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Potential of Dual-Purpose Organic Amendment for Enhancing Tomato (*Lycopersicon esculentum* M.) Performance and Mitigating Seedling Damage by Mole Cricket (*Gryllotalpa africana* spp.)

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Authors' contributions

This work was carried out in collaboration between all authors. Author CN designed the study, prepared organic input, processed data, performed statistics, literature searches and wrote the first manuscript draft. Authors CBT and CAN established and managed the field trial and organic input, collected data and performed literature searches. Authors JNO and TEN coordinated data collection and processing and performed literature searches. Authors PMM and RNN coordinated field site and data management and performed literature searches. Author AST coordinated the experimentation and manuscript preparation. All authors read and approved the final manuscript.

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ABSTRACT

Aim: Efficacy of locally produced dual-purpose organic amendment for improving tomato protection and yield was compared with synthetic pesticides and fertilizers.
Methodology: The experiment was setup as randomized complete block with three treatments (control, inorganic and organic) each replicated four times.
Results: Treatment was negatively correlated with tomato seedling damage by mole cricket (r = −0.86), with 100% efficacy in the organic treatment compared to 90% in the inorganic treatment and 80% in the control (P = .05). Treatment was negatively correlated with tomato blight (r = −0.57), with 100% blight infestation in the control compared to 8% in the inorganic treatment and 25% in the organic treatment (P = .05). No tomato plant was damaged in the organic treatment, compared to 12.5% in the inorganic treatment and 29.1% in the control (P = .001). The total plant damage was negatively correlated with treatment (r = −0.97) and positively correlated with seedling damage (r = 0.90), blight (r = 0.57) and wilt (r = 0.97). The highest tomato yield occurred in the inorganic treatment with 43.9 t ha^{-1} and organic treatment with 38.1 t ha^{-1}, which differed (P = .05) significantly from the control with 1.5 t ha^{-1}. Tomato yield correlated positively with the number of leaves per plant (r = 0.66), but was negatively correlated with blight (r = −0.70) and wilt (r = −0.60). The highest number of leaves per plant was recorded in inorganic treatment with 30 and organic treatment with 28, compared to 15 in the control (P = .05). Treatment was positively correlated with number leaves per plant (r = 0.63), while the number of leaves was negatively correlated with blight incidence (r = −0.92).
Conclusion: The dual-purpose organic amendment is an effective sustainable alternative for improving tomato protection and yield compared to inorganic inputs.

Keywords: Blight; mole cricket; mucuna; piper; tithonia.

1. INTRODUCTION

Vegetable consumption is a major source of micronutrients, vitamins and health-promoting compounds that mitigate diseases and malnutrition in humans [1]. Despite the importance of tomato, poor soil fertility and crop nutrition coupled with various pests and diseases limit both the quantity and quality of tomato produced [2]. Tomato early blight (*Alternaria solani*) or late blight (*Phythophthora infestans*) and Fusarium Wilt (*Fusarium oxysporum*) often cause plant death and yield loss [3-5]. Meanwhile, mole cricket (*Gryllotalpa africana spp.*) are critical pests at early seedling growth after transplanting that cause damage via feeding on roots or stems/leaves, and through their tunnelling behaviour in rhizosphere [6-9]. In addition, herbivorous feeding by mole cricket on stems/leaves increases the probability of introducing plant pathogens to seedlings, since some insects serve as vectors [10].

Various management practices including the use of bio-control agents have been employed to control mole cricket [11,12]. Combinations of synthetic pesticides, fungicides and inorganic fertilizers are commonly used to control tomato pests/diseases and boost plant nutrition/growth. However, the pesticides, fungicides and fertilizers are scarce and expensive for smallholder farmers in Sub-Saharan Africa (SSA), coupled with potential negative externalities. Hence, there is increasing need for sustainable alternatives that are environmentally safe, readily available, affordable and adapted to the specific needs of smallholder farmers in SSA [13,14]. Meanwhile, some botanicals such as Neem, *Piper* and Moringa have demonstrated comparable efficacy with synthetic pesticides and fungicides for mitigating crop pests and diseases, with less negative environmental effects [15-18]. Some plant biomasses have dual-properties for simultaneously improving plant nutrition and protection, such as *Mucuna spp* [19,20] and *Tithonia diversifolia* [21,22]. *Tithonia* biomass demonstrated strong potential to rejuvenate soils while mitigating pests and diseases [23,24]. Similarly, *Mucuna* biomass influenced soil microbes and suppressed nematodes [25,26]. Correspondingly, *Piper guineense* seed extracts demonstrated strong potential for mitigating insect pests and diseases [27-29]. In addition, a combination of *T. Diversifolia*, *P. Guineense* and Oil Palm Bunch Ash served both as insecticide and fertilizer, which decreased sweet potato weevil damage and increased yield [30].

The objective of this study was to enhance tomato protection and yield via sustainable integrated soil fertility management by using a locally produced dual-purpose organic amendment that is adapted to the specific needs of farmers. Thereby, simultaneously mitigating tomato pests and diseases while improving soil fertility and plant nutrition, which stimulates crop growth and enhance yield. Therefore, compared to treatments that combine synthetic pesticide and inorganic fertilizer inputs, it was hypothesized that locally produced dual-purpose organic amendment (i) will effectively mitigate tomato seedling damage by mole cricket, (ii) will reduce disease incidence and (iii) enhance tomato nutrition and yield.

2. MATERIALS AND METHODS

2.1 Experimental Site and Setup

The investigation was conducted at Moli-Buea in Southwest Cameroon, situated between latitudes 4º3'N and 4º12'N of the equator and longitudes 9º12'E and 9º20'E. The soil is derived from weathered volcanic rocks dominated by 51.6% silt, 42% clay and 6.4% sand [31]. Buea has a mono-modal rainfall regime with less pronounced dry season and 85-90% relative humidity. Heavy rainfall occurs between June and October while the dry season starts from November to May with 2085-9086 mm mean annual rainfall between March and November [32]. The mean monthly air temperature ranges between 19℃ and 30℃, while soil temperature at 10 cm depth decreases from 25℃ to 15℃ with increasing elevation from 200 m to 2200 m above sea level [33,34]. The experiment was conducted between December 2015 and February 2016, and setup as a randomized complete block with three treatments (organic, inorganic and control) and four replicates each.

2.2 Production of Dual-Purpose Organic Amendment

The dual-purpose organic amendment for both soil and foliar application is comprised of a homogenized mixture (1:4 ratio) of water-soluble extract of African black pepper *(Piper guineense)* and anaerobically produced organic liquid extract. The water-soluble *Piper* extract was produced by grinding 500 g of ripe sun-dried *Piper* with a kitchen blender, and the fine powder dissolved in 7 L fresh spring water and stored at room temperature prior to use. The anaerobically produced organic liquid extract was produced in a 250 L plastic container designed locally into an anaerobic digester. The local anaerobic digester comprised of two outlets at the top. One outlet was fitted with an outlet pipe firmly attached with plastic around it that prevents air from entering into the digester and the other end of the pipe was dipped into a 10 L water-filled jar for anaerobic respiration and gaseous exchanges. The other outlet was tightly locked with a removable cork and used for stirring the content of the digester regularly to enhance the digestion process.

The production of dual-purpose organic amendment started on November 3, 2015 when the digester was filled with 100 L fresh spring water. The following materials were added to the digester; 25 kg sunflower (*Tithonia diversifolia)* leaves and stems, 25 kg (leaves, stems, cobs and seeds) of the cover-crop *(Mucuna cochinchinensis)*, 25 kg cow dung, 25 kg fresh sugarcane stems *(Saccharum officinarum)*, 0.5 kg fresh cow milk, 1 kg garlic *(Allium sativum)*, 1 kg onion *(Allium cepa* L.*)* and 1 kg ginger *(Zingiber officinale* L.*)*. *Mucuna* and *Tithonia* were added to improve plant nutrition and protection [31,35,36). Ginger, onion and garlic were supplemented due to their insecticidal and fungicidal properties [36,37]. Fresh cow milk was added in order to enrich the digester and facilitate fermentation via enhanced microbial activity. The fresh sugarcane served as glucose source for enhanced microbial activity and fermentation. Cow dung was added in order to enrich the content with macronutrients, improve microbial activity and facilitate fermentation. The content of digester was fermented for sixteen weeks at local air temperature, and stirred every three days with a wooden stick, to ensure homogeneity and enhanced fermentation. All materials used in the production process were thoroughly washed with fresh spring water and sterilized with a local chlorine detergent (Eaux de Javel; Clorox®, USA).

2.3 Management of Tomato Plants

Hybrid tomato (*Lycopersicon esculentum* M.) seeds (F1 Cobra 26; TECHNISEM® France) were purchased from an agro-shop in Buea, Cameroon. Seeds were pre-germinated on a 2.5×1 m nursery bed beside the experimental field, at 15x15 cm inter-row spacing. The nursery bed was prepared by clearing with a cutlass and tilled manually with a hoe. The nursery seedlings were amended with 0.5 kg of NPK fertilizers (20:10:10) and treated with 35 ml synthetic insecticide (K-Optimal; SCPA SIVEX International® France; comprising active components Lambda – cyhalothrine 15 g/l + Acetamipride 20 g/L) and 100 g fungicide (Mancozan super; SCPA SIVEX International® France; comprising active components 640 g/kg Mancozebe + 80 g/kg Metalaxyl) in 15 L of water, and applied with knapsack sprayer. After four weeks, vigorous tomato seedlings were transferred from the nursery to 20 m^2 (5×4 m) experimental plots of approximately 30 cm high manually raised soil beds. The seedlings were planted at 1×0.5 m spacing, with one seedling per stand and 35 stands per plot.

2.4 Application of Treatments

Except for the control that received no input, all treatment plots were amended with the respective inputs one day after transplanting, and the procedure was repeated every 5 days over eight weeks. For the organic plots, 1 L dual-purpose organic amendment was diluted in 9 L water (1:9) and hand-sprayed with Knapsack sprayer on plants (leaves and stems) and the surrounding soil (about 5 cm from the plant) at approximately 250 ml per plant. For the inorganic treatments, 200 g of NPK (20:10:10) fertilizer was applied at 5 g per plant, by ringing at about 5 cm from the plant. A knapsack sprayer was used to spray a mixture of 35 ml synthetic insecticide (K-Optimal; SCPA SIVEX International® France) and 100 g fungicide (Mancozan super; SCPA SIVEX International® France) on plants leaves and stems, and the surrounding soil (about 5 cm from the plant) at approximately 250 ml per plant.

2.5 Management of Weeds and Irrigation

Before transplanting tomato seedlings, the experimental site was cleared manually using a cutlass and tilled with a hoe. After transplanting, weed emergence was monitored regularly and weeded manually using a hoe. The experimental site was irrigated manually using a hand-held watering can before seedlings were transplanted, and manual irrigation was used to supplement the soil moisture every two days during experimentation.

2.6 Data Collection and Analysis

2.6.1 Mole cricket damage on seedlings

The experimental plots were regularly monitored for the occurrence of mole crickets during the day and night by visual observation. Visible symptoms of plant damage caused by mole crickets were recorded including damaged plants. The daily number of seedlings destroyed by mole crickets was recorded for each treatment over four weeks beginning one day after transplanting.

2.6.2 Blight and number of leaves

Three weeks after planting, ten plants were randomly selected on each plot and marked for weekly visual assessment of blight incidence and the number of leaves per plant. The total number of leaves per plant was determined by weekly visual count over six weeks. Visual scoring of tomato blight was performed weekly on the basis of field observation over four weeks [38-42]. Tomato plants were recorded as infected based on prevalence of blight symptoms and calculated using the standards adopted from Fokunang et al. [43]:

$$\text{Incidence} = \frac{\text{Number of infected plants}}{\text{Total number of plants}} \text{ X 100}$$

2.6.3 Wilt and number of dead plants

The number of wilted plants per plot was determined by weekly visual counts over six weeks, and presented as percentage of the total plants. The total number of dead plants [%] was presented as the sum of seedling damage by mole cricket and wilt during the entire experimental period.

2.6.4 Harvest and yield

Fresh ripe tomato fruits were hand-harvested starting six weeks after planting, with ten harvests at an interval of three days. The mature fresh fruit weight was recorded using top-loading balance and yield was expressed in tons per hectare.

2.7 Statistical Analysis

All data sets were subjected to statistical analyses using STATISTICA 9.1 for Windows [44]. Statistics are presented as F and P values for the ANOVA model, and Tukey P values are given for the pairwise comparison of significant treatment means. Dependent variables (e.g. tomato yield, seedling damage, number of leaves, blight and wilt) were subjected to univariate analysis of variance (ANOVA, P = .05) to test effect of treatments (n=3) as categorical predictors. Significant treatment means were compared by posthoc Tukey's HSD test (P = .05), and Spearman Rank Order Correlation (P = .05) was performed to determine the degree of association between the dependent variables and the categorical predictors.

3. RESULTS

3.1 Impact of Treatments on Tomato Damage by Mole Cricket

The dual-purpose organic amendment effectively protected tomato seedlings from mole cricket damage during the entire experimental period with no recorded seedling damage. However, young tomato seedlings in the inorganic treatment plots were only damaged up to the third week after seedlings were transplanted (3333 seedlings ha^{-1}). Meanwhile, the young tomato seedlings in the control were damaged up to the third week (6667 seedlings ha^{-1}) and fourth week (3333 seedlings ha^{-1}). These resulted in a total seedling damage of 3333 damaged seedlings per hectare for inorganic treatment that doubled in control with 6667 damaged seedlings, while no seedling damage was recorded in the dual-purpose organic amendment plots (ANOVA: $F_{2,9}$ = 18.0, P = .001; Fig. 1). Hence, treatment effects differed (Tukey's HSD, P = .05; Fig. 1) significantly in mitigating tomato seedling damage by mole cricket, with 100% mitigation rate recorded in the organic treatment, against a damage rate of up to 10% in the inorganic treatment and 20% in the control treatment. Correspondingly, a negative correlation occurred between treatments and tomato seedling damage by mole cricket (r = −0.86, P = .05).

3.2 Effect of Treatments on Tomato Diseases and Death

3.2.1 Diseases

The occurrence of tomato diseases was assessed as the average incidence of blight and wilt across the different treatments. The incidence of tomato blight differed (ANOVA: $F_{2,9}$ = 64.3, P = .001; Table 1) significantly between treatments. The control plots recorded 100% blight compared to 8.3% for inorganic treatment and 25% in the organic treatment (Tukey's HSD, P = .05; Table 1). Furthermore, a negative correlation occurred between treatments and tomato blight (r = −0.57, P = .05). Meanwhile, no wilt incidence was recorded in the organic treatment, which differed (ANOVA: $F_{2,9}$ = 4.3, P = .05; Table 1) significantly from the inorganic treatment with 2.5% wilt and 9.1% in the control.

3.2.2 Dead plants

The overall rate of plant damage resulting from the combined effect of mole cricket and wilt differed (ANOVA: $F_{2,9}$ = 16.8, P = .001; Table 1) significantly between treatments. No plant damage was recorded in the organic treatment, as compared to 12.5% damage in the inorganic

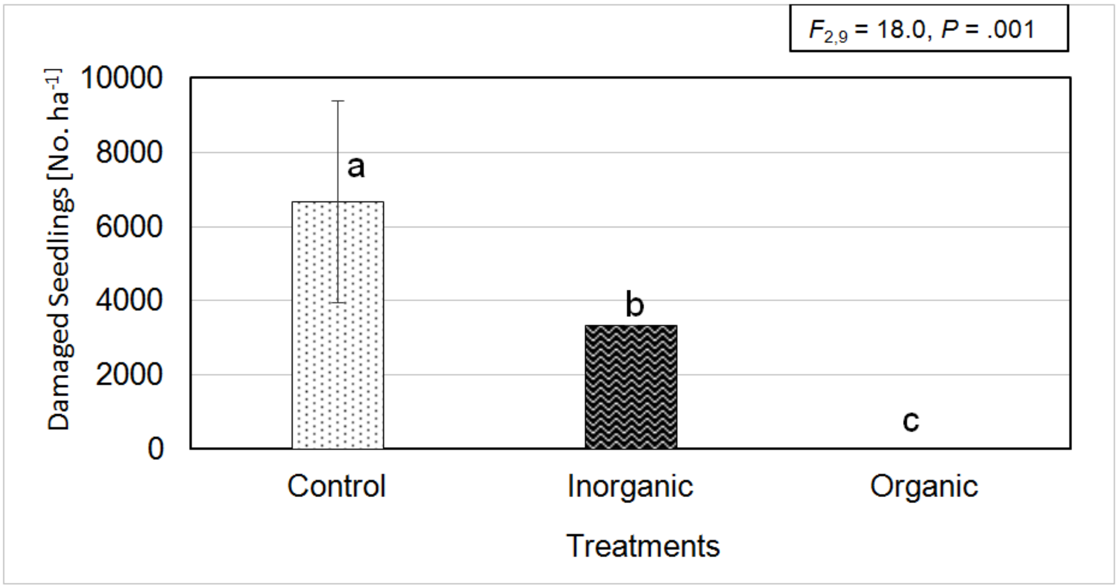

Fig. 1. Mean number (± SD) of tomato seedlings damaged by mole crickets across treatments; Data sets with different letters are significantly different according to Tukey's HSD, P = .05

Table 1. Effect of treatments on tomato blight, wilt and dead plants (% ± SD); Data sets with different letters are significantly different according to Tukey's HSD, *P* = .05

Treatments	Blight [%]	Wilt [%]	Total dead plants [%]
Control	100 ± 0.0a	9.1 ± 6.3a	29.1 ± 11.1a
Inorganic	8.3 ± 16.7b	2.5 ± 5.0a	12.5 ± 5.0b
Organic	25.0 ± 12.9b	0.0 ± 0.0b	0.0 ± 0.0c

Treatment and 29.1% damage in the control (Tukey's HSD, *P* = .05; Table 1). In addition, a negative correlation occurred between treatments and the total number of damaged plants (*r* = −0.97, *P* = .05). Meanwhile, the total number of damaged plants was positively correlated with the rate of seedling damage by mole cricket (*r* = 0.90, *P* = .05), blight incidence (*r* = 0.57, *P* = .05) and wilted plants (*r* = 0.97, *P* = .05).

3.3 Influence of Treatments on Tomato Performance

3.3.1 Number of leaves per plant

The overall performance of tomato was evaluated as the number of leaves per plant and fresh fruit yield. The mean plant leaves ranged between 15 and 30 leaves per plant and differed (ANOVA: $F_{2,9}$ = 34.0, *P* = .001; Fig. 2) significantly across treatments. The highest number of leaves was recorded in the inorganic treatment with 30 and organic treatment with 28 leaves, as compared to 15 leaves per plant in the control treatment (Tukey's HSD, *P* = .05; Fig. 2). In addition, a positive correlation occurred between treatments and the number of tomato leaves per plant (*r* = 0.63, *P* = .05), while a negative correlation occurred between tomato leaves and blight incidence (*r* = −0.92, *P* = .05).

3.3.2 Yield

Tomato yield increased (ANOVA: $F_{2,9}$ = 133.1, *P* = .001; Fig. 3) significantly in the inorganic and organic treatments as compared to the control. The highest tomato yield of 43.9 t ha^{-1} was recorded in the inorganic treatment followed by 38.1 t ha^{-1} in the organic treatment, compared to 1.5 t ha^{-1} in the control (Tukey's HSD, *P* = .05; Fig. 3). Meanwhile, a positive correlation occurred between tomato yield and the number of leaves per plant (*r* = 0.66, *P* = .05), whereas negative correlations occurred between tomato yield and blight (*r* = −0.70, *P* = .05) or wilt (*r* = −0.60, *P* = .05).

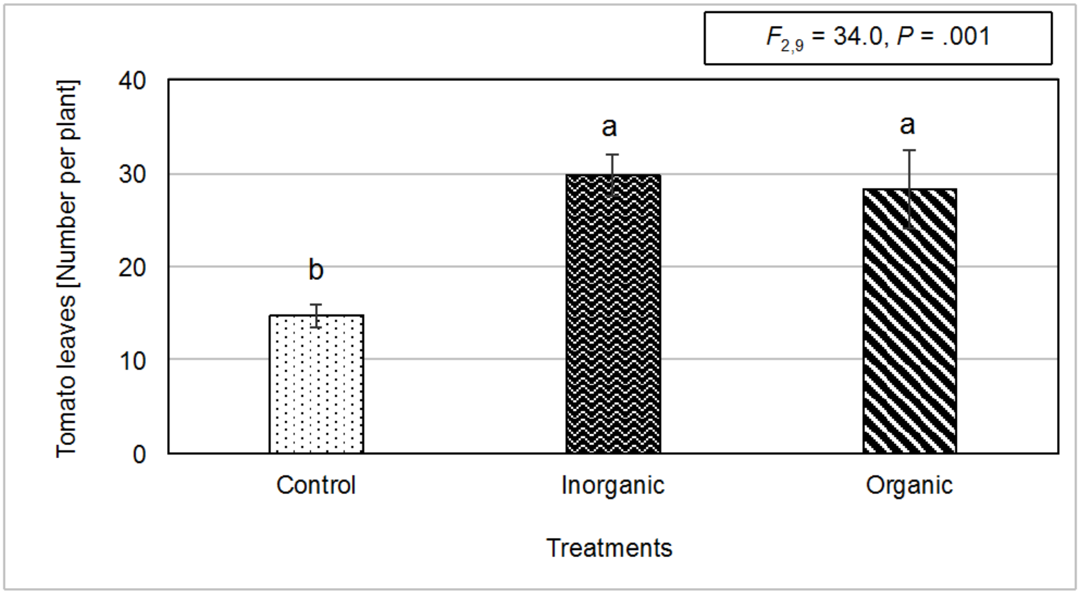

Fig. 2. Mean number (± SD) of tomato leaves per plant across treatments; Data sets with different letters are significantly different according to Tukey's HSD, *P* = .05

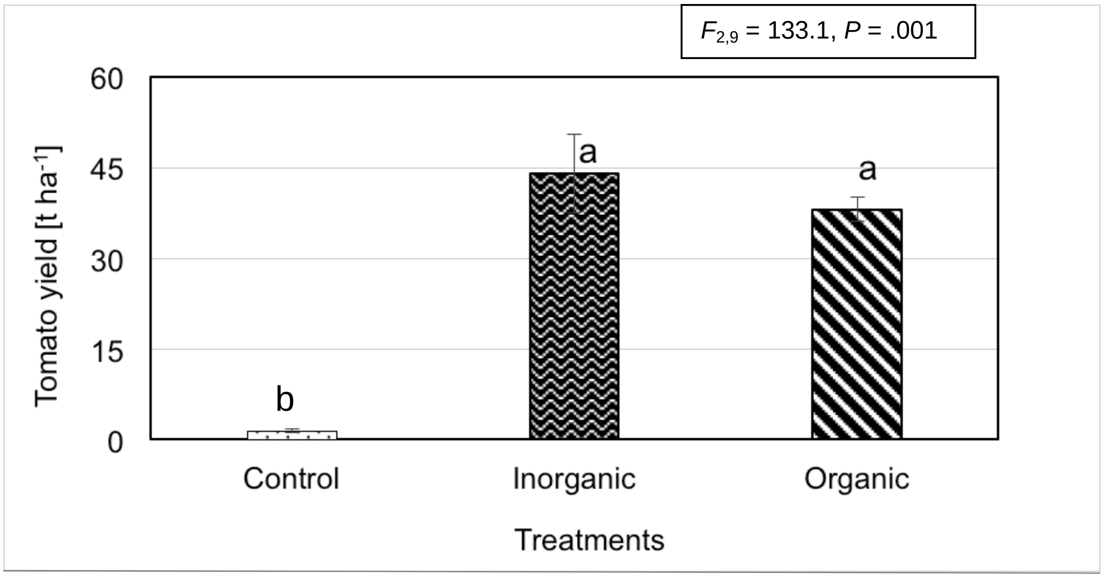

Fig. 3. Mean (± SD) tomato yield (t ha^{-1}) across treatments; Data sets with different letters are significantly different according to Tukey's HSD, *P* = .05

4. DISCUSSION

4.1 Impact of Treatments on Tomato Damage by Mole Cricket

The impact of mole cricket was assessed as the main damaging pest during early seedling growth after tomato transplant (Fig. 1). Although, mole cricket has been mentioned as a major tomato insect pest in Ghana [45], previous studies on tomato pests in the Buea area did not mention mole crickets as an economic pest [2,46]. This implies that mole cricket is emerging as an important tomato pest that focuses on newly transplanted seedlings. The observed result is consistent with the first hypothesis of this study, and demonstrates significant advantage of the locally produced dual-purpose organic amendment for mitigating early tomato seedling damage by mole crickets while stimulating young seedling growth beyond the plant size that can be easily damaged by mole crickets. This finding is consistent with other botanicals like neem and moringa extracts that were used to control tomato pests and diseases [47]. The 100% survival of tomato seedlings in the plots amended with organic input indicates a strong ability to protect crops as deterrent or irritant that scared mole crickets. Various plant-derived extracts constitute bioactive compounds and secondary metabolites (i.e. alkaloids, flavonoids, phenolic, etc.) with insecticidal and antifungal potentials for mitigating insect pests and diseases [27,29]. *Piper*-derived extracts demonstrated strong potential for mitigating insect pests [27-29]. The efficacy of the locally produced dual-purpose organic amendment is consistent with reports where *Piper* extract was effective as contact botanical insecticides in reducing insect pest damage, even when combined with garlic or lemon grass oil [28,48]. Correspondingly, the efficacy of mixed powders of *Piper guineense* and *Zingiber officinale* was reported against *Callosobruchus maculatus* [49-52]. Similarly, combinations of neem and garlic extracts suppressed insect populations in cabbage fields [53-55]. The efficacy of *Piper* as insecticide is due to the active ingredient isobutyl amides (natural lipophilic amides piperine and piperiline) plant secondary metabolites that act as neurotoxins in insects [56]. In addition, cowpea plants treated with *Piper* extract had lesser insect pest leave damage [57]. Furthermore, combination of powders of *Tithonia diversifolia* leaves, *Piper guineense* seeds and oil palm bunch residue ash reportedly reduced pest infestation and acted as bio-stimulant that increased the growth of plantain plantlets in the nursery [58].

Meanwhile, *Mucuna* (leaves, pods and seeds) comprises stinging hairs, L-DOPA with serotonin and bioactive phytochemicals (i.e. mucunine, mucunadine, mucuadinine, prurienine, nicotine, beta-sitosterol, glutathione, lecithin, alkaloids, flavonoids, saponins, tannins, cyanoglycosides, etc.), which may cause irritation and nervous disorders that likely mitigated tomato pests and diseases [59,60]. The dual-properties of *Mucuna* [19,20] and *Tithonia* [21,22] likely contributed in enhancing tomato nutrition and protection against mole crickets and diseases. *Mucuna* biomass reportedly influenced soil microbes and suppressed nematode populations [25,26]. Similarly, *Tithonia* biomass demonstrated strong potential for rejuvenating arable soils while mitigating pests and diseases [23,24]. In Zambia, the aqueous extract of neem plant caused high mortality on armoured ground crickets that infest millets [61]. Therefore, a combination of bioactive compounds and secondary metabolites from the different organic materials in the dual-purpose organic amendment likely contributed in improving tomato nutrition, stimulating growth and yield, while mitigating mole cricket damage as compared to the inorganic treatment.

4.2 Effect of Treatments on Tomato Diseases

The observed results (Table 1) support the second hypothesis of this study that the dual-purpose organic amendment mitigates tomato diseases, which is consistent with the observed effects on tomato pests. The comparable lower rate of blight that was recorded in the dual-purpose organic and inorganic treatments in relation to the control indicates suitability of the organic amendment for controlling tomato diseases. This is consistent with the reported reduction in symptoms and *Fusarium* population in tomato plants treated with *Piper* leaf extract [62]. Moreover, other studies used aqueous neem extract to suppress mycelial growth of *Alternaria solani* and *Fusarium oxysporum* on tomato plants [63,64]. Meanwhile, rapidly growing and highly succulent tomato plants exposed to fertilization with ammonium nitrate are more susceptible to blight [65,66]. Tomato blight is often initiated by air-borne sporangia or oospores in soils and seeds [67], causing up to 78% yield loss [68]. Therefore, the combine effects of the different botanicals (*Piper*, *Mucuna* and *Tithonia*) in the dual-purpose organic amendment likely contributed in mitigating tomato blight and wilt [23,56,60].

4.3 Influence of Treatments on Tomato Performance

The results for tomato leaves and yield performance (Figs. 2 and 3) corroborate the third hypothesis of this study that locally produced dual-purpose organic amendment enhances tomato nutrition and yield. However, this resulted in comparable yield for both organic and inorganic treatments that only differed from the control. Hence, the dual-purpose organic amendment maximises tomato productivity by simultaneously improving soil fertility/nutrition and crop protection against pests and diseases. Furthermore, the dual-purpose organic amendment is cheap, readily affordable and adapted to the specific needs of smallholder farmers, without any negative consequences. The effectiveness of locally produced organic amendments as bio-stimulants likely enhanced nutrient availability and plant nutrition that stimulated growth, which is consistent with reports of improved tomato performance via *Tithonia* and *Mucuna* mulches [31]. The higher comparable tomato leaves and yield performance recorded in the organic and inorganic treatments confirmed the locally produced dual-purpose organic amendment as a sustainable alternative for managing tomato pests and diseases, and improving soil fertility and plant nutrition. This is consistent with reports of improved performance of cowpea plants treated with *Piper* extracts [57]. The higher number of plant leaves and tomato yield is likely due to a combination of better crop nutrition resulting from the high nutrient content of the dual-purpose organic input and improved crop health [31,56,57,60]. In addition, the anaerobically produced dual-purpose organic amendment applied as foliar spray possibly enhanced nutrient uptake by tomato plants that increased plant performance to a comparable level with the commercial inorganic fertilizer input. Similarly, Moringa leaf extract spray reportedly increased nutrition, growth and yield of tomato [47]. Meanwhile, the extremely low tomato yield recorded in the control indicates high dependency on external inputs (i.e. fertilizer), either organic or inorganic. Thereby highlighting the importance of integrated soil fertility management practices in smallholder tomato production systems in SSA. Although not significant, the slightly higher tomato yield recorded in the inorganic treatment compared to the organic (Fig. 3) is likely due to more readily available nutrient supply by the inorganic fertilizers that enhanced tomato yield. Commercial inorganic fertilizers are adapted for plant nutrition at critical periods of crop needs, but further investigations are needed to determine the bio-stimulant and nutrient supply ability of the locally dual-purpose organic amendment.

5. CONCLUSION

It is not economically sustainable to produce tomatoes in the study area without external fertilizer inputs. The locally produced dual-purpose organic amendment demonstrated efficacy as a viable sustainable alternative to mitigate tomato seedling damage by mole crickets and improve tomato performance. In addition, it stimulated the growth of young tomato seedlings beyond the plant size that can easily be damaged by mole crickets. The accessibility of raw materials, simplicity of the technology and low cost of production, coupled with the dual-properties for improving crop protection and plant nutrition makes the organic amendment a sustainable alternative for use over synthetic pesticides and inorganic fertilizers for controlling tomato pests and diseases while improving soil fertility and crop nutrition. The locally produced dual-purpose organic amendment is adapted to the specific needs of smallholder farmers for integrated soil fertility management. Hence, it is an economically viable option for improving tomato protection and performance without jeopardizing human health and environmental sustainability.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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