil, improved dissolution of nutrients particularly phosphorus and soil structure hence better root growth and nutrient uptake (Sharma et al., 2017). Sánchez et al. (2017) also reported the highest yield and tissue concentrations of K and P where compost consisting of chicken manure was applied. The highest N uptake obtained with vermicompost treatment as compared to EM compost and thermophilic compost can be attributed to the role of red worms in converting organic matter into more bioavailable form (Gupta et al., 2007). Vermicompost and inorganic fertilizer treatments improved N recovery efficiency in maize crop as compared to other treatments probably due to presence of readily mineralizable plant nutrients (Table 7). According to Snyder and Bruulsema (2007), nutrient recovery efficiency (NRE) of 50-90% is desirable; greater than 90%, risk of soil mining (soil nutrient depletion) occurs and less than 50% (very low NRE) risk of inefficient N use (N pollution) occurs. For instance, N recovery of 45% means that about 55% of N applied is lost beyond the root zone maybe through volatilization and leaching. Therefore, despite high N recovery efficiency (99%) for plots treated with inorganic fertilizer, there was a higher risk of soil nutrient mining.

The partial N balance in the soil after crop harvest in plots treated with organic fertilizers was very sustainable (<1) while that obtained with inorganic fertilizer was quite unsustainable (>1) in both regions (Table 7), further confirming the risk of soil N mining. Partial nutrient balance (PNB) refers to the ratio of the quantity of nutrients removed in harvested crop portions to the quantity of nutrients applied (Snyder and Bruulsema, 2007). A PNB value close to one indicates that mass balance exists and therefore sustainable. Agronomic efficiency (AE) considers how much the yield of a crop is increased per unit of nutrient applied. Higher agronomic efficiency obtained with inorganic fertilizer in both regions compared to organic fertilizer treatment may be due high crop nutrient recovery efficiency and presence of lime (CaO) in inorganic fertilizer which neutralized soil acidity over a short period of time (Mburu et al., 2011).

Conclusion

The use of organic amendments has shown high potential to mitigate soil acidity, improve soil fertility and eventually crop yield sustainably. The results of the study demonstrated that there was a significant increase in growth and yield components of maize due to the application of organic amendments and mineral fertilizer over no fertilizer treatment. However, the long-term adverse effect of inorganic fertilizer especially acidifying fertilizer on the soil and the environment makes its use undesirable. Therefore, compost from water hyacinth, which is locally available, can be effectively used as an organic soil amendment for soil restoration and crop production. Maize crop has a high nutrient requirement and sensitive to soil acidity, thus cannot perform well in infertile and extremely acidic soils. Therefore, application of organic fertilizer with readily mineralizable nutrients (vermicompost) has paramount importance in reclaiming infertile and acidic soils and improving maize growth and yield components. Since vermicompost contains essential plant nutrients in bioavailable forms, it could be recommended as the best alternative to inorganic fertilizer for reclaiming infertile and acidic soils in order to improve plant nutrients availability for enhanced productivity.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors appreciate the Center of Excellence for Sustainable Agriculture and Agribusiness Management (CESAAM) for funding this research project. Also, they are grateful to the National Agricultural Research Laboratories (NARL, Kenya) and Egerton University for the opportunity and support during analysis of this work in their laboratories. Finally, the authors sincerely appreciate Dala Rieko community based organization, Siaya County and Kisii National Polytechnic, Kisii County for availing their lands for experimental trials.

REFERENCES

- Abera T, Tufa T, Kumbi H, Tola B (2019). Evaluation of Vermicompost and NPS Fertilizer Rate on Yield and Yield Components of Highland Maize in Vertisols of Ambo. Results of Natural Resources Management Research.
- Achieng JO, Ouma G, Odhiambo G, Muyekho F (2010). Effect of farmyard manure and inorganic fertilizers on maize production on Alfisols and Ultisols in Kakamega, western Kenya. *Agriculture Biology Journal of Nature* 1(4):430-439.
- Amitava R, Sarkar N, Debashish S (2008). Influence of organic manures on productivity of two varieties of rice. *Journal of Central European Agriculture* 9(4):629-634.
- Atarzadeh SH, Mojaddam M, Nejad T (2013). The interactive effects of humic acid application and several of nitrogen fertilizer on remobilization of star wheat. *International Journal of Biosciences* 3(8):116-123.
- Babbu SB, Jagdeep S, Gurbir S, Gurpreet K (2015). Effects of Long Term Application of Inorganic and Organic Fertilizers on Soil Organic Carbon and Physical Properties in Maize–Wheat Rotation. *Agronomy* 5:220-238.
- Biswasi SK, Barik AK, Bastia DK, Dalei B, Nayak L, Ray M (2020). Effect of Integrated Nutrient Management on Growth, Productivity and Economics of Hybrid Maize in Odisha State.
- Burzaco JP, Ciampitti IA, Vyn TJ (2014). Nitrapyrin impacts on maize yield and nitrogen use efficiency with spring-applied nitrogen: Field studies vs. meta-analysis comparison. *Agronomy Journal* 106:753-760.
- Canatoy RC (2018). Effects of vermicompost on the growth and yield of sweet corn in Bukidnon, Philippines. *Asian Journal of Soil Science and Plant Nutrition* pp. 1-8.
- Chukwuka KS, Omotayo OE (2009). Soil fertility restoration potentials of *Tithonia* green manure and water hyacinth compost on a nutrient depleted soil in South Western Nigeria using *Zea mays* L. as test crop. *European Journal of Soil Biology* 1:20-30.
- Dhal GC, Roshan SW, Khwairakpam M, Kalamdhad AS (2012). Composting of water hyacinth using Saw dust/Rice straw as a bulking agent. *International Journal of Environmental Sciences* 2(3):1223-1238.
- Dominguez J, Edwards CA (2011). *Biology and ecology of earthworm species used for vermicomposting*. CRC Press USA. Elvira C, Sampedro.
- Estefan G, Sommer R, Ryan J (2013). *Methods of soil, plant, and water analysis. A manual for the West Asia and North Africa region*.
- Feller C, Blanchart E, Bernoux M, Lal R, Manlay R (2012). Soil fertility concepts over the past two centuries: the importance attributed to soil organic matter in developed and developing countries. *Archives of Agronomy and Soil Science* 58:S3-S21.
- Gajalakshmi S, Abbasi S (2004). Vermiconversion of paper waste by earthworm born and grown in the waste-fed reactors compared to the pioneers raised to adulthood on cow dung feed. *Biological Resource Technology* 94:53-56.
- GoK (2015). *Economic Review of Agriculture (ERA)*. Government of Kenya. Ministry of Agriculture, Livestock and Fisheries, Nairobi, Kenya. Available at: http://www.kilimo.go.ke/wp-content/uploads/2015/10/Economic-Review-of-Agriculture_2015-6.pdf
- Gomez KA, Gomez AA (1984). *Statistical procedures for agricultural research* (2nd ed.). John Wiley and Sons, 1984.
- Gupta R, Mutiyar PK, Rawat NK, Saini MS, Garg VK (2007). Development of a water hyacinth based vermireactor using an epigeic earthworm *E. foetida*. *Biological Resource Technology* 98:2605-2610.
- Hamidia A, Khodabande N, Mohammad AD (2010). Plant density and nitrogen effects on some traits of maize (*Zea mays* L.). *Plant Ecophysiology* 2:47-52.
- Haluschak P (2006). *Laboratory methods of soil analysis*. Canada-Manitoba Soil Survey pp. 3-133.
- He P, Jin J, Wang H, Cui R, Li C (2012). Yield responses and potassium use efficiency for winter wheat in North-Central. *Better Crops* 96:28-30.
- Hernandez A, Castillo H, Ojeda D, Arras A, Lopez J, Sanchez E (2010). Effects of vermicompost and compost on lettuce production. *Chilean Journal of Agricultural Research* 70:583-589.
- International Soil Reference and Information Centre (ISRIC) (2007). *Soils of the world and their properties*. Available online at: <http://www.isric.org>
- Jaetzold R, Schmidt H, Hornetz B, Shisanya C (2010). *Farm Management Handbook of Kenya* (2nd ed.). Gesellschaft für Internationale Zusammenarbeit, 2(A2), Nyanza Province. Brookpak Printing and Supplies, Nairobi, Kenya.
- Javaid A, Shah MBM (2010). Growth and Yield Response of Wheat to EM (effective microorganisms) and Parthenium Green Manure. *African Journal of Biotechnology* 9:3373-3381.
- Jjagwe J, Chelimo K, Karungi J, Komakech AJ, Lederer J (2019).

- Comparative performance of organic fertilizers in maize (*Zea mays* L.) growth, yield, and economic results. *Agronomy* 10(1):69
- Kamau JK, Chemining'wa GN, Nderitu JH, Ambuko J (2012). Growth, yield and quality response of snap bean (*Phaseolus vulgaris* L.) plants to different inorganic fertilizers applications in central Kenya. *Journal of Applied Biosciences* 55:3944-3952.
- Kannan RL, Dhivya M, Abinaya D, Krishna RL, Krishnakumar S (2013). Effect of integrated nutrient management on soil fertility and productivity in maize. *Bulletin of Environmental, Pharmacology and Life Sciences* 2(8), 61-67.
- Kovar, J. L., & Pierzynski, G. M. (2009). *Methods of phosphorus analysis for soils, sediments, residuals, and waters* second edition. Southern cooperative series bulletin 408 p.
- Liu B, Wua CH, Pana P, Fua Y, Heb Z, Wua L, Li Q (2019). Remediation effectiveness of vermicompost for a potentially toxic metal contaminated tropical acidic soil in China. *Ecotoxicology, Environment and Safety* 182:109394.
- Makinde EA, Ayoola OT (2010). Growth, yield and NPK uptake by maize with complementary organic and inorganic fertilizers. *African Journal of Food, Agriculture, Nutrition and Development* 10(3).
- Manish KP, Prakash M, Salikram G (2017). Growth Attributing Traits of Maize Affected by Different Nutrient Management in Lamjung Nepal. *International Journal of Applied Sciences and Biotechnology* 5(1):98-101.
- Mburu MW, Lenga FK, Mburu D (2011). Assessment of maize yield response to nitrogen fertilizer in two semi-arid areas of Kenya with similar rainfall pattern. *Journal of Agriculture, Science and Technology* 13(1):22-34
- Mohsin AU, Ahmad J, Ahmad AU, Ikram RM, Mubeen K (2012). Effect of nitrogen application through different combinations of urea and farm yard manure on the performance of spring maize (*Zea mays* L.) *The Journal of Animal and Plant Sciences* 22(1):95-198.
- Munroe G (2007). *Manual of on-farm vermicomposting and vermiculture*. Organic Agriculture Centre of Canada 39:40.
- NAAIAP (National Accelerated Agricultural Inputs Access Programme) (2014). *Soil Suitability Evaluation for Maize Production in Kenya*. Retrieved from www.naiiap.go.ke
- Negasi T (2014). *Characterization of Soil Nutrient Management and Post-harvest Handling Practices of Onion (*Allium cepa* L.) and Response of the Crop to Fertilization in Central Rift Valley of Ethiopia*, PhD Dissertation, Haramaya University, Haramaya, Ethiopia.
- Okalebo JR, Gathua KW, Woome PL (2002). *Laboratory methods of soil and plant analysis: A working manual* (2nd ed.). Sacred Africa, Nairobi, 21.
- Pandit NR, Schmidt HP, Mulder J, Hale SE, Husson O, Cornelissen G (2019). Nutrient effect of various composting methods with and without biochar on soil fertility and maize growth. *Archives of Agronomy and Soil Science* pp. 250-265.
- Patil JH, Sanil PH, Malini BM, Manoj V, Deepika D, Chaitra D (2012). Vermicomposting of water hyacinth with poultry litter using rotary drum reactor. *Journal of Chemical and Pharmaceutical Research* 5:2585-2589.
- Sánchez ÓJ, Ospina DA, Montoya S (2017). Compost supplementation with nutrients and microorganisms in composting process. *Waste Management* 69(26):136-153
- Statistical Analysis System (SAS) (2004). *SAS/STAT user's guide*. Proprietary software version 9.2. SAS Institute, Inc., Cary, NC.
- Seufert V, Ramankutty N, Foley JA (2012). Comparing the yields of organic and conventional agriculture. *Nature* 485:229-232.
- Sharma A, Saha T N, Arora A, Shah R, Nain L (2017). Efficient Microorganism compost benefits plant growth and improves soil health in calendula and marigold. *Horticultural Plant Journal* 3(2):67-72.
- Singh RJ, Ghosh BN, Sharma NK, Patra S, Dadhwal KS, Mishra PK (2016). Energy budgeting and energy synthesis of rainfed maize-wheat rotation system with different soil amendment applications. *Ecological Indicators* 61:753-765.
- Snyder CS, Bruulsema TW (2007). *Nutrient use efficiency and effectiveness in North America*. Publisher: International Plant Nutrition Institute. IPNI.
- Srivastava PK, Gupta M, Singh N, Tewari SK (2016). Amelioration of sodic soil for wheat cultivation using bio-augmented organic soil amendment. *Land Degradation and Development* 27:1245-1254.
- Téllez TR, López EM, Granado GL, Pérez EA, López RM, Guzmán JM (2008). The water hyacinth, *Eichhornia crassipes*: an invasive plant in the Guadiana River Basin (Spain). *Aquatic Invasions* 3:42-53.
- Van Haute J (2014). *Evaluation of the effects of compost on soil properties, performance and yield of maize and beans in Kenya* (Doctoral dissertation, MSc. Thesis).
- Yagoub SO, Wigdan MA, Mariod AA (2012). Effect of urea, NPK and compost on growth and yield of soybean (*Glycine max* L.), in Semi-Arid Region of Sudan. *International Scholarly Research Network Journal of Agronomy* 1:38-44.