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ORIGINAL RESEARCH

Performance of vermicomposted wastes for tomato (*Lycopersicon Esculentum* Mill.), production: A case study of Embu, Kenya

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Abstract

Purpose To investigate the effect of vermicomposted kitchen, market and tea wastes on tomato growth and yield and assess the benefits and costs that arise.

Method A field experiment arranged in the randomized complete block design with five experimental treatments: vermicomposted kitchen, market, tea wastes, NPK fertilizer and a control, replicated thrice was conducted. Data were collected on plant height, number of leaves, number of branches, number of flower stalks, fruit number, fruit weight, above-ground biomass, marketable tomato yield, soil nutrient content, pH, texture and exchangeable acidity. Data obtained were analyzed using SAS version 9.4 by subjecting to one-way Analysis of Variance (ANOVA). Biophysical crop data means were separated using Tukey's Studentized Range (HSD) test at p=0.05 significance level. T-test was used to determine the difference in soil nutrient content (Nitrogen (N), Phosphorus (P), Potassium (K), and Carbon (C)) at the beginning and end of the study. The benefits and costs were analyzed using the benefit-cost ratio formula.

Results The three vermicomposts had a similar effect (p>0.05) in influencing most of the tomato crop variables such as plant height, leaves number, branch number and flower stalks number. Tea waste vermicompost and kitchen waste vermicompost gave significantly high tomato yields of 115 t ha^{-1} and 113 t ha^{-1} at p=0.0001 as well as the highest benefit-cost ratio of 1.4:1.

Conclusion Tea, market and kitchen wastes have a potential for use in the production of high-quality vermicompost that can be used as a soil amendment to enhance tomato performance.

Keywords Nutrients, Earthworms, Amendment, Performance, Benefit

Introduction

Tomato is a high-value horticultural crop in Kenya and an important vegetable worldwide (Nganga 2017; Olanrewaju 2017). Tomato provides nutrition, income and food security for the majority of small-holder farmers in Kenya (Gacheri 2016). Global tomato production in 2017 was approximately 182,301,395 tonnes (FAOSTAT 2019). In Kenya, despite efforts made to intensify tomato production, yields are on the decline; for instance, tomato production has decreased in recent years from 443,200 tonnes in 2014, 402,500 tonnes in 2015, 410,000 tonnes in 2016 and 283,000 tonnes in 2017 (Ochilo et al. 2019; FAOSTAT 2019). Tomatoes require N, P, K and magnesium (Mg) for proper growth and yield (Zuba et al. 2011). Vermicompost is high-quality soil amendment produced from the natural conversion of biodegradable waste material by the use of earthworms (Parekh and Mehta 2015). Vermicompost has been observed to improve the content of plant nutrients including NPK, magnesium (Mg), calcium (Ca), carbon (C), glucose, fructose, L-ascorbic acid and morphological fruit parameters such as peel firmness, circumference and dry matter content enhancing seedling growth and fruit quality (Xiao et al. 2016). Vermicompost has a beneficial result on photosynthetic pigments of vegetables and germination of seed (Ahirwar and Hussain 2015).

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Enhanced plant germination, percentage and vegetation productivity have been associated with vermicompost use (Zucco et al. 2015).

Tomato is among the major vegetables grown in Kenya with the main production systems being under open-field (rain-fed and irrigation) as well as in greenhouses to curb susceptibility to weather conditions and diseases (Wachira 2012). Nutrient management in Kenyan farms is vital in enhancing tomato production (Nganga 2017). Inorganic and organic fertilizers are applied to supply tomato crops with essential nutrients required for healthy growth (Kariithi 2018). Inorganic fertilizers such as NPK, DAP and CAN are employed in tomato production as they exert a positive influence on growth and yield, thus increasing tomato productivity (Oseko and Dienya 2015; Nganga 2017). Organic farm inputs such as cow manure and farm wastes are used in tomato production (Wamuswa 2017). Organic farming techniques such as polyculture are also practiced by tomato farmers in Kenya as they improve soil fertility, thus enhancing production (Sheffy 2007). In Central Kenya, farmers grow tomatoes using vermiliquid (100 litres per acre) obtained from vermiculture as it greatly aids in boosting production with the earthworms being fed on farm waste (Thomson Reuters Foundation 2018).

Cost-benefit analysis is an analytical tool for quantifying the costs and benefits derived from a decision, project or program, to determine the overall financial impact (Nas 2016). The benefits, as well as the costs, are summed up and the ratio between the two is obtained (Nas 2016). Ratios above 1 are considered economically feasible. Inorganic fertilizers are expensive and not always readily available in the market at all times while vermicompost (organic manure) is always available to farmers at an affordable cost (Kashem et al. 2015). Production of vermicompost is suitable in increasing farm yields (Kashem et al. 2015). It is a beneficial enterprise with better cost-benefit ratios in contrast to the deployment of chemical fertilizers (Devkota et al. 2014). The present study was used to investigate how vermicomposted kitchen, market and tea waste affect tomato productivity and the costs and benefits that arise from vermicompost use in tomato production.

Materials and methods

Study site

The study was carried out in the University of Embu agriculture demonstration farm in Embu County, Kenya. The University lies at latitude 0.5156° S and longitude 37.4560° E and is located along the Embu-Meru highway, 3 km from Embu Town. The site lies at an elevation of 1150 m asl (Kisaka et al. 2014). Embu has a bi-modal rainfall pattern in which long rains are received between March and June whereas short rains are received between October and December (Embu County Government 2013). Rainfall received at the study site is averaged at 800 mm annually (Kisaka et al. 2014). The mean annual temperature for the study area is 20.9 °C with a mean maximum of 24.5 °C and a mean minimum of 17.4 °C (Kisaka et al. 2014). The soils at the study site are Humic Nitisols with moderate to high fertility (Kisaka et al. 2014). The soils are deep and well-weathered with dark red to dark reddish brown color, with pH ranging between (4.8-5.4), less than 2% organic carbon levels, less than 0.2% N and less than 10 ppm P (Verde et al. 2013).

Study design, treatment application and experimental layout

The experiment employed randomized complete block design (RCBD) with the treatment plots being replicated thrice (Fig. 1).

The treatments were; 22.22 t ha^{-1} vermicomposted kitchen waste and vermicomposted market waste, 12.22 t ha^{-1} vermicomposted tea wastes, 648 kg ha^{-1} inorganic fertilizer (NPK) and control without fertilizer application. Vermicompost and NPK were applied to supply 124 kg N ha^{-1}. Kitchen waste that was vermicomposted comprised fresh carrot peels, cabbage and kales. Market waste that was vermicomposted comprised fresh banana, potato and fruit peels. Tea waste that was vermicomposted comprised the green tea leaves. Fifteen plots of 2.2 m by 2 m, with spaces of 0.5 m in between the plots were established. Tomato variety Rambo F1 (determinate) from Royal Seed Company was the crop tested. The experiment was conducted for two seasons. The first season was between November 2018 and February 2019 with the second season being between March 2019 and May 2019. Rambo F1 tomato seeds were sown in the nursery and transplanted to the plots after four weeks in both seasons. The land was prepared using a hoe to a depth of 20 cm. The soil was leveled using a rake. The tomato seedlings were transplanted at a spacing of 60 cm by 45 cm. Weeding was done twice a month. Spraying against diseases and pests was done every two weeks using Difenoconazole fungicide at

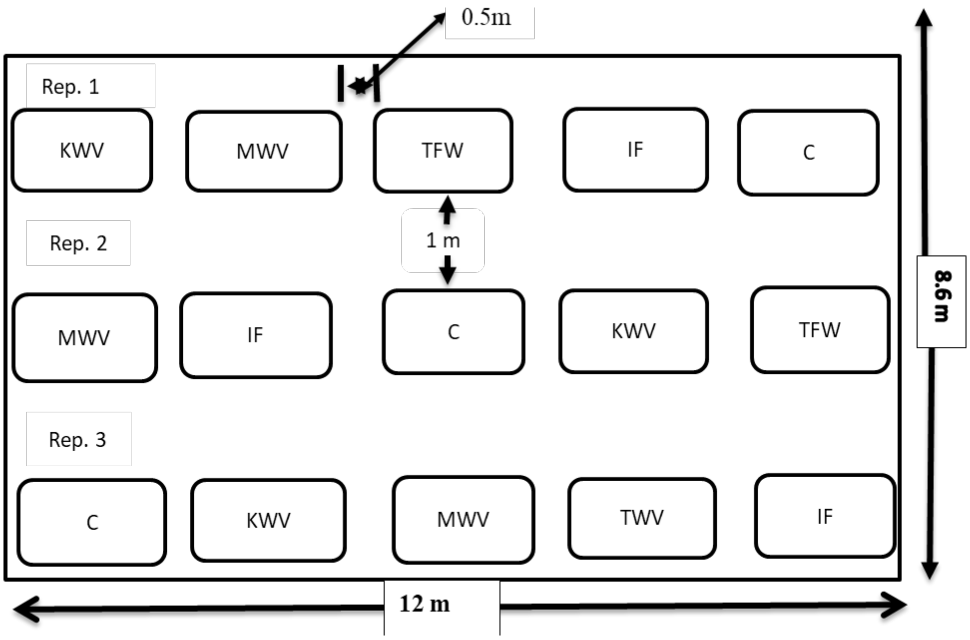

Fig. 1 Experimental layout with treatment application in RCBD

Key: KWV-Kitchen waste vermicompost, MWV-Municipal waste vermicompost, TWV-Tea waste vermicompost, IF-Inorganic fertilizer, C-Control

rates of 0.5 liters ha^{-1} and Imidaclopride + Betacyfluthrine pesticide at rates of 0.2 liters ha^{-1}. Staking was done on the fifth week of each season. Surface irrigation was performed every two days using a hosepipe. The crop was harvested sequentially (twice every week) at physiological maturity.

Determination of soil nutrient content

Soil samples were collected from the University of Embu Agriculture demonstration farm experimental plots, before and after input application. The samples (< 0.5 mm) were oven-dried at 40° C. Total Nitrogen was determined following the micro Kjeldahl method of Page et al. (1982). Total Phosphorus was extracted following the procedure of Mehlich et al. (1962) and the content was determined spectrophotometrically. Total Potassium was extracted following the procedure described by Berry et al. (1946) and the content was determined with a flame photometer. Soil pH was determined in a 1:1 (w/v) soil–water suspension with a Universal soil pH – meter following the procedure described by Mehlich et al. (1962). Soil texture was determined following the hydrometer method of Hinga et al. (1980). Exchangeable acidity was determined following titrimetric method of Okalebo et al. (2002). Total organic carbon (TOC) was done following the calorimetric method of Anderson and Ingram (1993).

Tomatoes harvesting

Tomatoes were harvested following the procedure of Arah et al. (2016) whereby, the tomatoes were harvested in a partially ripe mature stage.

Data collection

Agronomic data collected included: germination date, weekly plant height, number of leaves, first flowering date, number of flowers stalks, number of fruits per plant, fruit weight (t ha^{-1}), number of branches per plant, marketable yield (t ha^{-1}) and above-ground dry biomass (t ha^{-1}). Data were collected from the inner four plants per plot. Fruits' weight was determined using an electronic weighing balance. Dry biomass was obtained by drying the crops in the sun. Yield and plant dry biomass were obtained by collecting yield and biomass data from four representative plants in each plot in g m^{-2}. The means for each treatment were obtained from all the representatives of the replicates and used to calculate the values for a hectare by extrapolation from the representative area occupied by the four plants. The g m^{-2} was converted to t ha^{-1} by dividing by 100.

Plant biomass (dry) was calculated following the procedure of Montes et al. (2011);

$$Standing\ biomass = \frac{dry\ weight\ (of\ above\ ground\ tissue)}{plot\ area} \quad .....1$$

The economics was calculated by considering the total costs (earthworms cost, transport, labor cost, DAP cost, organic waste cost and implements costs), and benefits that arose from substituting inorganic fertilizers with vermicompost. Data obtained was organized and arranged in MS Excel. The benefit-cost ratio formula was used according to Adhikary et al. (2016) whereby:

$$BCR = \frac{Gross\ return}{Total\ cost\ of\ production} \quad ....2$$

Data analysis

Statistical analysis for biophysical data and benefit-cost ratios was carried out using SAS software version 9.4 SAS, 2013. Data obtained were subjected to two-way analysis of variance (ANOVA) using SAS proc GLM code of the model RCBD. Significantly different treatment means were separated using Tukey's Studentized Range (HSD) at p=0.05 significance level.

Results and discussion

Effect of vermicomposted kitchen, market and tea wastes on soil nutrients

The texture of the soil that was used in the present study was clay. Market waste vermicompost significantly ($p<0.05$) enhanced the soil nitrogen content compared to kitchen waste and tea waste vermicomposts (Table 1).

Table 1 Effect of vermicomposted kitchen, market and tea wastes on soil nutrients

Parameter	Nitrogen (%)	Phosphorus (ppm)	Potassium (% me)	Organic Carbon (%)	Exchangeable acidity ($cmol_c kg^{-1}$ soil)	pH
Initial	0.21^c	15^c	0.78^d	2.26^b	0.4^a	4.51^d
KWV	0.27^b	50^a	1.77^b	2.61^a	0.2^b	5.47^a
MWV	0.33^a	40^a	1.7^c	2.47^b	0.27^b	5.04^c
TWV	0.27^b	50^a	1.94^a	2.61^a	0.23^b	5.28^b
Standard deviation	0.08	16.2	0.46	0.19	0.096	0.34
Coefficient of variation	27.93	41.81	30.20	7.74	34.82	6.6

Key: KWV-Kitchen waste vermicompost, MWV-Market waste vermicompost, TWV-Tea waste vermicompost

Vermicomposted kitchen, market and tea waste contained 0.5% N, 0.8% N and 0.7% N, respectively (Mochache et al. 2019). This enhanced the soil N content from 0.21% N to 0.27% (29%), 0.33% (57%) and 0.27% (29%), respectively. Vermicomposted kitchen, market and tea wastes contained 0.81 ppm P, 0.7667 ppm P and P 0.76 ppm P, respectively (Mochache et al. 2019). This increased the soil P content from 15 ppm P to 50 ppm P (233%), 40 ppm P (167%) and 50 ppm P (233%), respectively. Vermicomposted kitchen, market and tea waste had 2.74 me% K, 1.97 me% K and 2.42 me% K, respectively (Mochache et al. 2019). This increased the soil K content from 0.78 me% K to 1.77 me% K (127%), 1.7 me% K (118%) and 1.95 me% K (150%), respectively. Vermicomposted kitchen, market and tea waste contained 15% C, 15.33% C and 15.1% C, respectively (Mochache et al. 2019). This enhanced the C content of the soil from 2.26% C to 2.61% C (15%), 2.47% C (9%) and 2.61% C (15%), respectively.

Kitchen and tea waste vermicompost significantly ($p<0.05$) increased the soil phosphorus content compared to market waste vermicompost (Table 1). Tea waste vermicompost significantly ($p<0.05$) increased the soil potassium content compared to kitchen and market waste vermicomposts (Table 1). Kitchen and tea waste vermicomposts had a significant ($p<0.05$) effect on the soil organic carbon content compared to market waste vermicomposts (Table 1). Kitchen waste vermicompost had a significant ($p<0.05$) effect on the soil pH compared to tea waste and market waste vermicomposts (Table 1). The three vermicomposts had a neutralizing effect on soil acidity as the pH was raised from an initial value of 4.51 to 5.47 by kitchen waste vermicompost, 5.28 by tea waste vermicompost and 5.04 by municipal waste vermicompost.

T-test analysis on the soil samples treated with vermicompost revealed a significant difference ($p<0.05$) between the initial and final soil nutrient content after incorporation of kitchen, market and tea waste vermicompost (Table 2). However, there was no significant difference ($p>0.05$) in the nitrogen as well as exchangeable acidity of soils treated with market waste vermicompost as illustrated in (Table 2).

Table 2 Soil t-test analysis on vermicompost treated soils

Variable	t/p value	Treatment		
		KWV	MWV	TWV
Nitrogen (%)	t-value	3.84	1.76	3.84
	p-value	0.006	0.069	0.006
Phosphorus (mg Kg^{-1})	t-value	3.51	2.78	4.02
	p-value	0.009	0.02	0.005
Potassium (mg Kg^{-1})	t-value	3.58	2.77	5.24
	p-value	0.008	0.02	0.002
Carbon (mg Kg^{-1})	t-value	2.69	2.04	2.64
	p-value	0.02	0.486	0.023
Exchangeable acidity ($cmol_c kg^{-1}$ soil)	t-value	4.14	1.81	5.97
	p-value	0.004	0.065	0.001
pH	t-value	4.72	2.38	4.75
	p-value	0.003	0.03	0.003

These findings corresponded to those by Xu and Mou (2016) who observed that vermicompost addition to soil increased N by 66%, P by 56%, K by 204% and organic carbon by 43%, soil pH increased from 6.8 to 7.3. Wang et al. (2017), on the other hand, reported that vermicompost enhanced soil quality by increasing pH from 7.23 to 7.37, ammonium nitrogen, as well as water-soluble organic carbon, were also increased after treatment with vermicompost. A similar study by Nurhidayati et al. (2018) also found that vermicompost addition increased the soil nutrient content; for instance, soil N increased by 200%, P increased by 100% and K by 127%. Similarly, a study by Mahmud et al. (2018) showed that when vermicompost was applied to soil, the pH increased from 5.65 to 5.77 and significantly a total nitrogen increase of 114% was observed in the vermicompost treated soils compared to the control. The findings of this study also concurred with those of Yadav and Garg (2015) who observed that soils amended with vermicompost had an increased N content of 1700%, P content of 1650%, K content of 800% and C content of 1067% compared to the control. The increased soil nutrient content in vermicompost applied soils was attributed to castings produced by earthworms in vermicompost as well as the decomposition activities of earthworms on organic residues (Adhikary 2012). These enhanced the soil organic matter as well as the nutrient status by recycling nitrogen, phosphorus and potassium (Saranraj and Stella 2012). Differences in the effect of vermicompost on the soil parameters were attributed to the different vermicompost types utilized as well as the soil types. The differences were also attributed to be a function of different decomposition rates related to temperature, moisture and residue quality.

Kitchen waste vermicomposted had the highest C: N ratio of 29.4 followed by tea waste vermicompost at 19.4 and market waste vermicompost had the lowest C: N ratio of 18.7 (Table 3).

Effect of vermicomposted kitchen, market and tea wastes on plant height

In the first season, significant differences ($p<0.05$) were recorded in the 3rd, 5th, 6th, 7th, 8th, 9th and 10th WAT (Fig. 2). In the second season, there was no significant difference ($p>0.05$) in the plant height in the 1st and 2nd WAT (Fig. 2).

Table 3 C: N ratio of vermicomposted kitchen, market and tea wastes

Treatment	Total Nitrogen (%)	Total Organic Carbon (%)	C:N ratio
KWV	0.51	15	29.4
MWV	0.82	15.33	18.7
TWV	0.78	15.1	19.4

Source: Mochache et al. (2019)

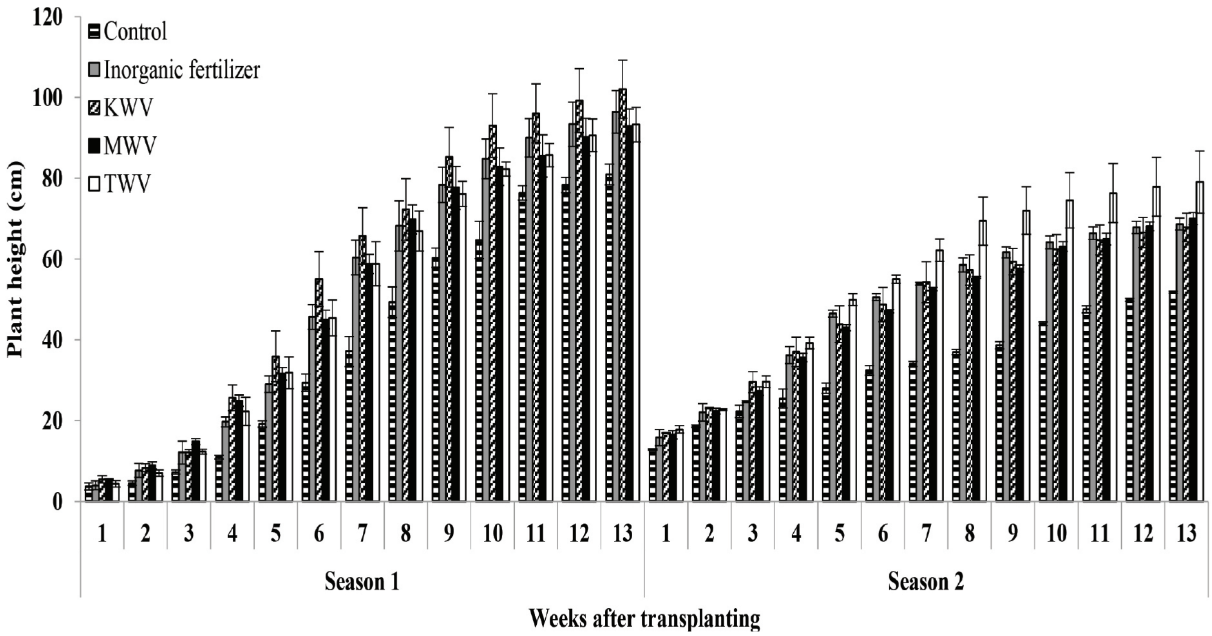

Fig. 2 Effect of vermicomposted kitchen, market and tea wastes on plant height

*Error bars represent standard error

Key: KWV-Kitchen waste vermicompost, MWV-Market waste vermicompost, TWV-Tea waste vermicompost

This was attributed to the nitrogen content of the treatment, whereby higher nitrogen content resulted in rapid plant growth; for instance, it resulted in increased plant height (Leghari et al. 2016). There was no significant difference ($p>0.05$) in the nitrogen content of the three vermicomposts (Mochache et al. 2019), thus giving no significant difference ($p>0.05$) in the plant height towards the end of two seasons (Fig. 2). There was no significant difference ($p>0.05$) in the plant height of the three vermicomposts compared to that of inorganic fertilizer due to the high nitrogen content contained in the NPK (17:17:17) fertilizer. The three

vermicomposts had a higher plant height than the control throughout the study as a result of lower nitrogen content in the control compared to that of vermicompost (Table 1; Mochache et al. 2019).

The results of the present study corresponded to those by Kashem et al. (2015), who reported that vermicompost application at a rate of 20 t ha^{-1} resulted in a maximum tomato plant height of 52.7 cm which was high compared to the control. In a similar study by Wang et al. (2017) vermicompost gave increased plant height of up to 90 cm compared to other fertilizer treatments, as a result of its high nitrogen content. Moreover, Thuy et al. (2017) stated that application of 35 t ha^{-1} of vermicompost gave a maximum tomato plant height of 87.5 cm in the autumn-winter season. Differences in plant height were attributed to differences in the tomato varieties utilized in the different studies.

Effect of vermicomposted kitchen, market and tea wastes on leaf Number

In season 1, treatments did not influence ($p>0.05$) the number of tomato leaves during the 1st, 2nd and 3rd WAT (Fig. 3). However, in the remaining weeks, statistical differences ($p<0.05$) among the treatments were observed, whereby market and kitchen wastes had significantly more ($p<0.05$) leaves than the control (Fig. 3). Similar trends were also observed in season 2, whereby significant differences ($p<0.05$) were observed from 3 WAT (Fig. 3).

The increased number of leaves was attributed to elevated available nitrogen in the soil contributed by vermicompost. Nitrogen enhanced the vegetativeness of crops by promoting leaf growth and development (Leghari et al. 2016). As reported by Mochache et al. (2019), there were no significant differences ($p>0.05$) in the nitrogen contents of the three vermicomposts, thus giving no significant differences ($p\geq0.05$) in the leaves number in both seasons (Fig. 3). There were no significant differences ($p>0.05$) observed between the three vermicomposts leaf number and the inorganic fertilizer leaf number throughout the study due to the high nitrogen content contained in NPK (17:17:17). Significant differences ($p<0.05$) were observed in the leaf number of the three vermicomposts compared to that of control toward the end of both seasons as a result of low nitrogen content associated with the control compared to that of vermicompost (Table 1; Mochache et al. 2019). The results obtained conformed to a previous study by Kashem et al. (2015), whereby application of 20 t ha^{-1} of vermicompost showed an increase of 54 leaves per plant compared to control treatment. In a similar study by Eswaran and Mariselvi (2016) vermicompost treated tomato plants yielded as high as 112 leaves per plant. Differences in leaves numbers could be attributed to the different tomato varieties grown in the different studies as well as soil types.

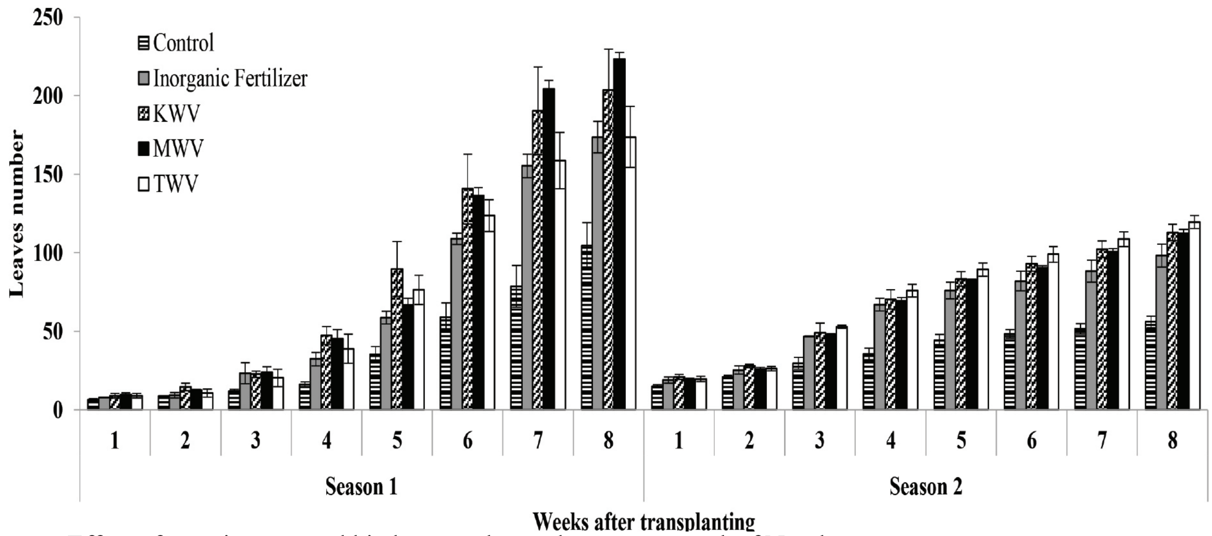

Fig. 3 Effect of vermicomposted kitchen, market and tea wastes on leaf Number

Effect of vermicomposted kitchen, market and tea wastes on the number of branches

In the first season, no significant difference ($p>0.05$) in the branch numbers was observed in the 2nd and 5th WAT (Fig. 4). Significant differences ($p<0.05$) in branch numbers were observed among the treatments from 4 WAT in the second season (Fig. 4). Market and kitchen waste vermicomposts had significantly more ($p<0.05$) branches compared to the control from 6 WAT in the first season (Fig. 4). In the second season, the three vermicomposts and inorganic fertilizers had significantly more ($p<0.05$) branches compared to control in the 7th and 8th WAT (Fig. 4).

Higher number of branches in fertilized treatments in the present study was attributed to nitrogen content which enhances branch number as noted by Etissa et al. (2013). Since there were no significant differences ($p>0.05$) in the nitrogen contents of the three vermicomposts as reported by Mochache et al. (2019), the branch numbers were statistically similar ($p>0.05$) in both seasons (Fig. 4). There were no significant differences ($p>0.05$) in the branch number observed between the three vermicomposts and the inorganic fertilizer throughout the study due to the high nitrogen content contained in NPK (17:17:17). Significant differences in the branch number ($p<0.05$) between the three vermicomposts and control were observed towards the end of both seasons as a result of low nitrogen content associated with the control compared to that of vermicompost (Table 1; Mochache et al 2019). These results agreed with those of Chanda et al. (2013) who reported that vermicompost treated tomato plants yielded 7 branches per plant which were high compared to treatments with chemical fertilizers and other organic inputs. Similarly, Gopinathan and Prakash (2014) reported that vermicompost treated plants gave the highest branch number (5 branches per plant) compared to other fertilizer treatments. Differences in branch number are attributed to the different tomato varieties grown by the different studies.

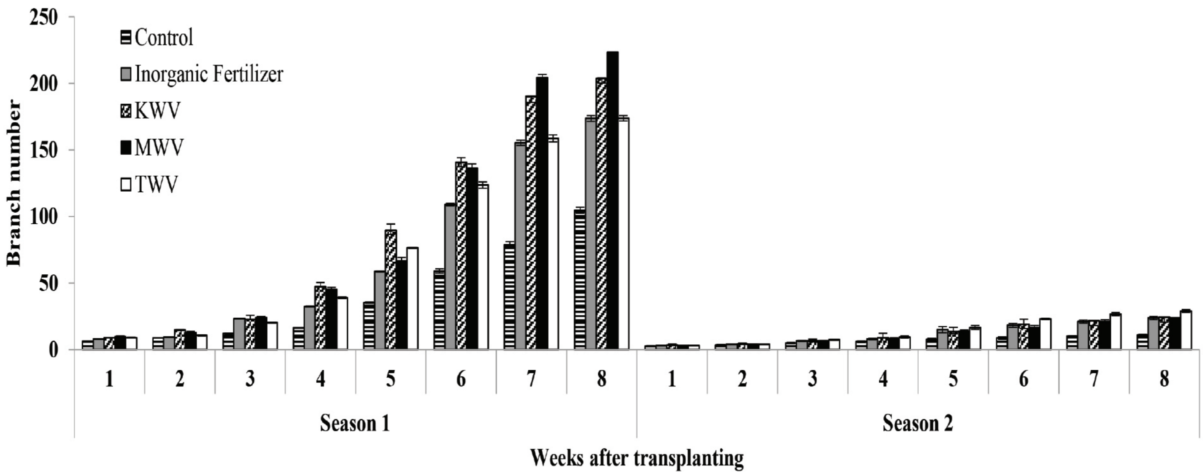

Fig. 4 Effect of vermicomposted kitchen, market and tea wastes on the number of branches

Effect of vermicomposted kitchen, market and tea wastes on the flower stalks number

In the first season of study, significant differences ($p<0.05$) in the number of flower stalks were observed only on 4 and 7WAT (Fig. 5). In the second season, however, significant differences ($p<0.05$) were observed throughout the seven weeks (Fig. 5). This was attributed to the increased phosphorus content of the treatments as it is associated with growth and development of flower stalks (Malhotra et al. 2018). Since the phosphorus contents of the three vermicomposts were statistically similar, ($p>0.05$) in the study by Mochache et al (2019), flower stalks' numbers in both seasons were also statistically similar ($p>0.05$) as shown in Fig. 5. There were no significant differences ($p>0.05$)

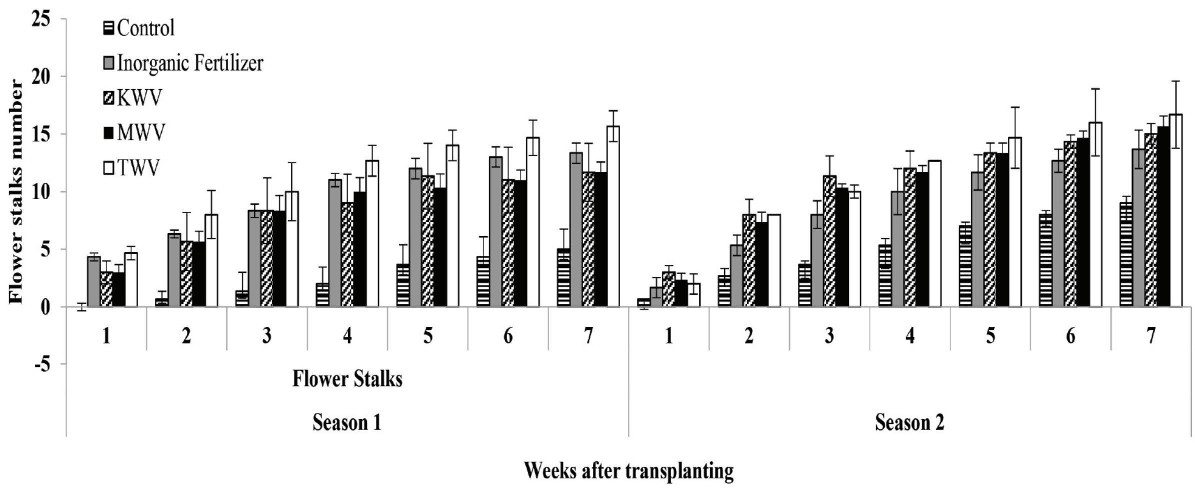

Fig. 5 Effect of vermicomposted kitchen, market and tea wastes on the number of flower stalks

in the flower stalks number observed between the three vermicomposts and the inorganic fertilizer throughout the study due to the high phosphorus content contained in NPK (17:17:17). Significant differences in the flower stalk number ($p<0.05$) were observed between the three vermicomposts and control towards the end of the first season and throughout the second season as a result of low phosphorus content associated with the control treatment compared to that of vermicompost treatments (Table 1; Mochache et al. 2019).

The findings of the present study corresponded to those by Taleshi et al. (2011) who observed that enhanced microbial activity and uptake of nitrogen associated with vermicompost use resulted in enhanced photosynthesis, nutrient as well as water uptake that ultimately led to improved flowering. Similarly, Zucco et al. (2015) and Mukta et al. (2016) reported that vermicompost treated tomato plants had more flowers compared to the control.

Effect of vermicomposted kitchen, market and tea wastes on the fruits number

Kitchen waste and tea waste vermicompost tomato plants had significantly higher ($p<0.05$) fruit number than market waste vermicompost by 19% and 14%, respectively, inorganic fertilizer by 32% and 29%, respectively and control treatment by 131% and 125%, respectively (Table 4). In season 2, no significant difference ($p>0.05$) was observed in the fruit number of the five treatments (Table 4).

Table 4 Effect of vermicomposted wastes on fruit number

Treatment	Fruit Number		
	Season 1	Season 2	Mean
Control	16.00[c]	2.00	9.00
NPK	28.00[b]	9.00	18.50
KWV	37.00[a]	6.33	21.67
MWV	31.00[b]	9.00	20.00
TWV	36.00[a]	11.00	23.50
P-value	0.0001	0.2317	
L.s.d	4.4563	12.508	

Key: KWV-Kitchen waste vermicompost, MWV-Market waste vermicompost, TWV-Tea waste vermicompost

Mochache et al. (2019) did not find significant differences ($p>0.05$) in the potassium contents of the three vermicomposts, thus giving no significant differences ($p>0.05$) in the fruit numbers in the second season (Table 4). Tea and kitchen waste vermicomposts had a significantly higher ($p<0.05$) fruit number compared to inorganic fertilizer in the first season due to higher potassium content contained in the two vermicomposts (Mochache et al. 2019) compared to that of NPK (17:17:17) fertilizer. Significant differences in the fruit number ($p<0.05$) between the three vermicomposts and control were observed in the first season as a result of low potassium content associated with the control compared to that of vermicompost treatments (Table 1; Mochache et al. 2019).

The results of the present study on more fruits in vermicomposted treatments correspond to the findings of Kashem et al. (2015), Eswaran and Mariselvi (2016) as well as Rahman and Akter (2018). Kashem et al. (2015) observed that tomato plants grown using vermicompost had 300% more fruits compared to the control. Similarly, Eswaran and Mariselvi (2016) concluded that tomatoes grown using vermicompost produced 340% more fruits than the control. In the study by Rahman and Akter (2018), tomatoes grown using vermicompost produced 80% more fruits compared to the control. The higher number of fruits in vermicomposted treatments was attributed to the potassium content associated with a high number of fruits as reported by Sultana et al. (2015) and Cruz et al. (2017).

Effect of vermicomposted kitchen, market and tea wastes on the fruit weight

Tea waste vermicompost had a significantly higher ($p<0.05$) fruit weight by 21% compared to control (Table 4). In the second season, however, there were no significant differences ($p>0.05$) in the fruit weight of the five treatments (Table 5).

This was associated with the potassium content of the treatment playing a great role in fruit development (Sultana et al. 2015; Cruz et al. 2017). There were no significant differences ($p>0.05$) in the potassium contents of the three vermicomposts (Mochache et al. 2019), thus giving no significant differences ($p>0.05$) in the fruit weight (Table 5). There were no significant differences ($p>0.05$) in the fruit weight observed between tea and kitchen waste vermicomposts compared to the inorganic fertilizer throughout the study due to the high potassium content contained in NPK (17:17:17). Significant differences in the fruit weight ($p<0.05$) were observed between the three vermicomposts and control in the first season and throughout the second season as a result of low potassium content associated with the control compared to that of vermicompost treatments (Table 1; Mochache et al. 2019). The findings of the present study on higher fruit weight in vermicomposted treatments agreed with those of Kashem et al. (2015), Eswaran and Mariselvi (2016) and Rahman and Akter (2018). The findings of Kashem et al. (2015) were: vermicompost treatment had a 3900% higher fruit weight compared to control treatment. These findings corresponded to those by Eswaran and Mariselvi (2016), who found out that mean fruit weight obtained from tomato plants grown in vermicompost was 439% higher than the control. In a similar study by Rahman and Akter (2018), vermicompost treatment had 39% higher tomato fruit weight compared to the control. The differences in fruit weight among the various studies were attributed to the different tomato varieties used as well as the quality of vermicompost.

Table 5 Effect of vermicomposted wastes on fruit weight

Treatment	Fruit weight (g)		
	Season 1	Season 2	Mean
Control	63.000[c]	35.77	49.39
NPK	99.33[ab]	64.8	82.10
KWV	98.67[ab]	55.52	77.10
MWV	85.33[b]	63.00	74.17
TWV	103.33[a]	66.03	84.68
P-value	0.0001	0.1016	
L.s.d	16.881	36.393	

Key: KWV-Kitchen waste vermicompost, MWV-Market waste vermicompost, TWV-Tea waste vermicompost

Effect of vermicomposted kitchen, market and tea wastes on the above-ground dry biomass

There was no significant difference ($p>0.05$) in the biomass of the tomato plants from all the treatments in both seasons (Table 6). Differences in biomass yields were attributed to the NPK content of the treatment which is related to the overall plant growth (Chaulagain and Lamichhane 2017). In the present study, there were no significant differences ($p>0.05$) observed in the above-ground dry biomass since vermicompost treatments had a statistically similar ($p>0.05$) nutrient content (Mochache et al. 2019) (Table 6).

Table 6 Effect of vermicomposted wastes on above ground dry biomass

Treatment	Biomass (t ha^{-1})		
	Season 1	Season 2	Mean
Control	22036	5334	13685
NPK	32322	8606	20464
KWV	47382	5757	26570
MWV	41295	6303	23799
TWV	45182	7879	26531
P-value	0.0579	0.7434	
L.s.d	26837	0.9488	

Key: KWV-Kitchen waste vermicompost, MWV-Market waste vermicompost, TWV-Tea waste vermicompost

There were no significant differences ($p>0.05$) in the biomass of the three vermicomposts compared to the inorganic fertilizer throughout the study due to the high nitrogen content contained in NPK (17:17:17). The three vermicomposts had high biomass compared to the control throughout the study as a result of the high nitrogen content of the vermicomposts compared to the control (Mochache et al. 2019; Table 1).

Nitrogen was responsible for increased plant height and increased above ground dry biomass (Popović et al. 2017). The findings of the present study concurred with those by Joshi and Vig (2010), who observed that vermicompost treated tomato plants gave high biomass by 143% compared to the control. In a similar study by Vaidyanathan and Vijayalakshmi (2017), vermicompost treated tomato plants had 135% higher dry plant biomass compared to the control. Similarly, Ahirwar and Hussain (2015) reported increased vegetable plant biomass in a vermicomposting study using vermicomposted coconut husks and rice hulls. The difference between these studies with the present study was due to tomato varieties as well as vermicompost quality.

Effect of vermicomposted kitchen, market and tea wastes on the marketable yield

In the present study, tea and kitchen waste vermicompost increased tomato marketable yields at 115 t ha^{-1} and 113 t ha^{-1}, respectively compared to inorganic fertilizer and the control treatment (Table 7).

Table 7 Effect of vermicomposted wastes on marketable yield

Treatment	Marketable Yield(t ha^{-1})		
	Season 1	Season 2	Mean
Control	28.11^{c}	2.20	15.16
NPK	84.76^{b}	21.60	53.18
KWV	112.66^{a}	14.87	63.77
MWV	82.22^{b}	21.60	51.91
TWV	114.77^{a}	29.30	72.04
P-value	0.0001	0.3005	
L.s.d	25.933	39.878	

Key: KWV-Kitchen waste vermicompost, MWV-Market waste vermicompost, TWV-Tea waste vermicompost

Significant differences in the number of fruits ($p<0.05$) between the three vermicomposts and control were observed in the first season as a result of low potassium content associated with the control compared to that of vermicompost treatments (Table 1). This could be attributed to elevated available macro and micronutrients, improved soil structure, enhanced water storage and ability of microbes to keep nutrients in available forms (for instance, phosphorus) that are associated with vermicompost application. The results of the present study corresponded to those by Hyder et al. (2015) and Vaidyanathan and Vijayalakshmi (2017) who obtained the highest tomato fruit yield of 1.1 t ha^{-1} and 4.4 t ha^{-1}, respectively, from vermicompost treated tomato plants. Moreover, Wang et al. (2017) reported an increased yield of tomatoes under vermicompost compared to other treatments. The findings of Tesfay et al. (2018) indicated that tomato plants grown in treatment of 8 t ha^{-1} of vermicompost gave the highest marketable yield of 33.1 t ha^{-1}. The high yield of tomatoes in vermicomposted treatment was attributed to higher nutrient contents as well as improved soil physical, chemical and biological properties.

Correlation analysis

Table 8 Correlation Coefficient (r) between growth parameters and nutrient content

Growth Parameters	Nutrient content
Height	0.07
Leaves number	0.25
Biomass	0.34

There was a low positive correlation between the nutrient content and plant height (0.07) (Table 8); this implied that there was an increase in plant height with an increase in the nutrient content of the soil; however, the relationship between the variables was not linear. This implied that nutrient content worked with other parameters, for instance moisture in increasing plant height. There was a low positive correlation between the nutrient content and the leaves number (Table 8) implying that there was an increase in leaves number with the increase in nutrient content but the relationship between the two variables was not strong. A medium positive correlation was observed between biomass and nutrient content, (Table 8) thus implying that there was an increase in plant biomass with an increase in the soil nutrient content; the relationship among the two variables is thus strong. This corresponded to the findings of Abdel-Mawgoud et al. (2007), who established that increasing nutrient content in soil planted with tomato crops led to increased plant height, leaves number as well as fresh and dry plant weight. Similarly, Xiukang and Yingying (2016) established that increased fertilizer rate led to enhanced rate of tomato leaf growth and plant height since tomato requires N, P and K in large quantities.

Table 9 Correlation Coefficient (r) between marketable yield and yield parameters

Yield Parameters	Marketable Yield
Fruit number	0.99
Fruit weight	0.94

There was a strong positive correlation between the fruit number and the marketable yield as well as fruit weight and marketable yield (Table 9). This implied that there was an increase in marketable yield with an increase in fruit number and fruit weight. The relationship between the two variables (fruit number and fruit weight) to the marketable yield variable was thus strong. There was a strong positive correlation of the fruit number and fruit weight to the marketable yield (Table 9). This corresponded to the finding of Das et al. (2017), whereby fruit yield had a significant positive correlation ($r=0.977$) to fruit number per plant. In a similar study done by Etissa et al. (2013), fruit yield had a strong positive correlation with the fruit number ($r=0.62$) and fruit weight ($r=0.42$).

Benefit-Cost Ratio of vermicompost use for tomato production

For season 1, both tea and kitchen waste vermicomposts had a significantly higher ($p<0.05$) benefit-cost ratio of 1.37:1 compared to inorganic fertilizer at 0.76 and control at 0.34 (Table 7). In season 2, however, no significant difference ($p>0.05$) was observed in the benefit-cost ratio of the five treatments (Table 10).

Table 10 Benefit-cost ratios of vermicomposted wastes for tomato production

Treatment	Season 1	Season 2	Season 1 and 2 mean
Control	0.340[c]	0.020[a]	0.180
NPK	0.760[bc]	0.20[a]	0.484
KWV	1.3667[a]	0.140[a]	0.753
MWV	0.9933[ab]	0.210[a]	0.602
TWV	1.3667[a]	0.280[a]	0.823
P-value	0.0005	0.3861	
L.s.d	0.5519	0.30337	

Key: KWV-Kitchen waste vermicompost, MWV-Market waste vermicompost, TWV-Tea waste vermicompost

This was attributed to the lower yields obtained from all the treatments as a result of drier conditions in the second season.

The findings obtained from the present study concurred with those of other vermicomposting studies, for instance, according to Alam (2011), vermicompost use in tomato production had the potential to yield a high benefit-cost ratio (2.59:1). In a similar study by Mohamed et al. (2015), vermicompost applied at a rate of 4% in growing sweet pepper yielded a maximum benefit-cost ratio of 1.67 in the first season and 1.74 in the second season. Guo et al. (2015), on the other hand, grew maize using vermicompost and obtained a benefit-cost ratio of 19:1. Similarly, Adhikary et al. (2016) applied 10 t ha^{-1} of vermicompost in tomato growth and obtained a BCR of 1.27:1. Moreover, Mahmud et al. (2018) also deduced that profit received from pineapples grown with vermicompost was slightly higher than that from pineapple fruits grown using chemical fertilizers. An economic advantage was realized in a similar vermicomposting study done by Austin (2015), whereby vermicompost treated Swiss chard yielded greater profit margins as compared to Swiss chard from the other treatments, the benefit-cost ratio was 13.2:1. Additionally, Rahman and Akter (2018) utilized vermicomposted kitchen waste that gave a benefit-cost ratio of 0.15:1 from growing tomatoes. The high benefit-cost ratio was attributed to the high yield obtained from the vermicompost treated crops compared to crops of treatments that contained no vermicompost.

Conclusion

This study demonstrated the effect of vermicompost produced from kitchen, market and tea wastes (using *Eisenia fetida* earthworms) on tomato growth and yield. Based on the findings, the following conclusions can be made: Kitchen wastes, tea waste and market wastes vermicomposts have the same effect in influencing most tomato growth variables including the number of branches, plant height and leaves number. Vermicompost treatments' effect on tomato above-ground biomass is similar but significantly higher compared to the control. Tea and kitchen waste vermicomposts give increased tomato yields (115 t ha^{-1} and 113 t ha^{-1}, respectively) as well as the highest benefit-cost ratio (1.37:1) and are therefore recommended for the production of tomatoes. The results of the present study show that tea and kitchen vermicomposts can be recommended for the production of tomatoes as they give increased yields. The effect is, however, highly variable depending on water availability. Tea waste vermicompost and kitchen waste vermicompost can be recommended for tomato crop growth as they yield higher profits to the tomato crop venture.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

References

Abdel-Mawgoud A, El-Greadly N, Helmy Y, Singer S (2007) Responses of tomato plants to different rates of humic-based fertilizer and NPK fertilization. J Appl Sci Res 3(2): 169-174

Adhikary S (2012) Vermicompost, the story of organic gold: A review. J Agric Sci 3: 905-917. https://doi.org/10.4236/as.2012.37110

Adhikary B, Dash KP, Sajib K, Mannal A (2016) Yield response of tomato under different combination of manure and fertilizers. J Agric and Vet Sci 9 (1): 6-16. https://doi.org/10.9790/2380-09110616

Ahirwar CS, Hussain A (2015) Effect of vermicompost on growth, yield and quality of vegetable crops. Int J Appl Pure Sci Agric 1(8): 49-56

Alam M (2011) Effect of compost and vermicompost use on the yield of tomato and their economics. Paper presented at the international symposium on organic matter management and compost use in horticulture. Acta Hortic 1018: 187-194. https://doi.org/10.17660/ActaHortic.2014.1018.18

Anderson JM, Ingram JSI (1993) Tropical soil biology and fertility: A handbook of methods. CAB International, Wallingford, Oxon, UK

Arah IK, Ahorbo GK, Anku EK, Kumah EK, Amaglo H (2016) Postharvest handling practices and treatment methods for tomato handlers in developing countries: A mini review. J Adv Agric, pp 1-8. https://doi.org/10.1155/2016/6436945

Austin PD (2015) An evaluation of vermicompost as a fast-acting nitrogen amendment to mitigate nitrogen deficiencies in organic vegetable production. Thesis, University of Vermont

Berry JW, Chappell DG, Barnes RB (1946) Improved method of flame photometry. J Ind Eng Chem Anal Ed 18(1): 19-24. https://doi.org/10.1021/i560149a005

Chanda G, Bhunia G, Chakraborty S (2013) Assessment of decomposition rate and recovery number of earthworm *Perionyx excavatus perrier* during vermicomposting by combined index (CBI). Glob Adv Res J Environ Sci Toxicol 2(8): 183-187

Chaulagain AD, Lamichhane JG (2017) Vermicompost and its role in plant growth promotion. Int J Res 4(8): 849-864

Cruz FJR, de MPR, Felisberto G, Santos ÁS, Barreto RF (2017) Potassium nutrition in fruits and vegetables and food safety through hydroponic system. Improvement of quality in fruits and vegetables through hydroponic nutrient management, London, United Kingdom, pp 23-44

Das SP, Moharana DP, Aslam T, Nayak NJ, Mandall AR (2017) Correlation studies of different growth, quality and yield attributing parameters of tomato (*Solanum lycopersicum L.).* Int J Agric Environ Biores 2 (2): 217-223

Devkota D, Dhakal S, Dhakal D, Dhakal D, Ojha R (2014) Economics of production and marketing of vermicompost in Chitwan, Nepal. Int J Agric Soil Sci 2: 112-117

Embu County Government (2013) County integrated development plan 2013-2017. http://www.embu.go.ke/wp-content/uploads/2016/09/embu-county-draft-cidp.pdf. Accessed 3 October 2017

Eswaran N, Mariselvi S (2016) Efficacy of vermicompost on growth and yield parameters of *Lycopersicum esculentum* (Tomato). Int J Sci Res Pub 6(1): 95-108

Etissa E, Dechassa N, Alamirew T, Alemayehu Y, Desalegn L (2013) Growth and yield components of tomato as influenced by nitrogen and phosphorus fertilizer applications in different growing seasons. Ethiop J Agric Sci 24(1): 57-77

Food and Agriculture Organization (2019) FAOSTAT. https://www.fao.org/faostat/en/#data/QCL

Gacheri V (2016) Effects of coloured agronets in the management of tomato (*Solanum lycopersicum L.*) pests and tomato yield in Kenya. Thesis, Kenyatta University

Gopinathan P, Prakash M (2014) Effect of vermicompost enriched with bio-fertilizers on the productivity of tomato (*Lycopersicum esculentum* mill.). Int J Curr Microbiol Appl Sci 3(9): 1238-1245

Guo L, Wu G, Li C, Liu W, Yu X, Cheng D, Jiang G (2015) Vermicomposting with maize increases agricultural benefits by 304%. Agron Sustain Dev 35(3): 1149-1155. https://doi.org/10.1007/s13593-015-0307-0

Hinga G, Muchena FN, Njihia CM (1980) Physical and Chemical Methods of Soil Analysis. National Agricultural research Laboratories, Nairobi, Kenya

Hyder SI, Farooq M, Sultan T, Ali A, Ali M, Kiani MZ, Tabssam T (2015) Optimizing yield and nutrients content in tomato by vermicompost application under greenhouse conditions. Nat Resour 6(7): 457-464. https://doi.org/10.4236/nr.2015.67044

Joshi R, Vig AP (2010) Effect of vermicompost on growth, yield and quality of tomato (*Lycopersicum esculentum* L.). Afr J Basic Appl Sci 2(3-4): 117-123

Kariithi T (2018) Effect of organic and inorganic fertilizers on growth, yield and quality of amaranths in Kiambu County, Kenya. Thesis, Kenyatta University

Kashem MA, Sarker A, Hossain I, Islam MS (2015) Comparison of the effect of vermicompost and inorganic fertilizers on vegetative growth and fruit production of tomato (*Solanum lycopersicum* L.). Open J Soil Sci 5(02): 53-58. https://doi.org/10.4236/ojss.2015.52006

Kisaka OM, Mucheru-Muna M, Ngetich FK, Mugwe J (2014) Rainfall variability, drought characterization and efficacy of rainfal data reconstruction: Case of eastern Kenya. Adv Met 2014: 1-16. https://doi.org/10.1155/2014/380404

Leghari SJ, Wahocho NA, Laghari GM, HafeezLaghari A, MustafaBhabhan G, HussainTalpur K, Lashari AA (2016) Role of nitrogen for plant growth and development: A review. Adv Environ Biol 10(9): 209-219

Mahmud M, Abdullah R, Yaacob J (2018) Effect of vermicompost amendment on nutritional status of sandy loam soil, growth performance, and yield of pineapple (*Ananas comosus var. MD2*) under field conditions. Agron J 8(9): 1-17. https://doi.org/10.3390/agronomy8090183

Malhotra H, Sharma S, Pandey R (2018) Phosphorus nutrition: Plant growth in response to deficiency and excess. In Plant Nutrients and Abiotic Stress Tolerance. New Delhi, India, pp. 171-190. https://doi.org/10.1007/978-981-10-9044-8_7

Mehlich A, Pinkerton A, Robertson W, Kepton R (1962) Mass analysis methods for soil fertility evaluation. Cyclostyled Paper, National Agric. Laboratories, Nairobi, Kenya

Mochache M, Yegon R, Ng'etich O (2019) Vermicomposting kitchen, municipal market and tea factory wastes using *Eisenia fetida* earthworms. Int J Environ Agric Biotech 4(3): 865-873. https://doi.org/10.22161/ijeab/4.3.37

Mohamed AA, Abdrabbo M, Abul-Soud M, Farag A (2015) Economic considerations of using different types of organic manure on sweet pepper yield under protected cultivation. Int J Innov Appl Stud 13(1): 185-189

Montes J, Technow F, Dhillon B, Mauch F, Melchinger A (2011) High-throughput non-destructive biomass determination during early plant development in maize under field conditions. Field Crops Res 121: 268-273. https://doi.org/10.1016/j.fcr.2010.12.017

Mukta S, Rahman MM, Mortuza MG (2016) Yield and nutrient content of tomato as influenced by the application of vermicompost and chemical fertilizers. J Environ Sci Nat Resour, pp. 115-122. https://doi.org/10.3329/jesnr.v8i2.26877

Nas TF (2016) Cost-benefit analysis*:* Theory and application. 2nd Edition, Lexington Books, Australia, 252 pp

Nganga GM (2017) Effect of plant spacing and inorganic fertilizer rate on tomato seed production. Thesis, University of Nairobi

Nurhidayati N, Machfudz M, Murwani I (2018) Direct and residual effect of various vermicompost on soil nutrient and nutrient uptake dynamics and productivity of four mustard Pak-Coi (*Brassica rapa L.*) sequences in organic farming system. Int J Recycl Org Waste Agricult 7(2): 173-181. https://doi.org/10.1007/s40093-018-0203-0

Ochilo WN, Nyamasyo GN, Kilalo D, Otieno W, Otipa M, Chege F, Lingeera EK (2019) Characteristics and production constraints of smallholder tomato production in Kenya. Sci Afr 2: 1-10. https://doi.org/10.1016/j.sciaf.2018.e00014

Okalebo JR, Gathua KW, Woomer, PL (2002) Laboratory methods of soil and plant analysis: A working manual. Second edition. TSBF-CIAT and SACRED Africa, Nairobi, Kenya

Olanrewaju T (2017) Trend analysis of tomato production in Nigeria 2010 to 2014. https://www.researchgate.net/publication/319987223_Trend_Analysis_Of_Tomato_Production_In_Nigeria_2010_TO_2014. Accessed 3 September 2019

Oseko E, Dienya T (2015) Fertilizer consumption and fertilizer use by crop (FUBC) in Kenya. https://africafertilizer.org/wp-content/uploads/2017/05/FUBC-Kenya-final-report-2015.pdf. Accessed 5 November 2019

Page AL, Miller RH, Keeney DR (1982) Methods of soil analysis (eds). Part 2. American Society of Agronomy. 2 nd edn, Madison, Winconsin, USA, pp 595-622

Parekh SA, Mehta MJ (2015) Vermicomposting as sustainable option for organic waste management. Int J Innov Emerg Res Eng 2(1):13-20

Popović V, Tatić M, Spalević V, Rajičić V, Filipović V, Šarčević-Todosijević LJ, Stevanović P (2017) Effect of nitrogen fertilization on soybean plant height in arid year. In Proceedings, 2nd International and 14th National Congress of Soil Science Society of Serbia "Solutions and Projections for Sustainable Soil Management, pp. 65-73

Rahman H, Akter A (2018) Effect of kitchen waste compost and vermi-compost in combination with chemical fertilizer on the production of tomato. Research & Reviews: J Crop Sci Technol 6(3): 15-24. https://doi.org/10.13140/RG.2.2.22593.40803

Saranraj P, Stella D (2012) Vermicomposting and its importance in improvement of soil nutrients and agricultural crops. Novus Nat Sci Res 1(1): 14-23

Sheffy J (2007) Organic farming in Kenya: A growing demand for consistent supply. Global Environmental Management Education Center. https://www.ifoam.bio/sites/default/files/page/files/organicfarminginkenya-growingdemandforconsistentsupply.pdf. Accessed 24 October 2019

Sultana S, Kashem MA, Mollah AK (2015) Comparative assessment of cow manure vermicompost and NPK fertilizers and on the growth and production of zinnia (*Zinnia elegans*) flower. Open J Soil Sci 5(09): 193. https://doi.org/10.4236/ojss.2015.59019

Taleshi K., Shokoh-Far A, Rafiee M, Noormahamadi G, Sakinejhad T (2011) Effect of vermicompost and nitrogen levels on yield and yield component of safflower (*Carthamus tinctorius L.*) under late season drought stress. Int J Agron Plant Prod 2(1): 15-22

Tesfay T, Gebremariam M, Gebretsadik K., Hagazi M, Girmay S (2018) Tomato yield and economic performance under vermicompost and mineral fertilizer applications. Open Agric J 12(1): 262-269. https://doi.org/10.2174/1874331501812010262

Thomson Reuters Foundation (2018) With 'worm juice', Kenya's farmers boost their soil and harvests. https://www.the-star.co.ke/news/2018-09-14-with-worm-juice-kenyas-farmers-boost-their-soil-and-harvests. Accessed 24 October 2019

Thuy PT, Nghia NTA, Dung PT (2017) Effects of vermicompost levels on the growth and yield of HT152 tomato variety grown organically. Int J Agric Innov Res 5 (4): 513-518

Vaidyanathan G, Vijayalakshmi, A (2017) Effect of vermicompost on growth and yield of Tomato. Eur J Pharm Med Res 4 (9): 653-656

Verde BS, Danga BO, Mugwe JN (2013) Effects of manure, lime and mineral P fertilizer on soybean yields and soil fertility in a humic nitisol in the central highlands of Kenya. Int J Agric Sci Res 2(9): 283-291

Wachira JM (2012) Comparative analysis of greenhouse versus open-field small-scale tomato production in Nakuru-North district, Kenya. Thesis. Egerton University

Wamuswa N (2017) How I grow the best tomatoes in town. https://www.standardmedia.co.ke/article/2001237284/how-i-grow-the-best-tomatoes-in-town. Accessed 24 October 2019

Wang XX, Zhao F, Zhang G, Zhang Y, Yang L (2017) Vermicompost improves tomato yield and quality and the biochemical properties of soils with different tomato planting history in a greenhouse study. Front Plant Sci 8: 1-11. https://doi.org/10.3389/fpls.2017.01978

Xiao Z, Liu M, Jiang L, Chen X., Griffiths BS, Li H, Hu F (2016) Vermicompost increases defense against root-knot nematode (*Meloidogyne incognita*) in tomato plants. Appl Soil Ecol 105: 177-186. https://doi.org/10.1016/j.apsoil.2016.04.003

Xiukang W, Yingying X (2016) Evaluation of the effect of irrigation and fertilization by drip fertigation on tomato yield and water use efficiency in greenhouse. Int J Agron 2016: 1-10. https://doi.org/10.1155/2016/3961903

Xu C, Mou B (2016) Vermicompost affects soil properties and spinach growth, physiology, and nutritional value. HortScience 51(7): 847-855. https://doi.org/10.21273/HORTSCI.51.7.847

Yadav A, Garg VK (2015) Influence of vermi-fortification on chickpea (*Cicer arietinum* L.) growth and photosynthetic pigments. Int J Recycl Org Waste Agricult 4: 299-305. https://doi.org/10.1007/s40093-015-0109-z

Zuba SN, Nogueira WCL, Fernandes LA, Sampaio RA, Costa CD (2011) Yield and nutrition of tomato using different nutrient sources. Hortic Bras 29(1): 50-56. https://doi.org/10.1590/S0102-05362011000100009

Zucco MA, Walters SA, Chong SK, Klubek BP, Masabni JG (2015) Effect of soil type and vermicompost applications on tomato growth. Int J Recycl Org Waste Agricult 4:135-141. https://doi.org/10.1007/s40093-015-0093-3