

1 **Importance of NPK Foliar Fertilization for Improving Performance of Tomato**
2 **(*Solanum lycopersicum* L.), Managing Diseases and Leafminer (*Tuta absoluta*)**

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4 Christopher Ngosong^{1*}, Clovis B. Tanyi¹, Cyril A. Njume¹, Priscilla M. Mfombep²,
5 Justin N. Okolle³, Thomas E. Njock¹, Raymond N. Nkongho¹, Aaron S. Tening¹

6

7 ¹Department of Agronomic and Applied Molecular Sciences, Faculty of Agriculture
8 and Veterinary Medicine, University of Buea, P.O.Box 63 Buea, South West Region,
9 Cameroon.

10 ²Department of Agriculture, Higher Technical Teachers' Training College Kumba,
11 University of Buea, P.O.Box 249 Kumba, South West Region, Cameroon.

12 ³Institute of Agricultural Research for Development – IRAD Ekona, PMB 25 Buea,
13 South West Region, Cameroon.

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15 Corresponding author: Christopher Ngosong; E-mail: ngosongk@yahoo.com

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25 **Authors' contributions**

26 This work was carried out in collaboration between all authors. CN designed and
27 supervised the establishment of the field trial and treatments, processed data and
28 performed statistics, conducted literature searches and wrote the first manuscript
29 draft. CBT and CAN established and managed the field trial, collected data and
30 performed literature searches. JNO and TEN coordinated harvests and data
31 collection, and conducted literature searches. PMM and RNN coordinated trial, data
32 management, and performed literature searches. AST coordinated experimentation
33 and manuscript preparation. All authors read and approved the final manuscript.

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48 **ABSTRACT**

49 **AIM:** To improve tomato performance, manage diseases and leafminer via NPK foliar
50 fertilization as compared to soil fertilization.

51 **METHODOLOGY:** Six treatments (control, soil NPK, Soil+Foliar NPK, Mucuna,
52 Tithonia and Mucuna+Tithonia) were evaluated for their potential to improve tomato
53 performance, manage diseases and leafminer.

54 **RESULTS:** Tomato disease incidence ranged from 12–100% across treatments that
55 differed ($P = .001$) significantly, with lowest in Soil+Foliar NPK and highest in control
56 compared to the other treatments ($P = .05$). A negative correlation occurred between
57 disease incidence and treatments ($r = -0.78$). Highest tomato blight occurred in
58 control ($P = .05$) that correlated negatively with treatments ($r = -0.79$). Highest
59 septoria leaf spot occurred in control ($P = .05$) that correlated negatively with
60 treatments ($r = -0.73$). No leafminer was recorded in Soil+Foliar NPK, followed by
61 Mucuna+Tithonia as compared to other treatments ($P = .05$). Leafminer correlated
62 negatively with treatments ($r = -0.88$). Tomato disease severity correlated negatively
63 with treatments ($r = -0.73$) and ranged from 9–93% across treatments that differed
64 ($P = .001$) significantly. Lowest disease severity occurred in Soil+Foliar NPK with the
65 highest in control compared to other treatments ($P = .05$). Tomato fruit rot correlated
66 negatively with treatments ($r = -0.63$) and positively with blight ($r = 0.52$), ranging
67 from 1-17 across treatments that differed ($P = .001$) significantly, with highest in
68 control compared to other treatments ($P = .05$). Tomato yield ranged from 10–20 t ha⁻¹
69 and differed ($P = .001$) significantly across treatments, with highest in Soil+Foliar
70 NPK treatment and lowest in control ($P = .05$). Tomato yield correlated positively with
71 treatments ($r = 0.92$) and negatively with disease severity ($r = -0.68$).

CONCLUSION: NPK foliar fertilization demonstrated strong potential to improve tomato performance, manage diseases and leafminer as compared to soil amendments.

Keywords: Blight, foliar fertilizer, leafminer, mucuna+tithonia, septoria leaf spot

1. INTRODUCTION

Micronutrient deficiency causes malnutrition, poor health and high mortality in Sub-Saharan Africa (SSA), and vegetable diets are 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 the quantity and quality of tomato produced [7-9]. Nutrient losses from arable soils are higher than the natural replenishment capacity of soils in SSA and mineral fertilizers are often used to improve soil fertility [10,11]. Poor soil fertility and low mineral fertilizer inputs account for low crop performance in SSA, with huge yield gaps between the attainable potential and actual production [12,13]. Various organic and inorganic inputs are used to improve soil fertility and plant nutrition [14-16], but the mode of application (i.e. soil or foliar) may exert further influence on their performance.

Tomato is susceptible to many diseases caused by 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 leading to 78% yield loss [23,24]. Septoria leaf spot or septoria blight is a devastating foliar disease caused by *Septoria lycopersici* fungus that may result in 100% crop loss [25-27]. Leafminer (*Tuta absoluta*) is an invasive

tomato pest that thrives during all cropping cycles causing physiological and yield effects [28-30] with 80–100% yield loss by attacking leaves, stems, flowers and fruits [31,32]. Leafminers make serpentine mines in leaves that damage cells while mesophyll mining reduces leaf longevity, increases abscission and damages the stomata with reduced photosynthesis and disruption of water balance [30,33-35]. Continuous use of synthetic pesticides to control leafminer has increased pest resistance with negative consequences on some beneficial organisms [36-38].

Synthetic pesticides and fungicides are often used to control crop pests and diseases [20,39-41], but there is increasing the need for sustainable alternatives that are cheap, readily available and affordable without environmental effects [42-44]. Plant biomass can simultaneously improve soil fertility and crop protection but the mode fertilizer application may play a vital role [45]. Both *Mucuna* [46-49] and *Tithonia* [50,51] residues demonstrated nutritional and crop protection potentials. *Tithonia* residue rejuvenated soils and mitigated pests or diseases [52-54] while *Mucuna* residue influenced soil microbes and suppressed nematodes [55,56].

Tomato plants require specific nutrients within short critical periods and nutrient deficiency increases susceptibility to pests and diseases, which requires sustainable management practices that integrate plant nutrition and protection [5,57]. This study was intended to enhance tomato performance by simultaneously improving plant nutrition and managing disease or leafminer pest via NPK foliar fertilization. It was hypothesized that NPK foliar fertilization (i) will effectively control tomato diseases and leafminer, and (ii) enhance tomato yield compared to soil fertilizer amendments.

2. MATERIALS AND METHODS

2.1 Experimental Site and Setup

The study was conducted at a long-term field site in Lysoka - Buea, South West Region of Cameroon, situated between latitudes 4°3'N and 4°12'N and longitudes 9°12'E and 9°20'E. The soil is derived from weathered volcanic rocks dominated by silt and clay [14]. The area has mono-modal rainfall regime with less pronounced dry season and 85–90% relative humidity [58]. Heavy rainfall occurs between June and October while the dry season is between November and May with about 2875mm annual rainfall [58]. Mean monthly air temperature ranges from 19–30°C while soil temperature at 10 cm depth decreases from 25°C to 15°C with increasing elevation from 200 to 2200 m, respectively, above sea level [59,60]. The long-term field site was setup in 2014 as randomized complete block design with six treatments (control, soil NPK fertilizer, Soil+Foliar NPK fertilizer, *Mucuna cochinchinensis*, *Tithonia diversifolia* and Mucuna+Tithonia) and four replicates each.

2.2 Fertilizer Treatments

The control was not amended with any fertilizer input since the establishment of the long-term field site. The three organic plots were amended with plant biomass of *Mucuna*, *Tithonia*, and *Tithonia*+*Mucuna* at 1:1 ratio. After tomato seedlings were transplanted, organic plots were immediately mulched with a single dose of 10 kg plant dry matter for sole *Mucuna* or sole *Tithonia* and 5 kg each (1:1 ratio) for a mixture of *Mucuna* and *Tithonia* that is equivalent to five tons per hectare [61]. The NPK content of *Mucuna* and *Tithonia* biomass has been described in Ngosong et al. [14]. *Mucuna* biomass was obtained from a previously cultivated field while *Tithonia* biomass was harvested from roadsides and abandoned fields. Fresh *Mucuna* and *Tithonia* biomass were sundried for one week and stored at room temperature prior to field application. Three weeks after transplanting tomato seedlings, all plants were

manually earthed-up with surrounding soil to make raised beds (about 30 cm high).

The two inorganic treatments comprised soil NPK fertilizer or combination of soil and foliar NPK (Soil+Foliar). For soil NPK fertilization, 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 was applied immediately after tomato seedlings were transplanted while the second was applied three weeks later [11]. For soil and foliar NPK, half the amount of soil NPK was applied as described above and 50 g NPK 20.20.20+ (AGROVERT® Netherlands) foliar NPK was dissolved in 15 L fresh water and sprayed on tomato plants one week after transplanting and the procedure was repeated two weeks later. In addition, 100 g NPK 15.15.30+(AGROVERT® Netherlands) foliar NPK was dissolved in 30 L water and sprayed on tomato plants at five, seven and nine weeks after transplanting.

2.3 Establishment of Tomato Plants

Hybrid tomato (*Solanum lycopersicum* L.) seeds (F1 Cobra 26; TECHNISEM® France) were purchased from an agro-shop in Buea Cameroon. This tomato variety is commonly used in the study area and it is adapted for Sahelian and tropical areas by combining disease tolerance and high productivity. The tomato seeds were pre-germinated at 15x15 cm inter-row spacing on nearby 7x1 m nursery established on 21st March 2016. The nursery was established by clearing with a cutlass and tilled manually using a hoe. The nursery 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 active ingredients) and pesticide 25 ml Garmalin 80 (Agromaf® Cameroon; comprising 40 g/L Imidaclopride + 40 g/L Lambdacyhalothrine active ingredients) dissolved in 5 L water. Two weeks

after germination, young seedlings were treated with fungicide 30 ml Pyriforce (SSI® France; comprising 600 g/L Chlorpyrifos-Ethyl active ingredient), 20 ml Cigogne 360 (SCPA SIVEX International® France; comprising 360 g/L Cypermethrine active ingredient) and 40 g Mancozan super (SCPA SIVEX International® France).

Four weeks after the establishment of the nursery (18th April 2016), vigorous tomato seedlings were transferred to all twenty-four experimental plots (six treatments and four replicates each) measuring 5×4 m (20 m²) each. The tomato plants were planted at 1 m inter-row and 0.5 m intra-row spacing with one seedling per stand and 35 stands per plot. Three weeks after tomato seedlings were transplanted, 1 m wooden sticks were used to stake each tomato plant vertically.

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 tomato seedlings, the entire field was weeded manually using a cutlass and tilled using a hoe. After tomato seedlings were transplanted, the experimental site was monitored regularly for the emergence of weeds and weeded manually using a hoe.

2.5 Field Management of Pests and Diseases

All experimental plots received the same input for pest and disease management and any observed difference between treatments is likely due to effects of the different fertilizers (i.e. organic or inorganic) and their mode of application (i.e. soil or foliar). The experimental site was monitored regularly for pests or diseases and sprayed with appropriate pesticides and fungicides once a week using Knapsack sprayer. The following insecticides were used for field pest management; 30 ml of Pyriforce (SSI®

France), 30 ml Lamida Gold 90 (SC Ningbo Technical[®] China; comprising 30 g/L Imidaclopride + 60 g/L Lambdacyhalothrine active ingredients), 10 ml Emacot 019 (Savana[®] France; comprising 19 g/L Emamectine Benzoate active ingredient) and 20 ml Cigogne 360 (SCPA SIVEX International[®] France). The following fungicides were used for disease management; 100 g Mancozan super (SCPA SIVEX International[®] France) or 100 g Mancolax 72 (SSI[®] France) each comprising 640 g/kg Mancozebe + 80 g/kg Metalaxyl active ingredients.

2.6 Data Collection

2.6.1 Tomato Yield

At physiological maturity, ripe tomato fruits were harvested twice a week (i.e. every three days) and weighed using a top loading balance starting from 13th June 2016 to 18th July 2016. Tomato yield was calculated as mean ($t\ ha^{-1} \pm SD$) of nine harvests from treatment replicates within 32 days.

2.6.2 Tomato fruit rot

Tomato fruit rot caused by *Alternaria solani* with rare infection of unripe green fruits while semi-ripe and ripe fruits are more susceptible to pathogens [19] and facilitated by lesions or insects like the polyphagous fruit fly *Dacus punctatifrons* Karsch [62-64]. Fruit rot symptoms were visually assessed eight and nine weeks after seedlings were transplanted and data were presented as the number (Mean $\pm$ SD) of rotted tomato fruits per plant.

2.6.3 Disease incidence

Four weeks after transplanting tomato seedlings, visual observation was performed on the leaves of all plants for visible symptoms of tomato blight and septoria leaf spot over five weeks [5,65-67]. Total disease incidence or specific disease incidence (blight and septoria leaf spot) was recorded as infected plants (Mean % $\pm$ SD) based on the occurrence of blight and septoria leaf spot symptoms and calculated using the standards adopted from Fokunang et al. [68]:

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

2.6.4 Disease severity

Four weeks after tomato seedlings were transplanted, visual observation and scoring of disease severity (blight and septoria leaf spot symptom) were performed over five weeks on all leaves, stems, and flowers of five randomly selected plants per plot [5,65-67]. Percentage disease severity (Mean % $\pm$ SD) was estimated by scoring disease prevalence on 0–5 scale rating according to Akhtar et al. [69; Table 1].

Table 1. The measurement scale for scoring 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 Leafminer

Plants were monitored regularly for the occurrence of leafminer (*Tuta absoluta*) larvae and adults. These small black or yellow flies were recognized on leaves by their mines made during feeding [70]. Tomato plants were monitored over five weeks and identified as infested based on visual observation of leafminers and their trails or tunnels on leaves. Data on leafminer was presented as percentage (Mean % $\pm$ SD) according to the formula presented above for disease incidence.

2.7 Statistical Analyses

Data sets were subjected to statistical analyses using STATISTICA 9.1 for Windows [71]. Tomato disease incidence (blight and septoria leaf spot) and severity, leafminer and tomato performance (fruit rot and yield) were subjected to analysis of variance (ANOVA, $P = .05$) as dependent variables to test effects of treatments ($n=6$) as categorical predictors. Pairwise comparison of significant means was performed by post-hoc Tukey's HSD test ($P = .05$). Spearman Rank Order Correlation was performed to determine the degree of association between dependent variables and categorical predictors ($P = .05$).

3. RESULTS

3.1 Influence of Treatments on Tomato Diseases

Tomato disease incidence ranged from 12–100% across treatments that differed (ANOVA: $F_{5,18} = 10.9$, $P = .001$; Fig. 1) significantly. The highest disease incidence occurred in the control while the lowest occurred in the Soil+Foliar NPK treatment, which differed (Tukey's HSD, $P = .05$; Fig. 1) significantly from the other treatments.

A strong negative correlation occurred between treatments and disease incidence ($r = -0.78, P = 0.05$).

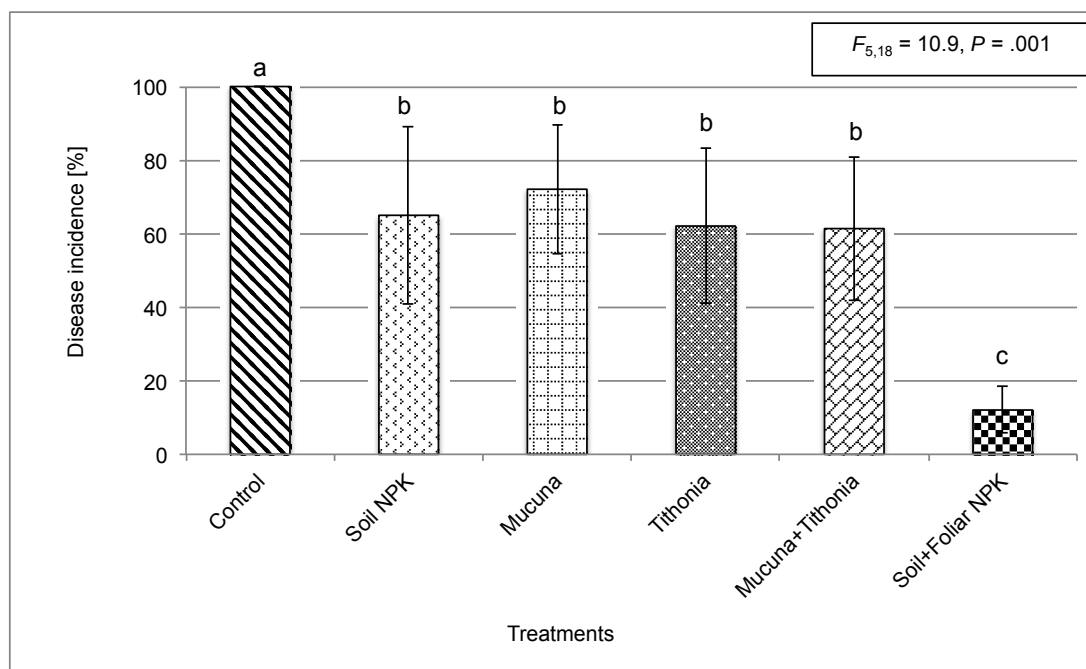


Fig. 1. Effect of treatments on tomato disease incidence (Mean % $\pm$ SD); Data with different letters are significantly different according to Tukey's HSD, $P = .05$.

3.1.1 Blight

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

Table 2. Effect of treatments on tomato blight and septoria leaf spot (Mean % $\pm$ SD); Data within a 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

Septoria leaf spot ranged from 10.7–81.4% across treatments that differed (ANOVA: $F_{5,18} = 28.1$, $P = .001$; Table 2) significantly. The highest incidence of septoria leaf spot occurred in the control that differed (Tukey's HSD, $P = .05$; Table 2) significantly from the other treatments. The lowest incidence of septoria leaf spot occurred in the Soil+Foliar NPK treatment that differed (Tukey's HSD, $P = .05$; Table 2) significantly from the control and demonstrated strong tendency to differ from the soil NPK or organic treatments. 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 9–93% across treatments that differed (ANOVA: $F_{5,18} = 18.1$, $P = .001$; Fig. 2) significantly. The lowest disease severity

occurred in the Soil+Foliar NPK fertilizer treatment that differed (Tukey's HSD, $P = .05$; Fig. 2) significantly from the other treatments. However, there was no significant difference in disease severity between the soil NPK and organic treatments. A strong negative correlation occurred between disease severity and treatments ($r = -0.73$, $P = .05$). Based on the disease severity score, Soil+Foliar NPK was highly resistant while soil NPK and Mucuna+Tithonia treatments were susceptible. The control and sole Mucuna or Tithonia treatments were highly susceptible.

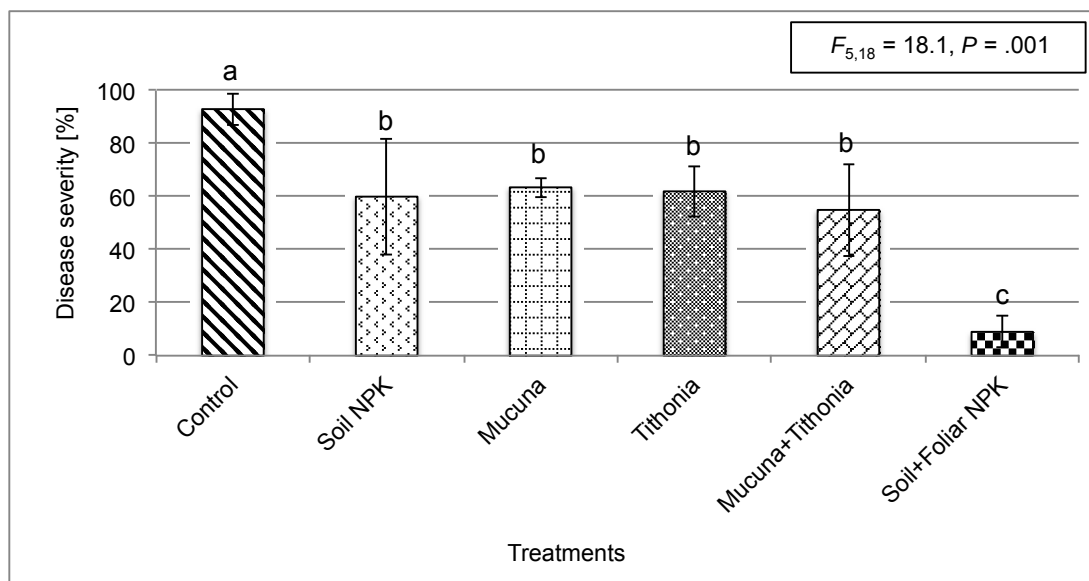


Fig. 2. Effect of treatments on tomato disease severity (Mean % $\pm$ SD); Data with different letters are significantly different according to Tukey's HSD, $P = .05$.

3.3 Effect of Treatments on Leafminer

Leafminer infestation ranged from 0.0–29.3% across treatments that differed (ANOVA: $F_{5,18} = 11.7$, $P = .001$; Fig. 3) significantly. No leafminer infestation occurred in Soil+Foliar NPK and followed by the Mucuna+Tithonia treatment, which differed (Tukey's HSD, $P = .05$; Fig. 3) significantly from the other treatments. Leafminer infestation in Mucuna and Tithonia treatments differed (Tukey's HSD, $P = .05$; Fig. 3)

significantly from the control and soil NPK treatments. A strong negative correlation occurred between leafminer infestation and treatments ($r = -0.88$, $P = .05$).

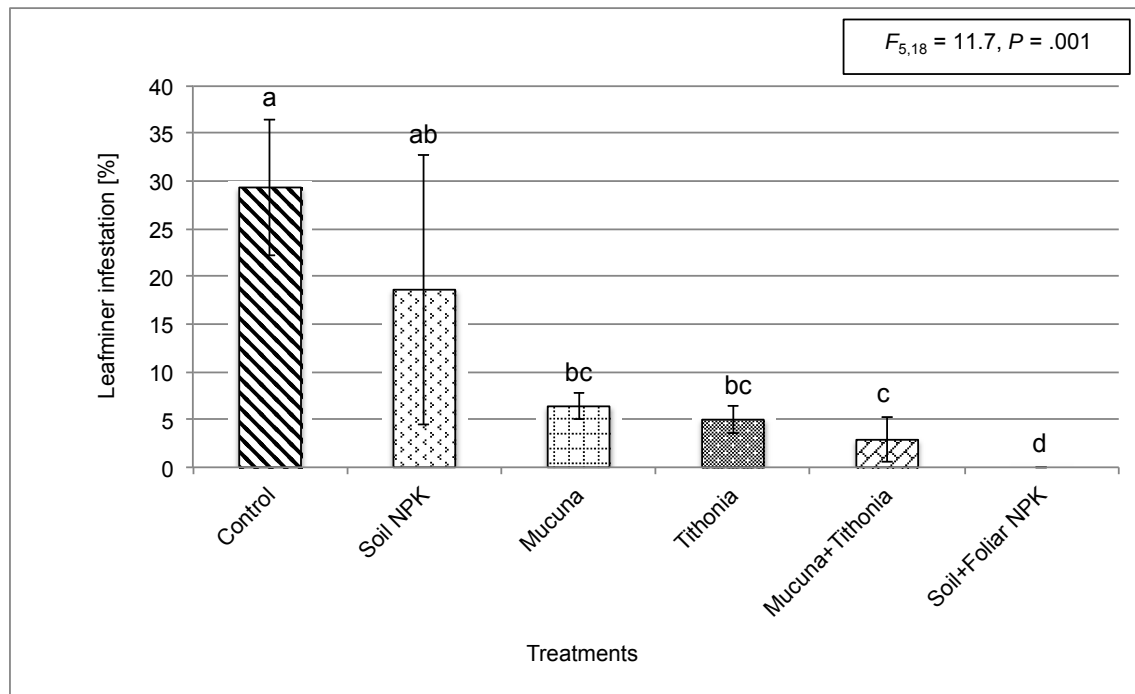


Fig. 3. Effect of treatments on leafminer infestation (Mean % $\pm$ SD); Data with different letters are significantly different according to Tukey's HSD, $P = .05$.

3.4 Impact of Treatments on Tomato Performance

3.4.1 Fruit Rot

Tomato fruit rot ranged from 1–17 fruits across treatments that differed (ANOVA: $F_{5,18} = 41.1$, $P = .001$; Fig. 4) significantly. The highest tomato fruit rot was recorded in control that differed (Tukey's HSD, $P = .05$; Fig. 4) significantly from the other treatments. The soil NPK treatment demonstrated strong tendency to differ from the other treatments. Tomato fruit rot was negatively correlated with treatments ($r = -0.63$, $P = .05$) and positively correlated with blight ($r = 0.52$, $P = .05$).

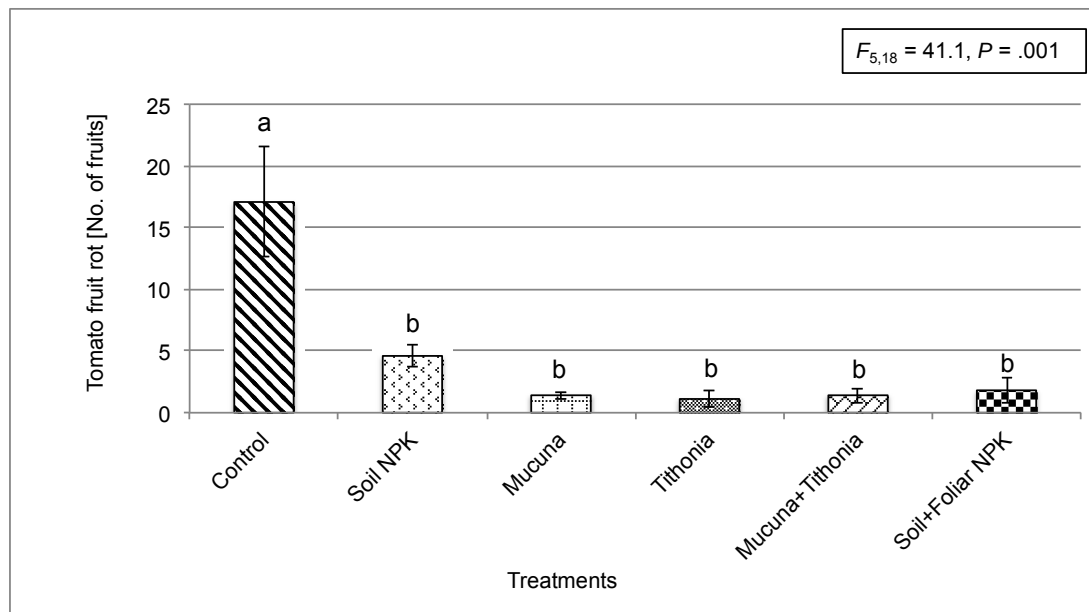


Fig. 4. Effect of treatments on tomato fruit rot (Mean number $\pm$ SD); Data with different letters are significantly different according to Tukey's HSD, $P = .05$.

3.4.2 Yield

Tomato yield ranged from 10–20 t ha⁻¹ across treatments that differed (ANOVA: $F_{5,18} = 54.8$, $P = .001$; Fig. 5) significantly. The highest tomato yield was recorded in Soil+Foliar NPK and the lowest in control, which differed (Tukey's HSD, $P = .05$; Fig. 5) significantly from the other treatments. Tomato yield was positively correlated with treatments ($r = 0.92$, $P = .05$) and negatively correlated with disease severity ($r = -0.68$, $P = .05$), which resulted in decreased yield as tomato blight increased.

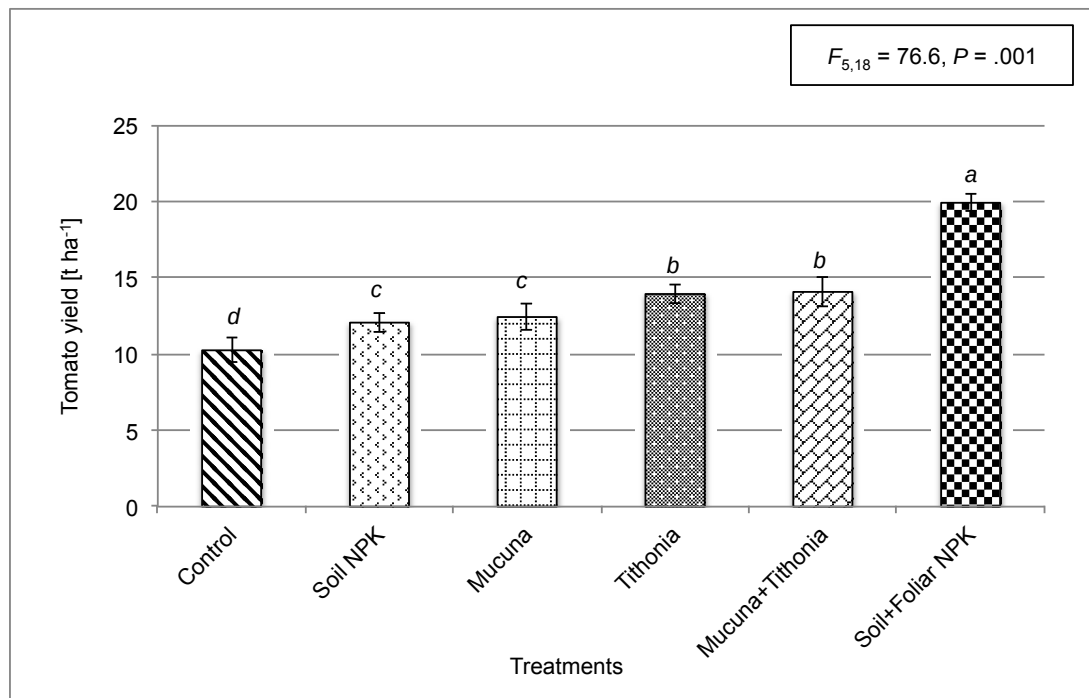


Fig. 5. Effect of treatments on tomato yield ($t\ ha^{-1} \pm SD$); Data with different letters are significantly different according to Tukey's HSD, $P = .05$.

4. DISCUSSION

4.1 Influence of Treatments on Leafminer and Diseases

Since all experimental plots were treated with the same synthetic pesticides and fungicides, differences in leafminer infestation and disease incidence were likely due to other factors. Despite the harmonized management of pests and diseases, high disease resistance occurred in Soil+Foliar NPK, followed by susceptibility in soil NPK and Mucuna+Tithonia treatments, and high susceptibility in control and sole Mucuna or Tithonia treatments (Fig. 2). This is consistent with the first hypothesis of this study and strongly suggests the influence of other active resistance-inducing factors in the different treatments. This observed difference in disease severity is likely due to effects of the different fertilizer types and/or their mode of application (soil input or foliar spray). Variations in disease incidence (Figs. 1, Table 2) and leafminer (Fig. 3)

reflects the different fertilizer inputs and highlights the potential role of alternative factors that controlled diseases and leafminer. This is likely due to the interaction of improved plant nutrition and chemical effects associated with the different fertilizers (organic or inorganic) and their mode of application (soil input or foliar spray). However, tomato disease incidence and severity (Figs. 1 and 2) demonstrated a significant advantage of NPK foliar fertilization for controlling tomato diseases and leafminer, which is followed by the soil NPK and organic treatments. These results support the first hypothesis that NPK foliar fertilization will effectively control tomato diseases and leafminer.

Synthetic fungicides are used to control plant diseases [72,73] with idiosyncratic responses [20,78]. Captafol+folpet was applied in the soil to manage diseases and enhance yield [74,75]. Mancozeb formulations were used to control tomato blight and broad-spectrum Strobilurin fungicides were used to control leaf spot and stem rot [76,77], while synthetic pesticides were used to control vegetable pests [39-41]. However, sustainable alternative organic inputs have also been used to manage crop pests and diseases [42-44]. The results of this study (Figs. 4 and 5) are consistent with improved plant nutrition and protection reported for *Mucuna* [46-49] and *Tithonia* [50,51] biomass amendments. *Mucuna* biomass enhanced soil fertility and controlled pests or diseases [79,80] while *Tithonia* biomass rejuvenated soils and mitigated pests or diseases [52-54]. Similarly, neem extract suppressed the growth of *Alternaria solani* on tomato plants [81,82]. The form of plant nutrition may influence diseases and rapidly grow highly succulent tomato plants exposed to high ammonium nitrate fertilization were more susceptible to blight [7,9]. Tomato blight is initiated by air-borne sporangia or oospores in soils and seeds with up to 78% yield loss, which can be controlled by soil amendments as observed in this study [23,24].

Septoria leaf spot caused by soil-borne fungus *Septoria lycopersici* is one of the most devastating foliar diseases in humid regions during rainfall and frequent dew [26]. The incidence and severity of septoria leaf spot likely influenced tomato fruit rot and yield [25,27]. Bio-pesticides acted as good alternatives for synthetic pesticides for managing tomato diseases [45]. Similarly, soil amendments in this study may have controlled pathogen development of *Septoria lycopersici* in the soil, which reduced tomato disease incidence and severity. Leafminer is an invasive pest that caused 80–100% yield loss and synthetic pesticides were used for their control on all experimental plots [31,32]. However, the highest leafminer infestation occurred in control while the lowest occurred in Soil+Foliar NPK compared to other treatments, which is consistent with the first hypothesis. This indicates the potential resistance of leafminer to synthetic pesticides and suggests other resistance-inducing factors in Soil+Foliar NPK treatment that are likely related to associated chemicals in the NPK foliar fertilizer [36,37]. The resistance-inducing factors likely initiated physical, biological and chemical defense mechanisms that controlled pests with no leafminer in Soil+Foliar NPK treatment.

4.2 Impact of Treatments on Tomato Performance

Tomato performance (Fig. 5) is consistent with the second hypothesis that advocated enhanced tomato yield by NPK foliar fertilization as compared to soil amendments. Tomato yield for organic treatments is consistent with previous reports by Ngosong et al. [14] while improved tomato yield in Soil+Foliar NPK fertilization is consistent with other reports on the role of foliar fertilization [83-85]. Reduced tomato productivity is often due to the interaction of poor soil fertility/plant nutrition and high pest infestation or disease incidence. However, some plant residues have potentials to induce crop

resistance against pests and diseases while maintaining favorable soil fertility to sustain productivity. Mucuna and Tithonia residues sustainably and inexpensively improved soil fertility or plant nutrition with bio-control potential against pests or diseases [46-51]. Higher tomato yield in Soil+Foliar NPK fertilization is likely due to a combination of improved crop nutrition resulting from enhanced foliar feeding and crop protection via effects of associated chemicals in foliar fertilizer [85,86]. This is consistent with other studies that reported improved tomato performance via NPK foliar fertilization [87-89].

Reduction of field pests and diseases favors crop performance as reflected by the increased tomato yield with decreased leafminer and disease incidence or severity in this study. The causal fungus of septoria leaf spot does not directly infect fruits but may cause defoliation leading to fruit maturity failure and sunscald injury with 80–100% yield loss [17,25,26,31,32,45]. Leafminers likely caused physiological and yield effects via stomata damage, reduced photosynthesis and disruption of water balance [30,33-35]. Tomato performance is consistent with low pest infestation and disease incidence in the Soil+Foliar NPK fertilization followed by plant biomass amendments. Likely, the polyphagous fruit fly was unable to attack tomato fruits in foliar treatment due to effects of foliar NPK residues on tomato leaves and fruits [62-64]. Thereby highlighting the importance of NPK foliar fertilization for simultaneously improving plant nutrition and protection against leafminer or diseases. Although differences in the amount of NPK applied to tomato plants may have influenced the discrepancy in tomato yield between Soil+Foliar NPK and soil amendments, NPK foliar fertilization demonstrated strong potential to improve tomato yield and control leafminer or diseases. Overall, the best tomato performance recorded in Soil+Foliar NPK fertilization as compared to soil fertilization strongly demonstrate simultaneous

improvement of crop nutrition and control of leafminer or diseases.

5. CONCLUSION

The Soil+Foliar NPK fertilization demonstrated strong potential to improve tomato yield and control leafminer or diseases. Hence, NPK foliar fertilization is an importantly integrated soil fertility management strategy to simultaneously improve tomato yield and protection as compared to soil NPK or organic fertilizations. Overall, fertilization enhanced tomato performance with reduced leafminer and diseases, which highlights the need for fertilizer amendments in tomato production systems, irrespective of the fertilizer type or mode of application. Thereby necessitating fertilization strategies that simultaneously improve plant nutrition and protection against pests or diseases.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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