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Management of root knot nematodes (*Meloidogyne sp.*) and enhancing growth yield of greenhouse produced tomatoes by using fresh plant derived soil amendments

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Key words: *Lippia kituensis*, *Meloidogyne* sp., *Ocimum gratissimum*, organic amendments, tomato yield.

Abstract: Production of greenhouse tomato is hampered by myriad of challenges emanating from growth medium in the sub-Saharan Africa (SSA), which has led to instability in the production trend. A greenhouse experiment was conducted to study the effect of soil amendment with fresh plant biomass from *Lippia kituensis* Vatke and *Ocimum gratissimum* L. aimed at managing root knot nematodes (RKN) and enhancing tomatoes yield. The amendments were applied at 0 (soil negative control), *Lippia* and O*cimum*, each at 200 g, 400 g % and 800 g in 10 kg potted soil mixes, singly and in all possible combinations. Azadirachtin (0.3 w/w) was also used as a positive control. The mixtures were treated inoculums carrying 1000 second instar *Meloidogyne* sp. juveniles. An unbalanced factorial in a Randomized Complete Block Design with 3 replications was used. The parameters measured were nematode populations, root gall numbers, galling index, tomato growth, development and yield. Results indicated that interactive effect of soil amendment at 800 g of both *Lippia* and *Ocimum*, significantly ($p<0.05$) reduced the RKN population by 82.1% compared to the non-amended soil. At same rates, galls were reduced by 95.5% while galling index by 83.3%, compared to non-amended treatment. In plant development same amendment rates demonstrated higher vegetative growth. For fruit number and marketable yield, 76.7% and 82.2% more fruits per plant were recorded from 800 g LK+ OG at 800 g and Azadirachtin respectively, compared to non-amended soil. Based on the results, *Lippia* and *Ocimum* may be potential sources for nematicidal plant products for greenhouse tomato production.

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All relevant data are within the paper and its Supporting Information files.

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The authors declare no competing interests.

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1. Introduction

Tomato is among the leading greenhouse vegetable crops grown in Kenya in both soil and soilless media (HCD, 2012). Tomato constitutes 7% of the total horticultural produce in Kenya and 14% of all the entire vegetable produce (Ochilo *et al.,* 2019). In terms of production in the year

2018, Kenya was rated 7th amongst the leading countries in sub-Saharan Africa with 599,458 tonnes per year, though the trend has not been stable (FAO-STAT, 2018). To stabilize the trend of production, greenhouse technology is seen as one of the solutions in tomato production, due to high levels of efficiency and the potential to support sustainable socio-economic development. However, greenhouse tomato production has not been vibrant in Kenya as it should be in the tropical humid region (Sanzua *et al.,* 2018). This is because under soil-based production, there is nutrient depletion through plant uptake and leaching beyond the root-zone of vegetable crops (Kirimi *et al.,* 2011), resulting in reduced yield in the following season. Besides, the continuous growing of tomato in the greenhouse soil leads to accumulation of soil borne pests and pathogens especially bacterial wilt *Ralstonia solanacearum*, Fusarium wilt, and Nematodes (*Meloidogyne* sp.), which has forced most farmers to abandon greenhouse tomato production (HCD, 2017).

Studies have shown that soil based media with appropriate amendments combined with other additives may effectively manage soil-born pests and diseases (McSorley, 2011). Among the pests Root-knot nematodes (RKN) *Meloidogyne spp* are the most damaging nematodes in tomatoes grown in the tropics (Walker, 2007). Infection of roots with *Meloidogyne* initiates a series of events that changes the entire physiology of the host plant. Root galls result when nematodes penetrate the cells of the cortex and pericycle the endodermis and reach the stale. About 5-7 cells surrounding the nematode's head enlarged to become a specialized giant cells, much larger than others. The thick nuclei enlarge, become polyploidy and undergo series of synchronized division, (Mai and Mullin, 1996). Root symptoms may appear as root knots (root galls), root lesions, excessive root branching (Ogallo *et al*., 1997) as root tips are injured and roots rot when nematode is accompanied by plant pathogenic or saprophytic bacteria of fungi (Cerkaukas, 2004). These nematodes are prevalent in the greenhouse condition and invade almost all vegetable crops resulting in substantial yield losses (Stirling and Stirling, 2003). Bekal and Becker (2000) observed that at peak, 100 cm^3 of soil contained 1000 nematodes. This declines with weather variation to approximately 50 nematodes per 100 cm^3 of soil. According to Stirling and Kopittke (2000), the economic threshold of RKN on most crops range between 2 and 10.

On yield various authors have reported on reduction in tomato due to RKN *Meloidogyne spp* ranging from 28% to 68% (Safiuddin Shahab *et al.,* 2012). Under soil based greenhouse tomato production, nematode infestations are a serious constraint leading to a yield reduction (Pakeerathan *et al*., 2009). Suppressed plant growth and yield has been observed in nematode infested fields (Vovlas *et al.*, 2005). Many crops grown as vegetables are susceptible to *M. incognita* and *M. javanica* particularly tomato, aubergine, okra, cucumber, melon, carrot, gourds, lettuce and peppers (Varela *et al*., 2003).

It has been suggested by McSorley (2011) that reduction of nematodes in fields treated with plant biomass wastes results in improved soil structure, fertility and improvement of plant resistance from nematode toxins. Similarly, it may increase fungal and bacterial parasites population in the soil or other nematode antagonistic agents. Apart from nematode control, these plant based biomass also provide essential nutrients (such as N and P), which help to rebuild soil organic matter contents, and aid in the re-establishment of beneficial microbial populations (Suresh *et al.,* 2004; Allen *et al.*, 2007; Dauda *et al*., 2008). Additionally, higher organic matter content increases soil water holding capacity and supports thriving communities of decomposers and predators in the soil system. The nematicidal properties of plants may be a contribution from extracted biomolecules resident in the plant bodies. The major classes of compounds with proven nematicidal activity include alkaloids, fatty acids, glucosinolates, isothiocyanates, phenols, diterpenes and a variety of essential oils (Chitwood, 2002). Neem cake, known to be rich in Azaderachtin is also associated with strong nematicidal activity (Abbasi *et al.,* 2005). Laboratory extracted essential oils have also been reported to affect development of nematode eggs and second juvenile stage (J2) under *in vitro* conditions (Onifade, 2007). Other extracts with strong pesticidal properties include rotenone, nicotine and pyrethrins (Berger, 1994).

In Verbenaceae, *Lippia* is among the genus of aromatic plants due to their essential oils (Kosgei *et al*., 2014). They are shrubs or woody herbs, leaves opposite or verticilate, glandular. Flower is pedunculate, crowded spikes; corolla obscurely 2- lipped, fruits are 2 dry mericarps each with very small seed. Various species in Kenya include; *L. dauensis* (Chiov.) Chiov, *L. grandifolia* A. Rich, *L. javanica* (Birm. F.) Spreng, *L. kituensis* Vatke, *L. somalensis* Vatke (Beentje, 1994).

The species *L. kituensis* Vatke has opposite leaves, ovate or elliptic; flowers white with yellow throat. In a previous study by (Kosgei *et al*., 2014), phytochemical analysis from methanol extracts of *Lippia kituensis* Vatke were done and reported to possess monoterpenes, Sesquiterpenes, diterpenes and other essential oil which were found to be effective against larvae *of Rhipicephalus appendiculatus*. Some of the these essential oils included Alpha-pinene (-)-, Camphene, Sabinene, beta-myrcene, l-Phellandrene, Dl-limonene, Gamma-terpinene, Trans-sabinene hydrate, Alpha-terpinolene, Neo-allo-ocimene, Camphor (1S 4S)-(-)-, Camphore, borneol (=endo-borneol), 4-methyl-1-(1-methylethyl)- 3-Cyclohexen-1-ol, 4-terpineol. In the same extract, Sesquiterpenes yielded were; Beta-bourbonene, isopropyl-5-methyl-9-methylene- Bicyclo[4.4.0]dec-1-ene, Germacrene D, Gamma-Cadinene, 2-isopropyl-5-methyl-9-methylene- Bicyclo[4.4.0]dec-1- ene. Duschatzky *et al*. (2004) reported that nematicidal activity of the essential oils isolated from *Lippia juneliana* and *L. turbinata*, which were evaluated using *in vitro* experiments. In another study, the oils of *L. juneliana* and *L. turbinata* showed the highest nematicidal activity among the tested oils, killing more than 80% of the juveniles of the *Meloidogyne* sp. Analysis of the oils revealed that *L. juneliana* contain; piperitenone oxide (36.5%), limonene (23.1%), camphor (8%) and spathulenol (6.5%) and *L. turbinata* has limonene (43.3-60.6%) and piperitenone oxide (39.3- 17.8%).

The genus *Ocimum* L. (Lamiaceae) comprises 30-160 annual and perennial herbs and shrubs, collectively called basil. Species of this genus are popular sources of essential oils and aromatic compounds, of condiments, and ornamental plants (Nagai *et al*., 2011). The most cultivated species worldwide are *O. africanum* Lour. *O. americanum* L., *O. basilicum* L., *O. gratissimum* L., O. *minimum* L. and O. *tenuiflorum* L., mainly due to their economic and medical importance (Carović-Stank *et al*., 2010). Essential oils in *Ocimum* incude Linalool, Eugenol, Methyleugenol, Trans-α-bergamotene, p-Cresol, 2, 6-di-tert-butyl, δ-Cadinene and (Z, E)-α-Farnesene (Nagai *et al*., 2011). Sifola and Barbieri (2006) reported that *O. basilicum* essential oil is constituted of phenylpropanoids, like eugenol, chavicol and its derivatives, and terpenoids; limonene, linalool and methyl cinnamate. Masi *et al*. (2006), studying nine different cultivars of *O. basilicum* commonly utilized, were able to identify five distinct chemotypes based on the main essential oil constituent; Iso-pinocamphone (35.1%) and carvone (39.7%) which were the predominant components of the essential oil in cultivated *O. basilicum*. This was also confirmed in another study by Almeida *et al*. (2010).

Several species of *Ocimum* have been reported to yield oils of diverse nature (Matasyoh *et al.,* 2007; Ogendo *et al.,* 2008). Other studies have also shown that the leaf extract of *Ocimum gratissimum* contain potential bioactive components of essential oils. These are made up of eugenol, citrol linalol, charvicol, thymol, gerianol, triterpenoids saponins and alkaloids (Atuboyedia *et al.*, 2010). It was also reported by Echeverrigaray *et al.* (2010) that monoterpenoids significantly reduce the hatching of eggs and mobility of J2 of *Meloidoyne* spp. Onifade (2007), in the study to find the effect of essential oils from five *Ocimum* sp. on the pathogenicity of *Pratylenchus brachyurus* (Godfrey) in tomato, reported that *in vitro* at 25-100 µg mL^{-1}, the oils of *O. gratissimum* and *O. basillicum* completely inhibited egg hatching and larval survival of nematodes after 24 hours. More study is still needed to explore the potential of essentials and other compunds involved in the nematode control in the two plant families Verbenaceae and Lamiaceae. The current work was therfore focused on investigating the potency of *Lippia kituensis* Vatke and *Ocimum gratissimum* L. on the management of root knot nematodes *Meloidogyne* spp. In this study we report results of a greenhouse pot experiment to evaluate management of root knot nematodes using fresh plant derived soil amendments with *Lippia kituensis* Vatke. and *Ocimum gratissimum* L. and their effects on tomato yield.

2. Materials and Methods

Experimental site

The study was conducted in two growing seasons at the Horticulture Research and Teaching Field, Egerton University, Kenya between July 2015 and May 2016. The site received a mean rainfall of 1012 mm with a mean day temperature of 22°C and night ranges of 5-10°C (Jaetzold *et al.,* 2012). The pot experiment was conducted in a polytunnel greenhouse measuring 8 m wide × 60 m length and 3 m height, covered with UV stabilized polythene sheet gauge 200 µm.

Plant materials

Leafy twigs of *L. kituensis* Vatke. and *O. gratissimum* L. were collected in the wild around Egerton University at flowering stage, when essential oil was

at its peak in the plants in the month of July 2015 (Fig. 1). These two shrubs flower all the year around visited by bees hovering over the flowers to collect nectar from scent produced by the plants. The materials were chopped into aggregates approx. 0.5 cm; the aggregates were incorporated in various proportions (0 -negative control, 200 g, 400 g and 800 g) in 10 kg of potted solarized forest soil, singly and in all possible combinations.

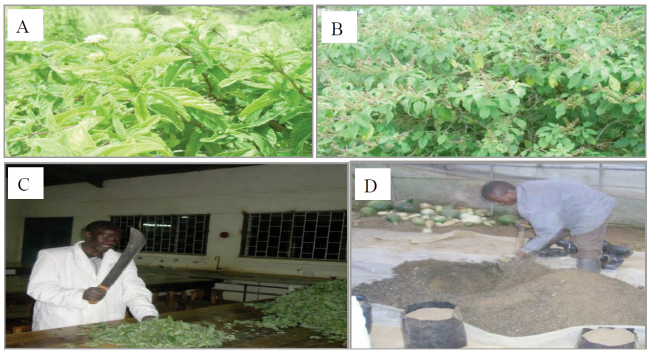

Fig. 1 - A. *Lippia kituensis* Vatke and B. *Ocimum gratissimum* L.; C. Chopping of the fresh *Ocimum gratissimum* plants into smaller pieces; D. Potting of the mixture (soil amendment process).

Crop establishment

The planting material used in the study was tomato seedlings 'Rio Grande' Rio Grande is a determinate tomato cultivar with a high yielding potential thus preferred by many farmers. This vigorous variety is well adapted to extreme temperatures. Due to the potential of heavy crops and to keep the fruit clean and easy to pick, it is recommended to support plants with stakes or cages. Seeds used to raise the tomato seedlings were obtained from Simlaws Seed Company in Nakuru (Kenya) and established in a nursery for 5 weeks before transplanting. Five weeks old tomato seedling were transferred to the substrates in the pots in the greenhouse to develop (Fig. 2). When plants reached a height of 30 cm, they were supported using sisal twines tied on a binding wire trellis at a height of 150 cm above the bed. Calcium ammonium nitrate (CAN, 26% N) was applied at the rate of 10 g per pot 21 days after transplanting (DAT) to maintain growth. Plants were pruned to maintain two stems per plant and watering was done continuously during the growing period with rates being adjusted according to plant growth phases. In the first 30 DAT, 2 l of water was applied per plant per day and thereafter, the rate was increased to 4 l to 42 DAT per day. From 43 DAT water supply was increased to 5 l per day as the plants developed, according to the work by Pires *et al*. (2011).

Fig. 2 - Transplants on treatment pots in the greenhouse.

Nematode augmentation, extraction and inoculum preparation

Nematodes were collected from a field previously grown with infested tomatoes and augmented on two weeks old potted tomato seedlings established in a greenhouse following the method of Siddiqui and Akhtar (2007). Specifically, Galls were extracted from the roots of infested tomatoes, chopped and mixed with the native soil. The mixture was added to pots planted with 2 week old tomato seedlings and the inoculum allowed to infest and multiply for 8 weeks.

After augmentation period, nematode egg masses were extracted from the heavily galled tomato roots by chopping the roots to lengths of 0.5 cm and macerating the tissues to release egg masses. These were placed in 15 cm diameter sieves of 1 mm pore size, lined with cross-layered tissue papers and incubated at 27°C to hatching in glass petri-dishes containing distilled water. After hatching, the second instar juveniles (J2) were transferred into 2 L conical flasks. Quantification of juveniles was done under a stereoscope with gridded petri dishes. Ten 1 ml replicate samples were drawn from the well mixed suspensions to establish the average number of juveniles per ml. The determined quantity was 20 juveniles per ml. Finally, the nematode inoculum suspension samples were adjusted to contain approx. 1000 juveniles in 50 ml of distilled water.

Nematode inoculation and determination of infestation parameters

The 50 ml J2s inoculum suspensions were added to pots containing the various plant biomass amended media planted with 28 day old tomato transplants. The inoculum was allowed to develop under normal tomato culture conditions in a polytunnel greenhouse. Destructive sampling of tomato plants to determine nematode infestation was conducted 100 DAT. Four plants from each replicate were sam-

pled at the peak of flowering.

Determination of macro nutrient from the tomato leaves

Nitrogen (Kjeldahl) and Phosphorus. Tomato leaves tissue were analyzed at 49 DAT for macro elements N, P, K, Mg and Ca. from the top of the plant, leaves were taken from the third and fourth leaflet per treatment. The sample materials were chopped into aggregates approx. 0.5 cm and oven dried at 70°C until constant weight. The oven dry plant samples were ground and wet digested by a sulfuric - percloric acid mixture as described by Cottenie *et al*. (1982). Nitrogen and phosphorus contents of vegetative samples were measured in the digesting extract according to the methods of AOAC (2012). Calcium and potassium content was determined in vegetative sample by ashing dry sample as described by Chapman and Pratt (1978) extract method.

Analysis of Potassium, Calcium and Magnesium. A substrate sample weighing 0.3 g was digested in digestion tubes using a digestion mixture comprising of HCl, HNO_3, HF and $H_3 BO_3$. The temperatures in the block was maintained at 360°C for two hours then samples cooled and transferred to 50 ml volumetric flasks and volume made to the mark. Calibration was done for each element using certified standards. Samples were analyzed using Atomic Absorption Spectrophotometer (AAS), Varian spectra AA10 AAS machine. The determination of these elements in the substrate was done using double acid method of extraction. AAS was used for estimation of these available elements in the tested substrate. This followed the procedure of Okalebo *et al.* (2002).

Experimental design and treatment layout

The experimental design used was a factorial embedded in a Randomized Complete Block Design and in total there were 17 treatments. There were three blocks and pots arranged in rows spaced at 0.6 m between and 0.4 m within the rows. There were 4 levels (0 g, 200 g, 400 g, and 800 g of organic amendments from each of the plant species, replicated 3 times. A negative control of solarized non-amended soil and a positive control of 0.3% w/w Azadirachtin, a farmer's standard commercially known organic based Neem extract were included. In total there were 17 treatment plots of 6 potted tomato plants in each block (Table 1).

Nematodes evaluation

Nematodes population. To determine the nematode population in the biomass amended pot soil treatments, second stage juveniles (J2) were extracted from 100 cm^3 composite sample of soil from each replicate, using the method described by Kimenju *et al.* (2010). Specifically, at 100 DAT, the soils from each of the four pots were sampled by taking 100 cm^3 of sample. The samples were placed in 9 cm diameter sieves with pore diameters of 1 mm lined with double layered tissue paper. The sieves were half immersed in metallic troughs containing 250 ml

Table 1 - Treatment combinations and description of soil amendment rates used in nematode management

Soil Amendments treatments (g/pot)	Description of treatments
0	0% w/w *Lippia kituensis* and 0% w/w *Ocimum gratissimum* (control)
200 OG	2% w/w *Ocimum gratissimum*
400 OG	4% w/w *Ocimum gratissimum*
800 OG	8% w/w *Ocimum gratissimum*
400 LK	4% w/w *Lippia kituensis*
200 LK +200 OG	2% w/w *Lippia kituensis* and 2% w/w *Ocimum gratissimum*
200 LK +400 OG	2% w/w *Lippia kituensis* and 4% w/w *Ocimum gratissimum*
200 LK +800G	2% w/w *Lippia kituensis* and 8% w/w *Ocimum gratissimum*
400 LK	4% w/w *Lippia kituensis*
400 LK+ 200 OG	4% w/w *Lippia kituensis* and 2% w/w *Ocimum gratissimum*
400 LK+ 400 OG	4% w/w *Lippia kituensis* and 4% w/w *Ocimum gratissimum*
400 LK+ 800 OG	4% w/w *Lippia kituensis* and 8% w/w *Ocimum gratissimum*
800 LK	8% w/w *Lippia kituensis*
800 LK +200 OG	8% w/w *Lippia kituensis* and 2% w/w *Ocimum gratissimum*
800 LK +400 OG	8% w/w *Lippia kituensis* and 4% w/w *Ocimum gratissimum*
800 LK +4 OG	8% w/w *Lippia kituensis* and 8% w/w *Ocimum gratissimum*
AZAD	Commercial (0.3% Azadirachtin) control

OG= *Ocimum gratissimum* L. (g/10 kg soil); LK = *Lippia kituensis* Vatke (g/10 kg soil), are soil organic amendments; 0 = no amendment; AZAD = positive control of commercially know pesticide Azadirachtin.

of distilled water to allow nematode migration into the water underneath for 24 hours. Nematode counts were determined in 10 replicate samples of 1 ml for each soil sample as previously described.

Gall number and galling index. For gall assessments, plants were gently uprooted and their roots thoroughly washed under tap water to remove all the adhering soil. Galling was determined by counts of galls size 1 mm diameter and above by a light microscope using the lowest objective lens x 4. Galled roots were spread in on plastic petri dish made of 1 cm^2 grids, numbered at the base. The galls were scored from each square to get the summation per plant. The galling index was scored on a scale of 1-10, where 0= no gall, 1= 1-50 galls, 2= 51-100 galls, 3= 101-150 galls, 4= 151-200 galls, 5= 201-250 galls, 6= 251-300 galls, 7= 301-350 galls, 8= 351-400, 9= 401-450 and 10= 451 and above (Kimenju *et al*., 2010). The scores were converted into numerical entries and their means worked out for analysis of variance.

Tomato growth evaluation

Number of leaves. Leaf count data was collected from 4 plants in each plot. Leaf count data collection was commenced 21 DAT and continued at intervals of 14 days up to 91 DAT. At each instance of data collection the mean number of leaves per plant from each replicate was computed. The mean number of leaves per treatment was determined by computing the means.

Plant height. Plant height data was collected from 4 plants in each plot. This started at 21 DAT and continued at 14 days interval up to 77 DAT. At each instance of data collection the mean height per plant from each replicate was computed. The mean height per treatment was determined by computing the means.

Root volume. Root volume data was determined by carefully removing the plants from the pot, shaking off the soil, and washed in running water on the trough at 100 DAT. Root volume was determined water displacement method in a one liter plastic measuring cylinder. The cylinder was filled to 500 ml mark, then the roots dipped carefully until the water just covered all the roots on the 4 plants used for root length determination and means computed to get the means.

Shoot and root dry weights. From the 4 plants used for root length and volume determination, shoots were separated from the roots at the collar. These were individually placed in kaki paper bags and dried in an oven at 70°C to constant weights. Both parts were weighed separately and means of the weights computed as above.

Physiological parameter

Stomatal conductance and chlorophyll content. Leaf stomatal conductance ($mmol \cdot m^{-2} \cdot s^{-1}$) was measured on four tomato tagged plants from each treatment. Using a steady state leaf porometer (SC-1, Decagon Devices, Pullman, WA), stomatal conductance was measured on a 2 weeks interval from 21 days after transplanting (DAT). Since tomato plants are hypostomatous, stomatal conductance was measured only on the abaxial leaf surface on 3 leaves on the upper parts of the plant and the average was computed. Leaf chlorophyll content was taken from the same leaves used for stomatal conductance. The instrument used was a chlorophyll content meter (CCM-200 plus, Opti-Sciences, Tyngsboro, MA) and measurement in chlorophyll concentration index units (CCIs), as an estimate of chlorophyll content on leaves.

Yield

Number of fruits per plant. Weekly piece meal harvesting of pink stage tomato fruits from the 4 tagged plants in each treatment was done. At each harvest, the number and weight of fruits were recorded for each treatment.

Marketable and Non-marketable fruit yield. Physiologically mature fruits (at pink stage) were harvested from the 4 tagged plants in each treatment. Harvesting was piece meal on weekly basis. At each harvest, fruits were sorted into marketable and non-marketable (kg/plant) separately and their weight determined and recorded. Fruit weight was taken from mature marketable fruits (at pink stage), harvested from the 4 tagged tomato plants from each treatment. These were weighed using a spring balance (ATZ, Shangai Precision and Scientific Instrument Co., Shangai, China) at each harvest and later summed up to give the total marketable weight (kg/plant).

Data analysis

Data for the two trials were pooled since there was no statistical difference between them. It was then subjected to analysis of variance (ANOVA) and means separated by the Tukey's HSD using The SAS statistical package version 9. The model fitted for this experiment was; $Y_{ijk} = \mu + \beta_i + \alpha_j + \gamma_k + \alpha\gamma_{jk} + \varepsilon_{ijk}$ where y_{ijkl} = tomato response, μ = overall mean, β_i = effect of the i^{th} block, α_j = effect of the j^{th} level of

Lippia kituensis Vatke ,γ_k = effect of the k^{th} level of *Ocimum gratissimum* L., $\alpha\gamma_{jk}$ = interaction effect of the j^{th} level of *Lippia kituensis* Vatke and k^{th} level of *Ocimum gratissimum* L. ε_{ijk} = random error component term which are normally and independently distributed about zero means with a common variance σ^2.

3. Results

Effect of soil organic amendment on nematode population, gall numbers and galling index

The different levels of amendments with *Lippia kituensis* Vatke and *Ocimum gratissimum* L. biomass and their combinations significantly (P<0.05) influenced nematode populations in the treatments (Table 2). Various rates of treatment reduced the juvenile populations when compared with the control. In single treatments of *Lippia* at 200 g, 400 g and 800 g, nematode numbers was reduced to 38.88 (25.9%), 19.29 (63.3%), and 20.58 (60.8%) respectively, compared to the non-amended treatments. *Ocimum* had similar trend with reduction to 47.38 (9.75%), 34.58 (34.1%) and 30.63 (41.7%), respectively (Table 2). However, the interactive effect of the two plant biomass from 400 g and above produced better nematode reduction than single treatments alone compared to soil.

Gall numbers and galling index were determined 100 DAT and were significantly P<0.05) influenced by organic amendments (Table 2). There was a general decrease of gall numbers in roots of tomato plants with increased levels of *Lippia* and *Ocimum* biomass in the potting soil. Application of *Lippia* singly at rates of 200 g, 400 g, and 800 g per pot reduced gall numbers to 190 (66.9%), 155 (73.0%) and 125.60 (78.1%) respectively compared to soil with *Ocimum* following the same trend with reduced galls numbers to 470.67 (18.1%), 422.5 (26.5%) and 175.3 (69.5%) respectively. Interactive effect of the two plant biomass above at the rates of 200 g was better reduction of gall numbers up to 25.17 galls (95.5%) and no significant differences (P<0.05) were evident among the various combinations.

The efficacy of the fresh plant biomass materials in managing nematode proliferation on tomato roots was also evident in the galling index scores from the various treatments. In general the gall index showed a reducing trend with increasing levels of *Lippia* and *Ocimum* biomass amendments. The interactive effect of the two plant species both at 800 g produced tomatoes with vigorous, fibrous root system with very few galls only observed under light microscope.

Table 2 - Effect of fresh organic amendments on nematode population, gall number and galling index

Amendments g/10 kg)	No. of nematodes (per 100 cm^3 soil)	No. of galls/plant	Galling index
0	52.50 a *	574.67 a	10.00 a
200 OG	47.38 b	470.67 b	10.00 a
400 OG	34.58 d	422.50 c	9.00 a
800 OG	30.63 ef	175.30 de	5.00 c
200 LK	38.88 c	190.00 de	7.30 b
400 LK	19.29 g	155.00 defgh	5.70 c
800 LK	20.58 g	125.60 defgh	3.00 de
200 LK + 200 OG	38.21 c	211.00 cd	4.67 c
200 LK + 400 OG	33.29 de	197.90 de	5.00 c
200 LK + 800 OG	28.33 f	123.40 defgh	3.67 cd
400 LK + 200 OG	17.50 gh	155.60 defgh	4.50 c
400 LK + 400 OG	12.25 i	130.17 defgh	3.00 de
400 LK + 800 OG	10.38 i	85.00 fgh	2.00 ef
800 LK + 200 OG	12.25 i	100.00 fgh	3.67 cd
800 LK + 400 OG	9.38 i	80.67 fgh	2.00 ef
800 LK + 800 OG	9.42 i	25.67 gh	1.67 ef
Azadirachtin	4.17 j	13.17 h	1.00 f

OG = *Ocimum gratissimum* L.; LK = *Lippia kituensis* Vatke; 0 = no amendment (soil).

* Means followed by the same letter series within a column are not significantly different according to Tukey's honestly significant difference (THSD) at P≤0.05.

Comparatively, those roots of plants grown in non-amended treatments (soil) had numerous galled roots which were less fibrous (Fig. 3).

Fig. 3 - The effect of *Lippia* and *Ocimum* on the tomato root system. A) LK+ OG at 800 g show fibrous root system, B) LK+OG at 200 g with fewer galls, and C) Non-amended soil high nematodes infestation.

Effect of fresh plant organic amendments on tissue of greenhouse tomato

The different levels of amendments of *Lippia* and *Ocimum* soil amendments had significant (P<0.05) influence on tomato plant tissue nutrients. The plant macro nutrient analyzed included N, P, K, Ca and Mg, which are the most essential element in tomato production. The interactive effect of the *Lippia* and *Ocimum* biomass were significantly higher in the tomato leaf tissues from both amendment rates above 400 g/10 kg of the substrate (Table 3). In single state, both plant biomass registered significantly higher N content at 800 g only.

Number of leaves

Tomato leaf numbers were significantly influenced by the use *Lippia* and *Ocimum* as soil organic amendments (Table 4). There were significantly (P<0.05) higher leaf number at 21 DAT in soil alone and 200g pots of both *Lippia* and *Ocimum* levels than 400g and above. However trend changed as from 35 DAT as from 35 DAT on 400 g of both species having the highest leaf numbers. At 49 DAT there were no significant difference (P<0.05 on treatment of both species from rates above as single or in combination 4 Non-amended soil had the least number of leave except for 21 DAT. Compared to the positive controls, Azadirachtin treated had relatively lower number leaves than 800 g of both *Lippia* and *Ocimum* combined, however this was higher than the un-amended soil.

Plant height

The result showed that the height of tomato plant was significantly (P<0.05) influenced by the *Lippia* and *Ocimum* levels (Table 5). Plants amended with 400 g of *Lippia* or *Ocimum* were taller than those of the lower levels of amendment and Azadairachtin. As in the leaf numbers plant height differences were observed 49 DAT were no difference were from each treatment up to the highest rate.

Root volume

The organic amendments significantly influenced the development of the total root volume of the tomatoes grown in the pots during the production seasons (Table 6). In root volume interactive effect

Table 3 - Effect of fresh plant organic amendments on tissue analysis of greenhouse tomato

Amendments (g/10 kg)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
0	2.95 d *	0.23 e	2.82 g	0.68 l	0.28 f
200 OG	3.35 bcd	0.33 cd	3.12 ef	0.98 k	0.33 ef
400 OG	3.45 abc	0.30 cde	2.92 fg	1.18 i	0.32 ef
800 OG	3.35 bcd	0.32 cd	3.12 ef	1.68 f	0.36 de
200 LK	3.55 ab	0.33 cd	3.32 de	1.08 j	0.42 cd
400 LK	3.75 ab	0.43 b	3.42 cd	1.58 g	0.31 ef
800 LK	3.85 a	0.56 a	3.72 ab	2.08 b	0.49 abc
200 LK + 200 OG	3.35 bcd	0.34 cd	3.32 de	1.88 d	0.36 de
200 LK + 400 OG	3.75 ab	0.35 bc	3.72 ab	1.38 h	0.36 de
200 LK + 800 OG	3.55 ab	0.60 a	3.12 ef	1.78 e	0.38 de
400 LK + 200 OG	3.85 a	0.38 bc	3.52 bcd	1.88 d	0.35 def
400 LK + 400 OG	3.65 ab	0.37 bc	3.82 a	1.98 c	0.37 de
400 LK + 800 OG	3.65 ab	0.55 a	3.72 ab	2.38 a	0.42 cd
800 LK + 200 OG	3.65 ab	0.61 a	3.62 abc	2.38 a	0.46 bc
800 LK + 400 OG	3.55 ab	0.59 a	3.72 ab	2.08 b	0.52 ab
800 LK + 800 OG	3.65 ab	0.58 a	3.82 a	2.38 a	0.54 a
Azadirachtin	3.05 cd	0.26 de	2.92 fg	1.08 j	0.28 f

OG = *Ocimum gratissimum* L.; LK = *Lippia kituensis* Vatke; 0 = no amendment (soil).
* Means followed by the same letter series within a column are not significantly different according to Tukey's honestly significant difference (THSD) at P≤0.05.

Table 4 - Effect of fresh plant biomass on tomato leaf numbers

Amendments g/10 kg)	Leaf numbers				
	21 DAT	35 DAT	49 DAT	63 DAT	77 DAT
0	12.00 ab *	13.06 gh	20.83 cd	21.83 fg	22.67 k
200 OG	11.39 abc	12.61 h	20.94 bcd	22.67 ef	23.67 j
400 OG	10.28 cdef	14.61 cde	21.94 abcd	25.61 cd	26.20 fg
800 OG	0.28 cdef	14.78 cd	25.39 abc	27.33 abc	27.73 de
200 LK	12.21 a	13.28 fgh	21.83 abcd	26.61 c	27.66 de
400 LK	10.06 defg	13.5 efgh	16.94 d	20.11 g	24.67 i
800 LK	11.22 abc	14.28 cdef	24.89 abc	22.67 ef	27.20 e
200 LK + 200 OG	9.50 efgh	14.28 cdef	23.28 abc	26.83 bc	27.32 de
200 LK + 400 OG	11.22 abc	14.94 bcd	24.39 abc	25.79 cd	27.33 de
200 LK + 800 OG	10.94 bcd	15.22 abc	23.39 abc	26.72 c	27.27 e
400 LK + 200 OG	10.28 cdef	15.22 abc	24.11 abc	29.28 ab	29.53 ab
400 LK + 400 OG	9.28 fgh	14.06 defg	21.17 abcd	23.83 de	26.53 ef
400 LK + 800 OG	10.78 cd	16.21 a	23.50 abc	27.11 bc	29.60 a
800 LK + 200 OG	10.61 cde	15.39 abc	24.22 abc	26.18 cd	28.60 bc
800 LK + 400 OG	8.61 h	16.00 ab	24.56 abc	26.33 cd	29.73 a
800 LK + 800 OG	9.06 gh	16.33 a	27.39 a	29.83 a	29.90 a
Azadirachtin	12.33 a	13.56 efgh	23.89 abc	27.17 bc	28.13 cd

OG = *Ocimum gratissimum* L.; LK = *Lippia kituensis* Vatke; 0 = no amendment (soil). DAT = Days after transplanting.
* Means followed by the same letter series within a column are not significantly different according to Tukey's honestly significant difference (THSD) at P≤0.05.

Table 5 - Effect of fresh plant biomass from *Lippia kituensis* Vatke and *Ocimum gratissimum* L. on tomato plant height

Amendments g/10kg)	Plant height		
	49 DAT	63 DAT	77 DAT
0	48.78 fg *	91.56 f	91.56 f
200 OG	49.33 f	94.00 ef	94.00 ef
400 OG	71.72 ab	99.00 cde	99.00 cde
800 OG	70.11 abc	98.93 cde	98.93 cde
200 LK	58.22 def	98.60 cde	98.60 cde
400 LK	60.06 cde	102.80 abcd	102.80 abcd
800 LK	73.67 a	108.40 a	108.40 a
200 LK + 200 OG	66.61 abcd	97.47 de	97.47 de
200 LK + 400 OG	72.83 a	99.73 bcde	99.73 bcde
200 LK + 800 OG	67.06 abcd	97.80 de	97.80 de
400 LK + 200 OG	62.22 bcde	101.27 abcde	101.27 abcde
400 LK + 400 OG	72.83 a	105.73 abcd	105.73 abcd
400 LK + 800 OG	69.67 abc	108.27 ab	108.27 ab
800 LK + 200 OG	65.78 abcde	100.13 abcde	100.13 abcde
800 LK + 400 OG	66.50 abcd	106.53 abc	106.53 abc
800 LK + 800 OG	76.00 a	105.47 abcd	105.47 abcd
Azadirachtin	69.28 abc	88.40f	88.40 f

OG = *Ocimum gratissimum* L.; LK = *Lippia kituensis* Vatke; 0 = no amendment (soil). DAT= Days after transplanting.
* Means followed by the same letter series within a column are not significantly different according to Tukey's honestly significant difference (THSD) at P≤0.05.

was observe in the amendment at 400 g of both species with highest of 312.3 cm^3. Azadirachtin treated soils recorded relatively lower with root volume of 89.00 cm^3, which was not significantly different from the non-amended soil.

Root and shoot dry weight

As observed in the root volume, root and shoot dry weight showed effect by *Lippia* and *Ocimum* levels in the treatments for the two seasons in a similar trend (Table 6). Interactive effect of the two plant

Table 6 - Effect of fresh plant biomass on tomato leaf numbers

Amendments (g/10 kg)	Root volume (cm^{-3})	Root dry weight (g)	Shoot dry weight (g)
0	69.33 i *	24.17 h	46.12 j
200 OG	135.33 h	28.50 h	57.92 i
400 OG	84.6 7i	44.17 cdef	73.86 fg
800 OG	281.00 d	39.83 defg	69.95 fgh
200 LK	132.00 h	39.67 defg	71.42 fg
400 LK	249.67 e	39.58 efg	77.01 e
800 LK	282.33 cd	38.58 fg	86.56 c
200 LK + 200 OG	286.67 bcd	38.00 g	66.47 h
200 LK + 400 OG	229.33 e	43.00 cdefg	66.53 h
200 LK + 800 OG	279.67 d	46.50 bc	75.66 ef
400 LK + 200 OG	194.67 f	45.17 cde	86.10 c
400 LK + 400 OG	165.67 g	45.25 cd	96.68 b
400 LK + 800 OG	312.00 a	53.08 a	99.78 ab
800 LK + 200 OG	248.67 e	56.08 a	97.67 b
800 LK + 400 OG	310.00 ab	53.17 a	98.78 b
800 LK + 800 OG	306.00 abc	53.00 a	100.85 a
Azadirachtin	89.00 i	51.75 ab	86.23 cd

OG = *Ocimum gratissimum* L.; LK = *Lippia kituensis* Vatke; 0 = no amendment (soil).
* Means followed by the same letter series within a column are not significantly different according to Tukey's honestly significant difference (THSD) at P≤0.05.

were significantly higher weight as from 400 g and above. As was observed in the root volume, highest root dry weight of 53.1 g was not significantly different from Azadirachtin treated soils 51.7 g but significantly different from the control soil 24.1 g. similarly interactive effect of LK and OG registered 101 g, significantly higher than Azadirachtin treated soils 86.2 g and soil 46.1 g in LK 800 g combined with 800 g OG, Azadirachtin treated soils and soil alone respectively.

Effect of organic amendments on physiology response of tomatoes

Chlorophyll content and stomata conductance

Organic amendments levels influenced chlorophyll content in the tomato plant positively as shown in figure 4. For both season, interactive effect of both

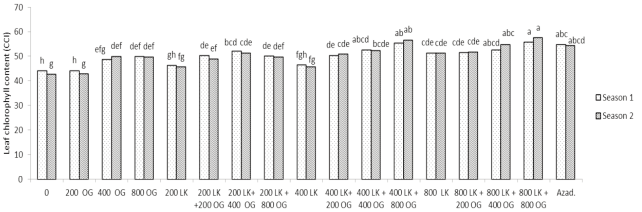

Fig. 4 - Effect of fresh plant organic amendments on tomato plant chlorophyll content taken after two week interval. Means followed by the same letter in a letter series within a column per season are not significantly different according to Tukey's honestly significant difference (THSD) at P≤0.05. OG =*Ocimum gratissimum* L. and LK = *Lippia kituensis* Vatke, are soil organic amendments in g/10 Kg soil, 0 = no amendment and AZAD = positive control of commercially know pesticide Azadirachtin.

plant species biomass were significantly higer than most of the single rates. Soil had the least chlorophyll content compared to the treated soils. The stomatal conductance of the leaves from the rates mentioned were affected in similar manner (Fig. 5). However Azadirachtin treated soil was not significantly different from highest combination of the biomass in stomatal conductance. Generally single treatments showed lower physiological process in the leaves.

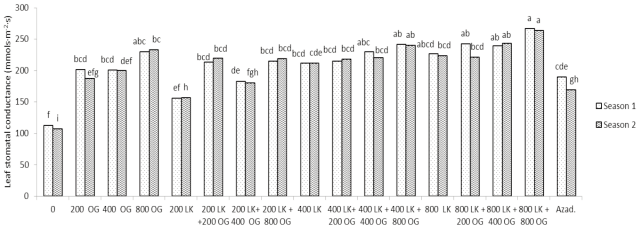

Fig. 5 - Effect of fresh plant organic amendments on tomato plant stomatal conductance taken after two week interval. Means followed by the same letter in a letter series within a column per season are not significantly different according to Tukey's honestly significant difference (THSD) at P ≤ 0.05. OG =*Ocimum gratissimum* L. and LK = *Lippia kituensis* Vatke, are Soil organic amendments in g/10Kg soil, 0= no amendment (soil), AZAD= Azadirachtin.

Number of fruits per plant

Lippia and *Ocimum*, significantly (P<0.05) influenced fruit number per plant (Fig. 6). Interactive effect of the two plants had mean of 62.72 fruits,

while non-amended control had 22.24 tomatoes per plant for season 1 and 2. Azadirachtin had 32.50 tomatoes per plant.

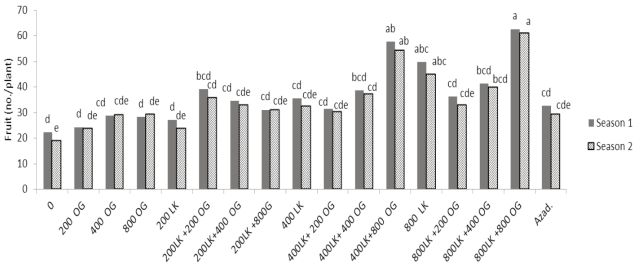

Fig. 6 - Effect of fresh plant biomass from the plant species Lippia kituensis and Ocimum gratissimum. on tomato plant fruit per plant. Means followed by the same letter in a letter series within a column per season are not significantly different according to Tukey's honestly significant difference (THSD) at P ≤ 0.05. OG =*Ocimum gratissimum* L. and LK = *Lippia kituensis* Vatke, are Soil organic amendments in g/10 Kg soil, 0 = no amendment and AZAD = positive.

Effect of fresh plant biomass on marketable yield and non-marketable yield

There was a general increase of marketable tomato fruits with the increase of the rates of plant organic amendment (Fig. 7A). The interaction between the especially above in *Lippia* or *Ocimum* 400 g produced tomato with higher t/ha than single treatments and soil media. Azadirachtin treated soil had better yield though significantly lower than those in 800 g of both species, which were rated as marketable.. Non-marketable showed a reverse trend on the fruit weight (Fig. 7). There was an opposite trend in the effect of the amendment from that of marketable. Any combination biomass lower than 400 g did not produce marketable but poor qualities fruits represented as blossom end rot, blotch ripening, puffiness, gold flex, car face, sunscald and very small size stony fruits, which rendered them non-marketable. (Fig. $7B_1$, $7B_2$, $7B_3$).

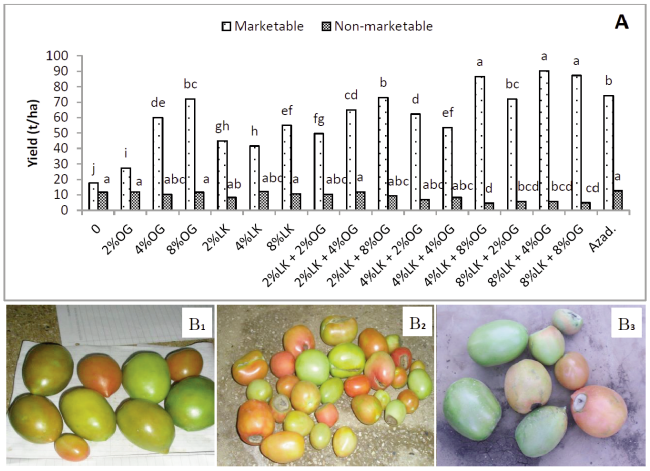

Fig. 7 - A. Effect of fresh plant biomass on marketable yield and fruit Quality. Means followed by the same letter in a letter series within a variable are not significantly different according to Tukey's honestly significant difference (THSD) at P≤0.05. OG =*Ocimum gratissimum* L. and LK = *Lippia kituensis* Vatke, are Soil organic amendments, 0 = no amendment and AZAD = Azadirachtin. (2% OG= 200 g OG, 4% OG= 400 g OG 8% OG= 800 g OG; 2% LK= 200g LK, 4% LK= 400 g LK, 8% LK= 800 g LK /10 Kg).
B. The picture shows difference in the quality of tomato at different rates of *Lippia* and *Ocimum* amendments B1= LK+OG at 800 g; B2= 0 LK+200 g OG; B3= Non-amended soil.

4. Discussion and Conclusions

The practice of adding organic matter to soil for management of soil pest and increase yield is as old as the agriculture (Akhtar and Alam, 1993) and this has been successfully explored to control some plant parasitic nematodes (Ferraz and Freitas, 2004; Lopes, 2011). This study revealed positive interactive effects of *Lippia kituensis* Vatke and *Ocimum gratissimum* L. as fresh biomass for the control of nematodes (*Meloidogyne* spp.) in greenhouse tomatoes. In overall, the results indicated effective nematode control in the tomato crop treated with the plant biomass compared to the control treatments where no amendments were applied. Additionally, it was generally observed that interactive effect of biomass treatments of the two species at the higher rates (400 g and 800 g) was more effective than the single treatments. In line with this study, Oka *et al*. (2007) reported sensitivity of plant-parasitic nematodes to plant derived amendments, however, they indicated that the effect varied with the nematodes species targeted and the rates applied. Our results further revealed that the second instar juveniles (J2) of *Meloidogyne* spp were more susceptible to higher rates of these treatments and effectively suppressed the nematodes in the media.

Several postulations on the mechanisms of action of these fresh biomass materials have been put forward. It has been reported that during the decomposition of these organic materials, volatile fatty acids, ammonia and hydrogen sulphide gases are released (McSorley, 2011) and these may enhance nematode control. Alternatively, other authors have explained the mechanisms of nematode population reduction by soil amendments with organic matter to involve

stimulation of antagonistic microorganisms, liberation of secondary volatile or nonvolatile phytochemicals with nematicidal properties (Lopes *et al*., 2011). As earlier reported by Chavarría-Carvajal and Rodríguez-Kábana (1998), the amendments may improve the growth of the plants and hence increase the tolerance and plant resistance to nematodes. In this study *L. kituensis* and *O*. *gratissimum* biomass additions to soil probably proved toxic to *Meloidogyne* spp. under greenhouse conditions, even at low rates of two species when combined at 200 g per pot of 10 kg of soil (Table 2). These results concur with the study of Lopes *et al.* (2011), who reported that soil amendment with the aerial portion of certain plant species has nematicidal properties. Similar results have been reported by Kagai *et al*. (2012), working with selected plant biofumigants in the management of plant parasitic nematodes in *Asclepias tubaerosa* L. In line with this study, Onifade (2007) earlier reported that essential oils from basil (*Ocimum basillicum*) had nematicidal effect on parasitic nematodes, especially *Meloidogyne* spp and *Pratylenchus penetrance* which is root lesion nematode. The second possible mechanisms for nematode suppression by these organic amendments could be direct inhibition or reduced infectivity of nematodes on the plant host. This may also be speculated that the use of *Lippia* and *Ocimum* as fresh soil organic amendment enhances antagonism in the soil mixes by increasing the abundance of other competing beneficial organisms, thus reduces the chances RKN survival. These results are in concurrence with a study by Claudius-Cole *et al*. (2010), which reported reduction of *Meloidogyne incognita* on cow pea *Vigna unguiculata* (L) Walp using plant extract. Besides, in agreeement with the present study Hasabo and Noweer (2005), earlier reported that the extract of *Ocimum* reduced nematode population on eggplant, and increased resultant fruit yields.

In the present study, different rates of amendments with *L. kituensis* Vatke and *O. gratissimum* L. biomass significantly influenced gall numbers and galling index in the treatments especially when the two plant biomass interacted (Table 2). This was demonstrated when galling index was drastically reduced. Various studies have shown similar observations in using organic amendments to control RKN. Breakdown of plant organic material releases nematicidal substances that may contribute to nematode control (Chen *et al*., 2000). Akhtar and Malik (2000) also reported that crops and weeds release biochemicals that counteract the activities of nematodes. This has also been confirmed by McSorley (2011) that nematicidal compounds released from decomposing materials can stimulate the natural enemies of nematodes and improving plant tolerance. In line with the present study, *Lippia* and *Ocimum* have been reported to yield essential oils of diverse nature (Atuboyedia *et al.*, 2010). Laboratory analysis of *Ocimum* yielded eugenol, citrol linalol, charvicol, thymol, gerianol, triterpenoids, saponins and alkaloids (Matasyoh *et al*., 2007; Ogendo *et al*., 2008). Based on the findings of the present investigation, it is plausible to suggest that these biomolecules extracted during decomposition of the plants biomasses helped to inhibit nematode activity in the amended soil, leading to low galling index. It also concur with observations by Onifade (2007) indicated that use of essential oils of *O. gratissimum* and *O. basillicum in vitro* at rates which completely inhibited egg hatching and larval survival of nematodes and this probably caused reduction of gall number.

From the present results on macro element analysis of the amended media, it is clear that besides acting as a nematicide for the management of RKN, *Lippia* and *Ocimum* also acted as plant nutrient source for tomato growth and yield. Mostly these element were significantly higher in the both amendment rates above 400g and above per 10 kg of the substrate (Table 3). Nitrogen, P, K Mg and Ca are essential macro element, important in entire plant growth and development. In particular, nitrogen is mostly required by plants to achieve high rates of growth and yield of tomato. The presence of these elements may promote physical and physiological changes in the plant and mostly related to photosynthesis, whereas Mg also plays a big role in chlorophyll structure (Taiz and Zieger, 2002). Nitrogen is a critical macronutrient influencing processes growth and development directly on source-sink relations, altering the distribution of assimilates between the vegetative and the reproductive part resulting into yield (Zuba *et al*., 2011). Phosphorus is for root development, flower initiation, seed and fruit development. Unlike N and P, K does not form any vital organic compounds in the plant, however, its presence is vital for plant growth, being known to be an enzyme activator that promotes metabolism (Silva and Uchida, 2000).

The effect of *Lippia* and *Ocimum* rates and their interaction on vegetative phase, increased leave number and height was revealed in this study (Table 4). With increased rates of organic amendment in the combination, it is probable that NPK levels in the soil

may also enhance growth, leading to the increase in leaf number. Leaf number is a function of N in plant (Otieno *et al.,* 2019) and this is very key for the higher number of leave observed at the rates of 800 g *Lippia* and 800 g of *Ocimum* combined. At DAT 21 there were more leaves in the non-amended soils compared to amended soil in seasons 1 and 2 (Table 4). This was probably due to the loss of nutrient especially N from the decomposing fresh organic amendments by microorganisms involved. The microorganisms involved in the decomposition possibly out-competed the tomatoes in the used the N available for the plant and this may have led to reduction in growth rate. However, this trend was changed as from 35 DAT upwards indicating that both *Lippia* and *Ocimum* had started releasing nutrient from decomposition process for tomato use. This is in conformity with observation made by Pakeerathan *et al.* (2009) in the management of *Meloidogyne incognita* using different green leaf manures on tomato under field conditions, where N contributed more toward the vegetative components (leaves and stems) of the plant than reproductive components.

The height of tomato was also influenced by the higher rates *Lippia* and *Ocimum* (Table 5) and probably this was a function of K in the organic amendments rates applied as observed in table 3. This is in consistence with El-Nemr *et al.* (2012) who reported Potassium (K) concentration as among the plant macronutrients that affected these growth parameters. In another study, Faruk *et al.* (2011) reported similar observation on the effect of poultry organic amendment on root knot nematode management and its influence on the height of greenhouse grown tomatoes.

The ability of plants to obtain water and mineral nutrients from the soil is related to their capacity to develop extensive roots and root hairs (Taiz and Zieger, 2002). As in Table 6, there was a significant increase in root volume with increased rates of *Lippia* and *Ocimum* especially when the two species were combined above 400 g, compared single rates and the controls. For root growth and development, organic amendments in the soil has been known to increase the bulk density of the growing media (Otieno *et al*., 2020), giving room for root system to explore wider range of the soil environment for more nutrients (Faruk *et al*., 2011; Otieno *et al.,* 2019). At lower amendment level, fewer root were observed, resulting in low root volume. In contrary, roots produced from 800 g of *Lippia* and *Ocimum* produced higher volume of fibrous roots. From this study it may be speculated that the root system of the tomatoes from highly amended media probably were affected in two ways; either by enhancing soil structure in favour of the roots growth (Otieno *et al.,* 2019), or reduction of nematodes population in the soil or both. Increasing amendments to the soil may alter many factors that affect root development in the rhizosphere. These include soil structure, particle aggregation, pH, salinity, level of Carbon dioxide, Oxygen and other chemicals (Akhtar and Malik, 2000). In this way, this probably increased the roots' ability to increase in dry weight and subsequently shoot dry weight. Similarly, the current result concurs Yadessa *et al*. (2010), whose findings showed that 10% of FYM produced significantly higher shoot and root dry weight compared to non-amended.

Leaf chlorophyll content (CCL) and stomatal conductance responded positively to increasing rates of these organic amendments. At 49 DAT, it was marked with maximum physiological processes in the crop (Figs. 4 and 5), indicating higher formation of chlorophyll content on the tomato crop at higher rates of *Lippia* and *Ocimum.* Nitrogen is an essential nutrient for normal growth and development of a plant as it is an integral part of the chlorophyll molecule (Kitonga-Mwanza, 2011), together with Mg; the principle site of light absorption necessary for photosynthesis. Stomatal conductance on the other hand was similarly influenced by both *Lippia* and *Ocimum* rates in the organic amendments (Fig. 4). Mostly K is involved in stomata closing and opening, therefore when galls have interfered with root system, the stomatal function may have been negatively affected at lower rate of amendments showing lower rate of stomatal conductance. This suggests that apart from the influence of K in the organic amendments, nematodes also played a part by the interference of the plant root system (Mai and Mullin, 1996), reducing the flow of water and minerals upward the plant.

From the current study, amendments rates influenced yield differently among the individual rates (Fig. 6). Highest yield in terms of fruit numbers registered per plant was observed in those with 400 g and above in rates of *Lippia* and *Ocimum* amendments, indicating that the production of fruits was probably from primary plant nutrients as reflected in tomato tissue analysis (Table 3). This observation is in agreement with that made by Walker (2007), where, the effect of organic amendments, fertilizers and fenamiphos was reported on reduction of parasitic and free- living nematodes as well as increased yield

of tomato. A number of authors have reported that adequate K nutrition is linked with increased yields (Kanai *et al.,* 2007; Afzal *et al*., 2015), which further confirm the current findings plant derived organic amendments and their impacts on tomato production.

Finally, the marketable yield of tomato is basically dependent on regular nutrient and moisture availability in growing media for plant use. Moisture in particular is essential for nutrient movement, whereas its irregular flow in the plant system may cause blossom end rot of (BER) in tomato. This scenario is more pronounced irregular Calcium mobility in both growing media and the plant system. As for the current study, application of both *Lippia* and *Ocimum* at 800 g level per 10 kg pot seemed to have increased water holding capacity of the amended soil since organic matter enhances the moisture availability in the media leading to more nutrient availabilty hence higher marketable yield. In concurrence to the present study, Akhtar and Malik (2000) reported higher marketable yield following the application of organic matter to the soil. The beneficial effects of organic amendments are generally assumed to be due to the provision to the crops, extra nutrients. The current study therefore emphasizes that yield obtained from high level amendment of *Lippia* and *Ocimum* were generally higher in marketable quality compared to non-amended soils. Conclusively, both plant organic amendments played an important role as both biopesticides and organic soil fertility for crop growth and development.

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