

Original Research Article

**Importance of Foliar Fertilizer for Improving Yield of
Tomato (*Lycopersicon esculentum* L.), Managing
Diseases and Leafminer (*Tuta absoluta*) Pest**

ABSTRACT

AIM: To determine the relative importance of different fertilizer types and method of application (i.e. soil or foliar) on tomato yield and controlling pests or diseases.

METHODOLOGY: The influence of six treatments (control, soil NPK, Soil+foliar NPK, Mucuna, Tithonia, and Mucuna+Tithonia) was evaluated on tomato performance (i.e. fruit rot and yield), pest infestation and disease incidence.

RESULTS: Tomato disease incidence ranged from 12–100% across treatments and differed ($P = .001$) significantly, with the lowest recorded in the Soil+Foliar NPK treatment ($P = .05$). A negative correlation occurred between treatments and disease incidence ($r = -0.78$). Tomato blight was negatively correlated with treatments ($r = -0.79$) and the highest was recorded in the control ($P = .05$). Septoria leaf spot was negatively correlated with treatments ($r = -0.73$), and the highest was recorded in the control ($P = .05$). Leafminer was negatively correlated with treatments ($r = -0.88$), and no Leafminer was recorded in the Soil+Foliar NPK, followed by Mucuna+Tithonia as compared to the other treatments ($P = .05$). Tomato disease severity ranged from 9–93% across treatments and differed ($P = .001$) significantly with the lowest recorded in the Soil+Foliar NPK treatment ($P = .05$). Meanwhile, disease severity was negatively correlated with treatments ($r = -0.73$). The highest

tomato fruit rot was recorded in the control ($P = .05$), while fruit rot was negatively correlated with treatments ($r = -0.63$) and positively correlated with blight ($r = 0.52$). Tomato yield ranged from 10–20 t ha⁻¹ and differed ($P = .001$) significantly across treatments, with the highest recorded in the Soil+Foliar NPK treatment and lowest in the control ($P = .05$). Meanwhile, a strong positive correlation occurred between tomato yield and treatments ($r = 0.92$) while a negative correlation occurred between tomato yield and disease severity ($r = -0.68$).

CONCLUSION: Foliar fertilizer application demonstrated strong potential to improve tomato yield and mitigate pest infestation or disease incidence in smallholder tomato production systems in Sub-Saharan Africa.

Keywords: *Blight, Foliar fertilizer, Leafminer, Mucuna+Tithonia, Septoria leaf spot*

1. INTRODUCTION

Micronutrient deficiency is one of the main causes of malnutrition, poor health and high mortality in Sub-Saharan Africa (SSA), and vegetable diets represent the most affordable and accessible sources of micronutrients [1-3]. Tomato is widely cultivated in Cameroon [4-6], but poor soil fertility, pest infestations and disease incidences reduce both quantity and quality of tomato [7-9]. Nutrient losses from arable soils are often higher than the natural replenishment capacity in SSA, and mineral fertilizers are often used to improve soil fertility [10,11]. Hence, poor soil fertility coupled with low mineral fertilizer inputs accounts for the low crop performance in SSA, with huge yield gaps between the attainable potential and actual production [12,13]. Meanwhile, various organic and inorganic inputs have been used to improve soil fertility [14-16]. However, besides the type of fertilizer that is used, the method of fertilizer application (i.e. soil or foliar input) may further influence the performance of different fertilizers.

Moreover, tomato is susceptible to over 200 diseases caused by varying hosts of pathogenic fungi, bacteria, viruses and nematodes [17,18]. Tomato early blight or fruit rot caused by *Alternaria solani* and late blight caused by *Phytophthora infestans* enabled plant death and significant loss of yield [19-22]. Tomato blight may be initiated by air-borne sporangia or oospores in soils and seeds, causing up to 78% yield loss [23,24]. Also, Septoria leaf spot or Septoria blight is a devastating foliar disease caused by the fungus *Septoria lycopersici* that may result in up to 100% crop loss [25-27]. Meanwhile, Leafminer (*Tuta absoluta*) is an important tomato insect pest that thrives during all cropping cycles, causing both physiological and yield effects on crops [28-30]. Leafminer is an invasive pest that causes 80–100% yield loss by attacking leaves, stems, flowers and fruits [31,32]. Leafminers make serpentine mines in the leaves that damage cells and mesophyll mining reduces leaf longevity and increase abscission, damages the stomata and reduces photosynthesis or disrupts water balance [30,33-35]. Moreover, the continuous use of synthetic pesticides for controlling Leafminer has resulted in resistance to some commercial products, with negative consequences on some beneficial organisms [36-38].

Globally, synthetic pesticides are often used to control vegetable pests and diseases [20,39-41]. However, there is increasing need for sustainable alternative integrated soil fertility management strategies including organic inputs that are cheap, readily available and affordable with less environmental effects [42-44]. Although some plant biomass materials can simultaneously improve plant nutrition and protection, the fertilizer type and method of application play an important role in controlling crop pests and diseases [45]. Mucuna [46-49] and Tithonia [50,51] have demonstrated nutritional and plant health management potentials. Tithonia biomass

75 rejuvenated soils and mitigated pests and diseases [52-54], while *Mucuna* biomass
76 influenced soil microbes and suppressed nematodes [55,56].

77 Vegetables require specific nutrients within short critical periods and nutrient
78 deficiency increases susceptibility to pests and diseases, which necessitate targeted
79 sustainable alternative management practices that integrate plant nutrition and
80 protection [5,57]. Hence, this study is aimed at determining the influence of fertilizer
81 types and the mode of fertilizer application on crop performance, pest infestations
82 and disease incidences. Therefore, it was hypothesized that (i) plant nutrition has
83 greater influence on tomato performance than pest infestation or disease incidence,
84 (ii) foliar NPK fertilizer application reduces tomato pest infestation and disease
85 incidence, with enhanced tomato performance compared to soil applications, and (iii)
86 mulching with *Mucuna* and *Tithonia* biomass enhance tomato nutrition and mitigates
87 pests and diseases.

88

89 **2. MATERIALS AND METHODS**

90 **2.1 Experimental Site and Setup**

91 The study was conducted at a long-term field site in Lysoka-Buea, Southwest
92 Cameroon, situated between latitudes 4°3'N and 4°12'N and longitudes 9°12'E and
93 9°20'E. The soil is derived from weathered volcanic rocks dominated by silt and clay
94 [14]. The area has mono-modal rainfall regime with less pronounced dry season and
95 85–90% relative humidity [58]. Heavy rainfall occurs between June and October,
96 while the dry season is between November and May, with about 2875mm annual
97 rainfall [58]. Mean monthly air temperature ranges between 19°C and 30°C, while
98 soil temperature at 10 cm depth decreases from 25°C to 15°C with increasing
99 elevation from 200 to 2200 m, respectively, above sea level [59,60]. The long-term

field site setup in 2014 was established as a randomized complete block design with six treatments (control, soil NPK fertilizer, soil+foliar NPK fertilizer, *Mucuna cochinchinensis*, *Tithonia diversifolia* and Mucuna+Tithonia) with four replicates each.

2.2 Fertilizer Treatments

The control plots were not amended with any fertilizer input since the long-term field site was established. The three organic plots were amended with biomass of Mucuna, Tithonia and Tithonia+Mucuna at 1:1 ratio. After tomato seedlings were transplanted, the organic plots were immediately mulched with a single dose of 10 kg plant dry matter for sole Mucuna and sole Tithonia, and 5 kg each (1:1 ratio) for their mixture, which is equivalent to about 5 t ha⁻¹ [61]. Mucuna biomass was obtained from a cultivated field the previous season, while Tithonia biomass was harvested from roadsides and abandoned fields. The biomass was sundried for one week and stored at room temperature prior to field application. All treatment plots were earthed-up with surrounding soil three weeks after transplanting.

The two inorganic plots comprised NPK fertilizer applied either as soil input or as a combination of soil input and foliar spray (soil+foliar). For the soil NPK fertilizer input, two split doses of 90 kg ha⁻¹ granular NPK 20:10:10 + CaO (ADER[®] Cameroon) were applied by ringing at 5 cm from plants. The first soil NPK input was applied immediately after tomato seedlings were transplanted and the second application was performed three weeks later [11]. For the foliar amendments, besides the application of soil NPK input as described above, 50 g of NPK 20.20.20+ (AGROVERT[®] Netherlands) foliar input was dissolved in 15 L of fresh water and sprayed on the tomato plants one week after transplanting and the procedure was

repeated two weeks later. Five weeks after tomato seedlings were transplanted to experimental plots, 100 g of NPK 15.15.30+(AGROVERT® Netherlands) foliar input was dissolved in 30 L of fresh water and sprayed on the tomato plants, and the procedure was repeated in the seventh and ninth weeks after the seedlings were transplanted.

2.3 Establishment of Tomato Plants

Hybrid tomato (*Lycopersicon esculentum* L.) seeds (F1 Cobra 26; TECHNISEM® France) were purchased from an agro-shop in Buea Cameroon. The seeds were pre-germinated at 15x15 cm inter-row spacing on 7x1 m nursery bed beside the experimental field. The nursery bed was established on 21st March 2016, by clearing with a cutlass and tilled manually using a hoe. Thereafter, the nursery bed was amended with 1.5 kg NPK 20.10.10 fertilizer and treated with fungicide 40 g Mancozan super (SCPA SIVEX International® France; comprising 640 g/kg Mancozebe + 80 g/kg Metalaxyl as active ingredients) and insecticide 25 ml of Garmalin 80 (Agromaf® Cameroon; comprising 40 g/L Imidaclopride + 40 g/L Lambdacyhalothrine as active ingredients) dissolved in 5 L of fresh water. Two weeks after germination, the young seedlings were treated with fungicide 30 ml of Pyriforce (SSI® France; comprising 600 g/L Chlorpyrifos-Ethyl as active ingredient), 20 ml of Cigogne 360 (SCPA SIVEX International® France; comprising 360 g/L Cypermethrine as active ingredient), and 40 g of Mancozan super (SCPA SIVEX International® France). Four weeks after establishment of the nursery, vigorous tomato seedlings were transferred to experimental plots of 5x4 m (20 m²), with a total of 24 plots and four replicates each for the six treatments. Tomato plants were planted at a spacing of 1 m between rows and 0.5 m within rows, with one seedling

per stand, giving a total of 35 stands per plot. Three weeks after tomato seedlings were transplanted, 1-m wooden sticks were used to stake the plants.

2.4 Management of Weeds and Irrigation

Soil moisture during the experimental period depended on the rain-fed system according to local rainfall regime. Prior to transplanting the tomato seedlings, the entire field was weeded manually using a cutlass and hoe. After the tomato seedlings were transplanted, the experimental site was monitored regularly for the emergence of weeds and when necessary the site was weeded manually using a hoe.

2.5 Management of Pests and Diseases on Experimental Plots

All the experimental plots received the same treatments for pest and disease management and any observed differences between the different treatments are likely due to the influence of the different treatments (i.e. fertilizer inputs and their mode of application). The experimental site was monitored regularly for the emergence of pests and diseases, and sprayed weekly with appropriate pesticides and fungicides using Knapsack sprayer. For field pest management, the following insecticide treatments were used; 30 ml of Pyriforce (SSI® France), 30 ml of Lamida Gold 90 (SC Ningbo Technical® China; comprising 30 g/L Imidaclopride + 60 g/L Lambdacyhalothrine as active ingredients), 10 ml Emacot 019 (Savana® France; comprising 19 g/L Enamectine Benzoate as active ingredient), and 20 ml Cigogne 360 (SCPA SIVEX International® France). For the management of diseases, the following fungicides were used; 100 g of Mancozan super (SCPA SIVEX

International[®] France) or 100 g of Mancolex 72 (SSI[®] France) each comprising 640 g/kg Mancozeb + 80 g/kg Metalaxyl as active ingredients.

2.6 Data Collection

2.6.1 Tomato Yield

Upon maturity, ripe tomato fruits were harvested every two days and weighed using a top loading balance until 19th June 2016 and the reported data for harvest is the sum of all the different harvests.

2.6.2 Tomato Fruit Rot

Tomato fruit rot symptoms were visually assessed eight and nine weeks after tomato seedlings were transplanted. Tomato fruit rot was recorded as the number of rot infected tomato fruits per plant for each plot. Tomato fruit rot is caused by *Alternaria solani* with rare infection of unripe green fruits while the semi ripe and ripe fruits are more susceptible to the pathogen [19]. However, the effect of this pathogen is facilitated by damages caused by lesions during farm management practices or insects such as the polyphagous fruit fly, *Dacus punctatifrons* Karsch [62-64].

2.6.3 Disease Incidence

Four weeks after transplanting the tomato seedlings, visual observation of tomato blight or Septoria leaf spot symptoms was performed on the leaves of all plants, over a period of five weeks [5,65-67]. The total disease incidence or specific disease incidences (i.e. Blight and Septoria leaf spot) were recorded as infected plants based on the occurrence of blight and Septoria leaf spot symptoms and calculated using the standards adopted from Fokunang et al. [68] as follows:

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

2.6.4 Disease Severity

Four weeks after tomato seedlings were transplanted, tomato disease severity was scored based on weekly visual observation of tomato blight or Septoria leaf spot symptoms on all the leaves, stems and flowers of five selected plants per plot, over a period of five weeks [5,65-67]. The disease severity (Table 1) was estimated by scoring disease prevalence on a scale rating of 0–5 according to Akhtar et al. [69].

Table 1. Measurement scale for scoring the disease severity on tomato plants.

Disease rating	Severity of symptoms for whole-plant	% Disease index	Disease response
0	No visible symptoms apparent	0	Immune
1	A few minute lesions to about 10% of the total leaf area is blighted and usually confined to the 2 bottom leaves	0.01-10	Highly resistant
2	Leaves on about 25% of the total plant area are infected	10.01-25	Resistant
3	Leaves on about 50% of the total plant area are infected	25.01-40	Tolerant
4	Leaves on about 75% of the total plant area are infected	40.01-60	Susceptible
5	Leaves on whole plant are blighted and plant is dead	> 60.01	Highly susceptible

2.6.5 Pest Infestation

Plants were also observed regularly for signs of pest infestation, particularly the occurrence of Leafminers (*Tuta absoluta*). Leafminers are small black or yellow flies whose larvae and adults feed on several crops including tomato, and are more easily recognized on the leaves by their mines made during feeding [70]. Tomato plants were identified as infested based on the visual observation of Leafminers or their trails/tunnels on plant leaves over a period of five weeks. Data on Leafminer pest

infestation was presented as the percentage infestation of plants according to the formula presented above for the disease incidence.

2.7 Statistical Analyses

Data sets were subjected to statistical analyses using STATISTICA 9.1 for Windows [71]. The incidence and severity of tomato diseases (i.e. Blight and Septoria leaf spot), pest infestation (Leafminer), tomato fruit rot and yield were subjected to analysis of variance (ANOVA, $P = .05$) as response design variables to test effects of treatments ($n=6$) as categorical predictors. Where significant, a pairwise comparison of means was performed by post-hoc Tukey's HSD test ($P = .05$). Meanwhile, a Spearman Rank Order Correlation was performed to determine the degree of association between the dependent variables and categorical predictors ($P = .05$).

3. RESULTS

3.1 Influence of Treatments on Tomato Diseases

The total incidence of tomato diseases ranged between 12% and 100% across treatments and differed (ANOVA: $F_{5,18} = 10.9$, $P = .001$; Fig. 1) significantly. The control recorded the highest disease incidence while the Soil+Foliar NPK treatment recorded the lowest disease incidence that differed (Tukey's HSD, $P = .05$; Fig. 1) significantly from the other treatments. Correspondingly, a strong negative correlation occurred between treatments and the total tomato disease incidence ($r = -0.78$, $P = 0.05$).

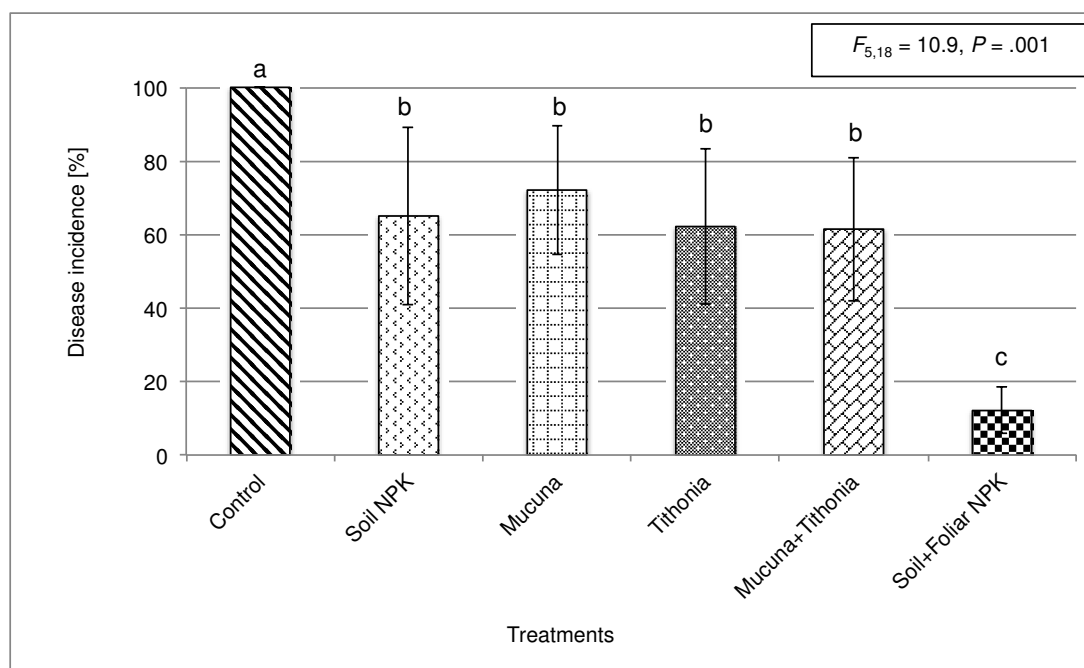


Fig. 1. Effect of treatments on tomato disease incidence (% $\pm$ SD); Data sets with different letters are significantly different according to Tukey's HSD, $P = .05$.

3.1.1 Blight

The prevalence of tomato blight ranged between 4.3% and 37.1% across treatments and differed (ANOVA: $F_{5,18} = 9.5$, $P = .001$; Table 2) significantly. The highest blight incidence was recorded in the control that differed (Tukey's HSD, $P = .05$; Table 2) significantly from the other treatments. The lowest incidence of blight was recorded in the Soil+Foliar NPK treatment that differed (Tukey's HSD, $P = .05$; Table 2) significantly from the control and demonstrated a strong tendency to differ from the other treatments. Correspondingly, a strong negative correlation occurred between treatments and tomato blight ($r = -0.79$, $P = .05$).

Table 2. Effect of treatments on tomato blight (% $\pm$ SD) and Septoria leaf spot (% $\pm$ SD); Data sets within column with different letters are significantly different according to Tukey's HSD, $P = .05$.

Treatments	Tomato diseases [%]	
	Blight	Septoria leaf spot
Control	37.1 $\pm$ 13.6 a	81.4 $\pm$ 18.4 a
Soil NPK	19.3 $\pm$ 10.3 b	27.1 $\pm$ 10.6 b
Mucuna	12.1 $\pm$ 8.5 b	22.9 $\pm$ 10.4 b
Tithonia	9.3 $\pm$ 1.4 b	12.9 $\pm$ 3.7 b
Mucuna+Tithonia	6.4 $\pm$ 1.4 b	14.3 $\pm$ 4.0 b
Soil+Foliar NPK	4.3 $\pm$ 1.6 b	10.7 $\pm$ 4.9 b

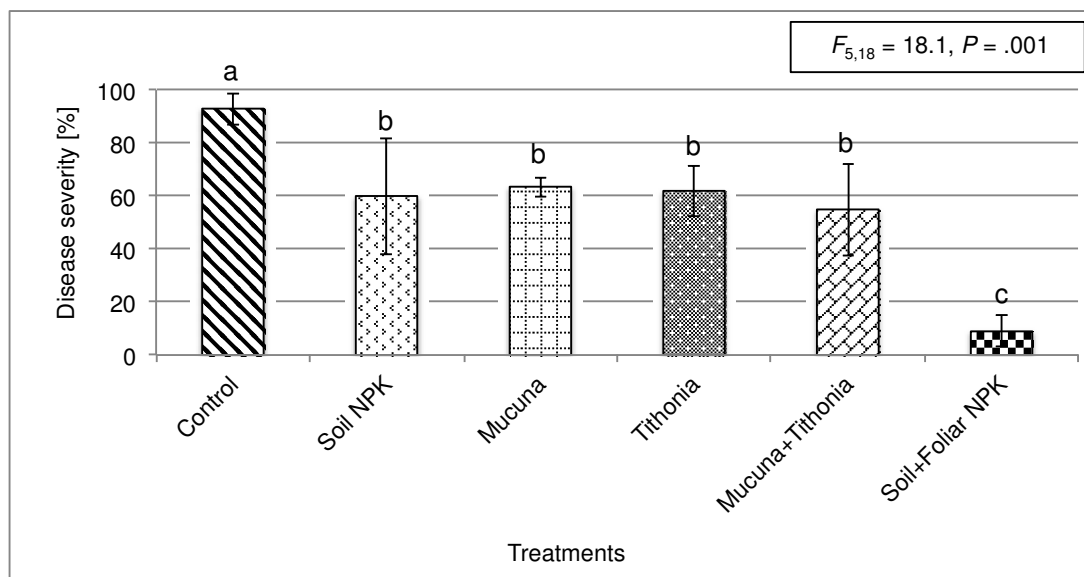
3.1.2 Septoria Leaf Spot

The prevalence of Septoria leaf spot ranged between 10.7% and 81.4% across treatments and differed (ANOVA: $F_{5,18} = 28.1$, $P = .001$; Table 2) significantly. The highest Septoria leaf spot was recorded in the control that differed (Tukey's HSD, $P = .05$; Table 2) significantly from the other treatments. The lowest incidence of Septoria leaf spot was recorded in the Soil+Foliar NPK treatment that differed (Tukey's HSD, $P = .05$; Table 2) significantly from the control, and demonstrated tendency to differ from the other treatments. Correspondingly, a strong negative correlation occurred between treatments and Septoria leaf spot ($r = -0.73$, $P = .05$).

3.2 Effect of Treatments on Disease Severity

Tomato disease severity ranged between 9% and 93% across treatments and differed (ANOVA: $F_{5,18} = 18.1$, $P = .001$; Fig. 2) significantly. Plots amended with

272 Soil+Foliar NPK fertilizers recorded the lowest disease severity, which differed
 273 (Tukey's HSD, $P = .05$; Fig. 2) significantly from the other treatments, while there
 274 was no significant difference in disease severity between soil applied NPK and all
 275 the organic treatments. Correspondingly, a strong negative correlation occurred
 276 between treatments and tomato disease severity ($r = -0.73$, $P = .05$).

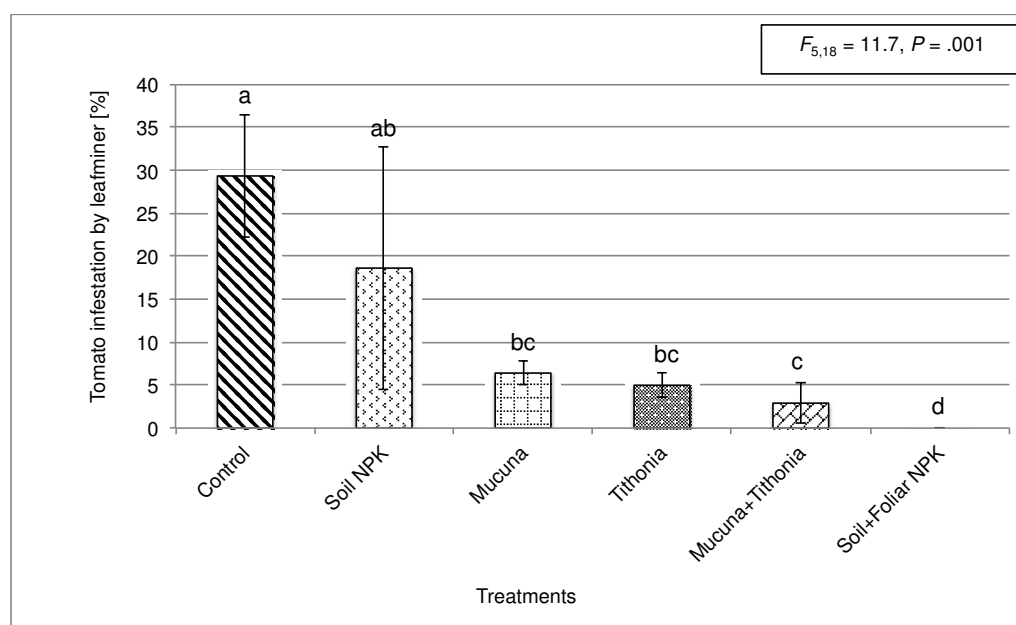


277
 278 Fig. 2. Effect of treatments on disease severity (% $\pm$ SD); Data sets with different
 279 letters are significantly different according to Tukey's HSD, $P = .05$.

280 3.3 Effect of Treatments on Leafminer Pest

281 Plant infestation by Leafminer ranged between 0% and 29.3% across treatments and
 282 differed (ANOVA: $F_{5,18} = 11.7$, $P = .001$; Fig. 3) significantly. No Leafminer infestation
 283 was recorded on plants in the Soil+Foliar NPK treatment, followed by the lowest
 284 Leafminer infestation on plants in the Mucuna+Tithonia treatment that differed
 285 (Tukey's HSD, $P = .05$; Fig. 3) significantly from the other treatments. Meanwhile
 286 Leafminer infestation in the Mucuna and Tithonia treatments differed (Tukey's HSD,
 287 $P = .05$; Fig. 3) significantly from the control and soil NPK treatments.

288 Correspondingly, a strong negative correlation occurred between treatments and
289 Leafminer infestation ($r = -0.88$, $P = .05$).



290

291 Fig. 3. Effect of treatments on tomato infestation (% $\pm$ SD) by Leafminer pest; Data
292 sets with different letters are significantly different according to Tukey's HSD, $P =$
293 .05.

294 3.4 Impact of Treatments on Tomato Performance

295 3.4.1 Tomato Fruit Rot

296 Tomato fruit rot ranged between 1 and 17 across treatments and differed (ANOVA:
297 $F_{5,18} = 41.1$, $P = .001$; Fig. 4) significantly. The highest tomato fruit rot was recorded
298 in control, which differed (Tukey's HSD, $P = .05$; Fig. 4) significantly from the other
299 treatments. Meanwhile, plots amended with soil NPK treatment only demonstrated a
300 strong tendency to differ from the other treatments. Correspondingly, a negative
301 correlation was observed between tomato fruit rot and treatments ($r = -0.63$, $P =$
302 .05), whereas tomato fruit rot and blight incidence were positively correlated ($r =$
303 0.52, $P = .05$).

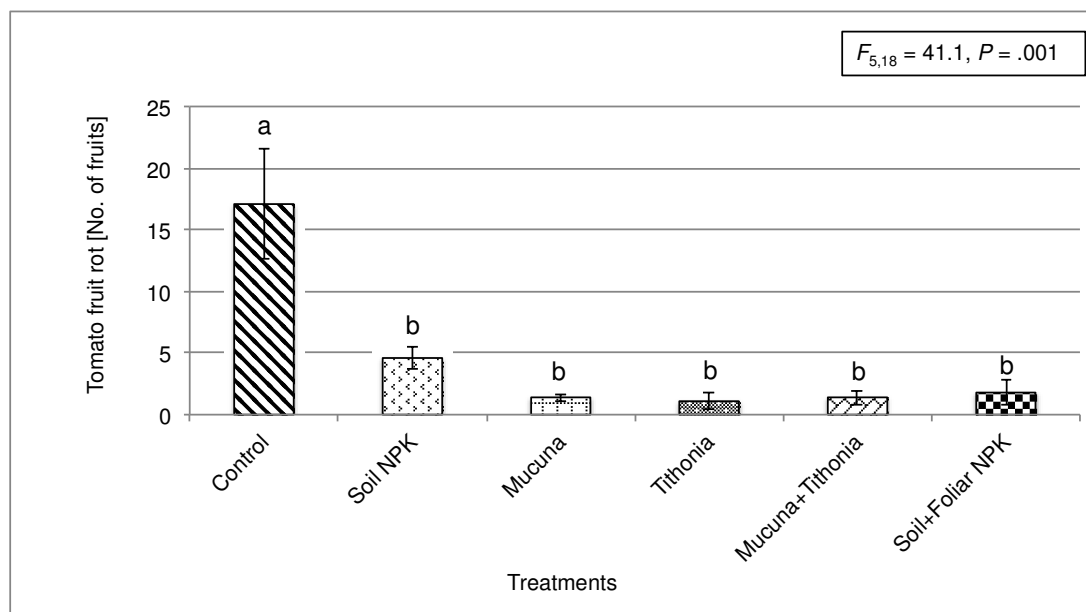


Fig. 4. Effect of treatments on tomato fruit rot (Mean number $\pm$ SD); Data sets with different letters are significantly different according to Tukey's HSD, $P = .05$.

3.4.2 Tomato Yield

Tomato yield ranged between 10 and 20 t ha⁻¹ and differed significantly across treatments (ANOVA: $F_{5,18} = 54.8$, $P = .001$; Fig. 5). Plots amended with Soil+Foliar NPK fertilizers recorded the highest yield while the control recorded the lowest yield, which differs significantly from the other treatments (Tukey's HSD, $P = .05$; Fig. 5). Correspondingly, a strong positive correlation occurred between treatments and tomato yield ($r = 0.92$, $P = .05$). Meanwhile, a negative correlation occurred between tomato yield and disease severity, resulting in the decrease in yield with increased tomato blight ($r = -0.68$, $P = .05$).

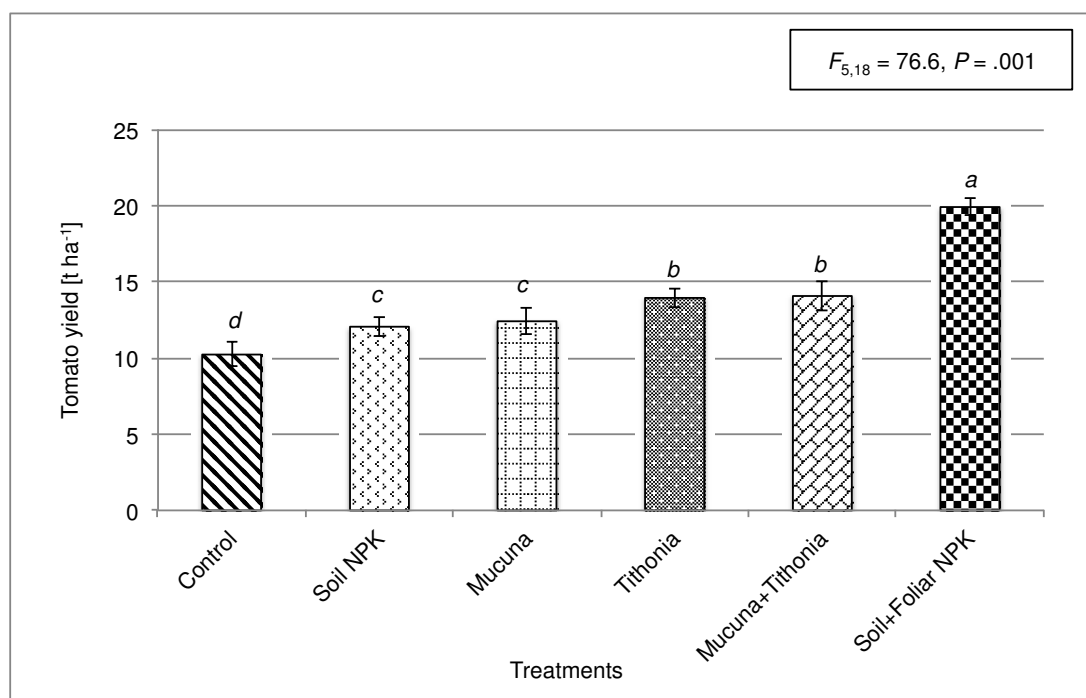


Fig. 5. Effect of treatments on tomato yield ($t\ ha^{-1} \pm SD$); Data sets with different letters are significantly different according to Tukey's HSD, $P = .05$.

4. DISCUSSION

4.1 Influence of Treatments on Pests and Diseases

Since all experimental plots received the same synthetic pesticides and fungicides for pest and disease management, any observed differences in pest infestation and disease incidence is likely due to other factors. Despite the harmonized treatments conducted on all experimental plots to manage field pests and diseases, the rate of pest infestation and disease incidence were not homogenous across treatments. This is likely related to other factors and possibly due to effects of the different fertilizer types and the different mode of fertilizer application (i.e. soil input or foliar spray). Correspondingly, the observed trend of variations for tomato pest infestation (Fig. 3) and disease incidence or severity (Figs. 1 and 2, Table 2) reflects the different fertilizer inputs. This strongly indicates possible alternative factors that

played a significant role in mitigating pest infestation and disease incidence, which is likely related to associated chemicals and improved nutrition from the different fertilizers (i.e. organic and inorganic) and the mode of application (i.e. soil input or foliar spray). Meanwhile, the results obtained for disease incidence and severity in this study (Figs. 1 and 2) demonstrates significant advantage of foliar fertilizer application, followed by soil input and plant biomass mulching for mitigating pest infestation and disease incidence. These results are consistent with the second and third hypotheses of this study, which advocate the importance of foliar spray and plant biomass mulching for managing tomato pests and diseases.

Synthetic fungicides have been successfully used to control plant diseases [72,73]. Soil application of captafol+folpet prevents disease and stem infection, with increased yield [74,75]. Mancozeb formulations were used to control tomato blight while broad-spectrum Strobilurin groups of fungicides were used to control leaf spot and stem rot [76,77]. Meanwhile, synthetic pesticides were used to control vegetable pests [39-41] with idiosyncratic responses [20,78]. However, sustainable alternative organic inputs have also been used to manage pests and diseases [42-44]. The results of this study (Figs. 4 and 5) are consistent with improved plant nutrition and protection reported for the biomass of *Mucuna* [46-49] and *Tithonia* [50,51]. *Mucuna* enhanced soil fertility and controlled pests or diseases [79,80], while *Tithonia* rejuvenated soils and mitigated pests or diseases [52-54]. Similarly, neem extract was used to suppress the growth of *Alternaria solani* on tomato plants [81,82]. Meanwhile, the form of plant nutrition may influence diseases as rapidly growing and highly succulent tomato plants exposed to high fertilization with ammonium nitrate were more susceptible to blight [7,9]. Tomato blight is often initiated by air-borne sporangia or oospores in soils and seeds causing up to 78% yield loss, and soil

amendments may control the development of this pathogen in soils with reduced disease incidence and severity as observed in this study [23,24].

Septoria leaf spot caused by the soil-borne fungus *Septoria lycopersici* is one of the most devastating foliar diseases in humid regions, particularly during the periods of rainfall and frequent dew [26]. Septoria blight severity and incidence likely caused effects on tomato fruit rot and yield [25,27]. Meanwhile, bio-pesticides act as good alternative to synthetic pesticides for controlling tomato diseases [45]. The soil amendments in this study may have controlled the development of the pathogen *Septoria lycopersici* in soils that likely resulted in reduced disease incidence and severity. Correspondingly, Leafminer is an invasive pest that causes severe losses in tomato production with 80–100% yield loss [31,32]. Despite the use of synthetic pesticides, the high Leafminer infestation recorded in the control compared to the other treatments indicates potential resistance to synthetic pesticides, and suggests other mitigating factors [36,37]. Meanwhile, the relatively lower Leafminer infestation recorded in the foliar fertilizer treatment is consistent with the second hypothesis of this study. This suggests other resistance inducing factors that are likely related to the associated chemicals in the foliar NPK fertilizer that possibly initiated physical, biological or chemical defence mechanisms in tomato plants that led to resistance.

4.2 Impact of Treatments on Tomato Performance

The results for crop performance obtained in this study (Figs. 4 and 5) are consistent with the hypothesis that foliar fertilizer application enhances plant nutrition and mitigates pests or diseases as compared to soil fertilizer inputs. Tomato yield for the organic treatments was consistent with Ngosong et al. [14], while the enhanced yield performance in the foliar applied fertilizer treatment is consistent with influence of foliar inputs reported in other studies [83-85]. Reduced crop productivity is often due

to poor soil fertility and increasing pest or disease problems, while plant biomass materials have demonstrated potentials for inducing plant resistance to pests and diseases, while maintaining favorable soil conditions to sustain productivity. *Mucuna* [46-49] and *Tithonia* biomass materials were used to sustainably and inexpensively grow crops by benefiting from soil fertility or plant nutrition and their biocontrol potential against pests or diseases [50,51]. Overall, the higher tomato yield recorded in the foliar NPK treatments is likely due to a combination of improved crop nutrition resulting from enhanced foliar feeding and improved crop health via effect of the associated chemicals on diseases and Leafminer pests [85,86]. Correspondingly, foliar fertilizer inputs improved the performance of tomato, corn and cotton [87-89].

Meanwhile, a reduction of the pest and disease incidences favours crop development and productivity, which is reflected in the performance of tomato in this study with increased yield as the pest infestation and disease incidence or severity decreased. The causal fungus of *Septoria* leaf spot does not directly infect fruits but may cause defoliation leading to fruit maturity failure and sunscald injury, which can result in 80–100% yield loss [17,25,26,31,32,45]. Meanwhile, Leafminers likely caused both physiologically and yield effects on crop performance via damage on the stomata, reduced photosynthesis and disruption of water balance [30,33-35]. Moreover, the results obtained for tomato performance in this study were consistent with the lower pest infestation and disease incidence recorded in the foliar fertilizer treatments followed by the plant biomass treatments. Likely, the polyphagous fruit fly was unable to attack tomato fruits in the foliar treatment due to the effect of the foliar fertilizer [62-64]. Thereby, highlighting the importance of foliar fertilizer input for improving plant nutrition and protection. Overall, the best tomato performance occurred in the treatment with foliar fertilizer input, which demonstrates improved

nutrition and management of pests or disease via foliar amendment as compared to the soil amendments.

5. CONCLUSION

Poor soil fertility and crop nutrition coupled with pest infestations and disease incidences cause significant tomato yield loss to smallholder farmers in SSA. Therefore, enabling tomato protection and yield increase via foliar fertilizer application as demonstrated by this study is an important management strategy for smallholder farmers in SSA, which simultaneously improve nutrition and yield while protecting tomato plants from field pests and diseases. Hence, foliar fertilizer application is a potential economically viable option for improving tomato protection and yield compared to the conventional soil inputs that are practiced in smallholder tomato production systems in SSA.

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