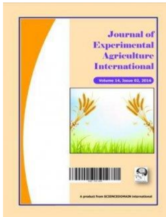

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Importance of NPK Foliar Fertilization for Improving Performance of Tomato (*Solanum lycopersicum* L.), Managing Diseases and Leafminer (*Tuta absoluta*)

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Authors' contributions

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

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ABSTRACT

Aim: To improve tomato performance, manage diseases and leafminer via NPK foliar fertilization as compared to soil fertilization.

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

Results: Tomato disease incidence ranged from 12−100% across treatments that differed (P = .001) significantly, with lowest in Soil+Foliar NPK and highest in control compared to the other treatments (P = .05). A negative correlation occurred between disease incidence and treatments (r = −0.78). Highest tomato blight occurred in control (P = .05) that correlated negatively with treatments (r = −0.79). Highest septoria leaf spot occurred in control (P = .05) that correlated negatively with treatments (r = −0.73). No leafminer was recorded in Soil+Foliar NPK, followed by Mucuna+Tithonia as compared to other treatments (P = .05). Leafminer correlated negatively with treatments (r = −0.88). Tomato disease severity correlated negatively with treatments (r = −0.73) and ranged from 9−93% across treatments that differed (P = .001) significantly. Lowest disease severity occurred in Soil+Foliar NPK with the highest in control compared to other treatments (P = .05). Tomato fruit rot correlated negatively with treatments (r = −0.63) and positively with blight (r = 0.52), ranging from 1-17 across treatments that differed (P = .001) significantly, with highest in control compared to other treatments (P = .05). Tomato yield ranged from 10−20 t ha^{-1} and differed (P = .001) significantly across treatments, with highest in Soil+Foliar NPK treatment and lowest in control (P = .05). Tomato yield correlated positively with 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 *Phythophthora 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 stomata damage with reduced photosynthesis, and disruption of water balance [30,33-35]. The continuous use of synthetic pesticides to control leafminer has increased pest resistance with negative consequences on some soil beneficial organisms [36-38].

Synthetic pesticides and fungicides are used to control crop pests and diseases [20,39-41], but there is increasing 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 of fertilizer application may play a vital role [45].

Both Mucuna [46-49] and Tithonia [50,51] residues have demonstrated nutritional and crop protection potentials in arable fields. Tithonia residues rejuvenated soils and mitigated pests or diseases [52-54] while Mucuna residues 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 diseases 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 2875 mm 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 7×1 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 synthetic pesticides and fungicides: 30 ml Pyriforce (SSI® France; comprising 600 g/L Chlorpyriphos-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 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 m^2) 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 Pest and Disease Management

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} ± SD) of nine harvests from treatment replicates within 32 days.

2.6.2 Tomato fruit rot

Tomato fruit rot caused by *Alternaria solani* rarely infect unripe green fruits, while semi-ripe and ripe fruits are more susceptible to pathogens [19], which is 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 ± 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 or specific (blight and septoria leaf spot) disease incidences were recorded as percentage infected plants (Mean ± SD) based on the occurrence of blight and/or 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 ± SD) was estimated by scoring disease prevalence on a scale rating of 0–5 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	0.0	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 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. Leafminer infestation was presented as percentage (Mean ± SD) according to the formula for disease incidence above.

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 form 12−100% across treatments that differed (ANOVA: $F_{5,18}$ =10.9, P = .001; Fig. 1) significantly. The highest disease incidence occurred in control while the lowest occurred in 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).

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).

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. 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 (Table 1), 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.

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 followed by Mucuna+Tithonia treatment, which differed (Tukey's HSD, P = .05; Fig. 3) significantly from the other treatments. Leafminer infestation in sole 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).

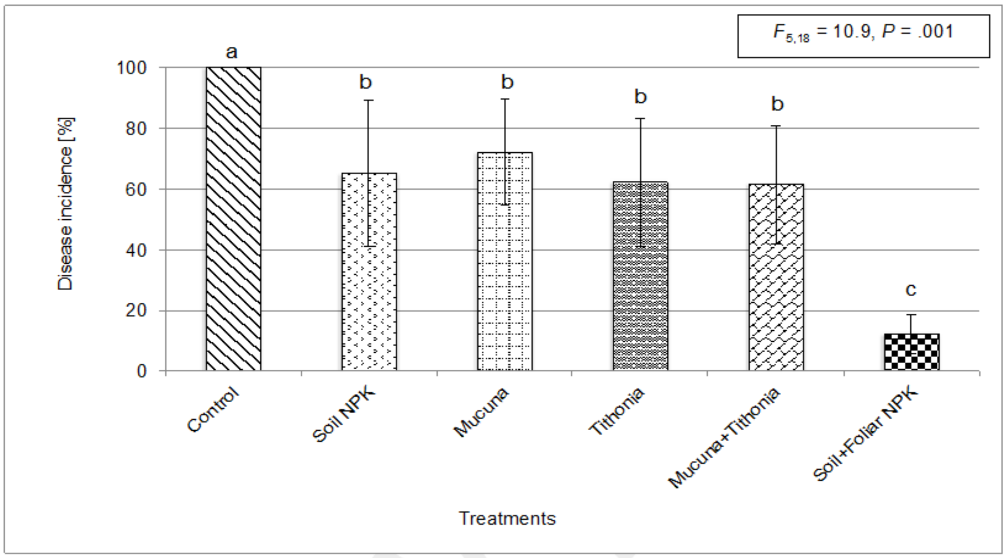

Fig. 1. Effect of treatments on percentage tomato disease incidence (Mean ± SD); Data with different letters are significantly different according to Tukey's HSD, P = .05

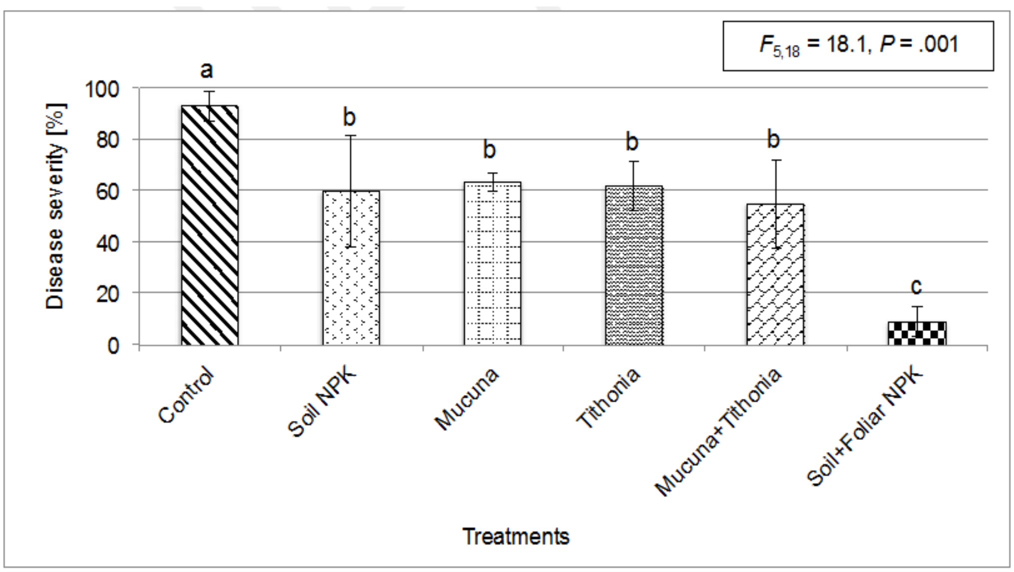

Fig. 2. Effect of treatments on percentage tomato disease severity (Mean ± SD); Data with different letters are significantly different according to Tukey's HSD, P = .05

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 correlated negatively with treatments (r = −0.63, P = .05) and positively with blight (r = 0.52, 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

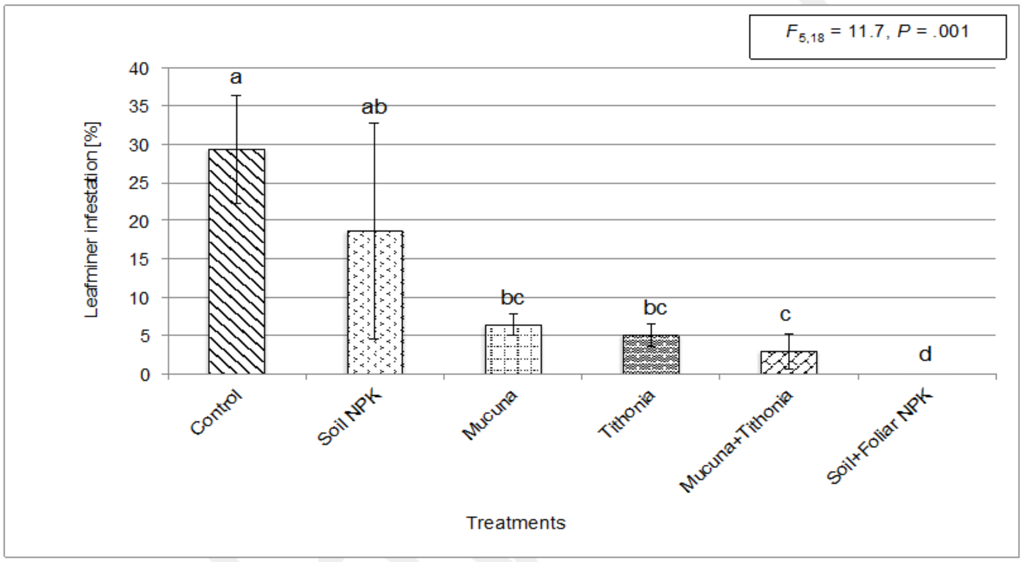

Fig. 3. Effect of treatments on percentage leafminer infestation (Mean ± SD); Data with different letters are significantly different according to Tukey's HSD, P = .05

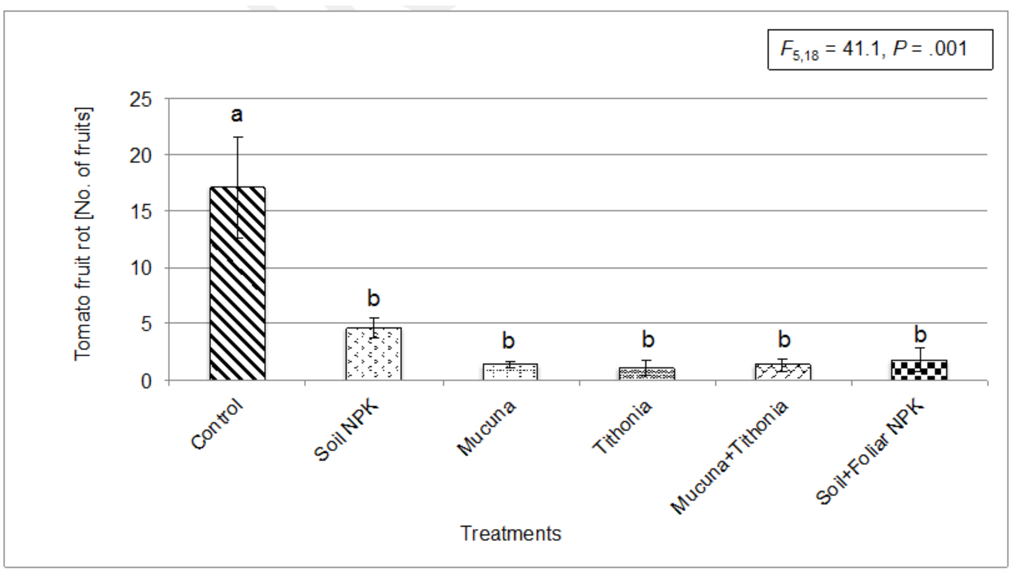

Fig. 4. Effect of treatments on percentage tomato fruit rot (Mean ± SD); Data with different letters are significantly different according to Tukey's HSD, P = .05

lowest in control, which differed (Tukey's HSD, P = .05; Fig. 5) significantly from the other treatments. Tomato yield correlated positively with treatments (r = 0.92, P = .05) and negatively with disease severity (r = −0.68, P = .05), which resulted in decreased yield as tomato blight increased.

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 (Fig. 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 effects of chemical elements that are associated with the different fertilizers (organic or inorganic) or 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 soil NPK and organic treatments. These results support the first hypothesis that NPK foliar fertilization will effectively control tomato diseases and leafminer.

Synthetic fungicides have been used to control plant diseases [72,73] with idiosyncratic responses [20,74]. Captafol+folpet was applied in the soil to manage diseases and enhance yield [75,76].

Mancozeb formulations were used to control tomato blight and broad-spectrum Strobilurin fungicides were used to control leaf spot and stem rot [77,78], 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

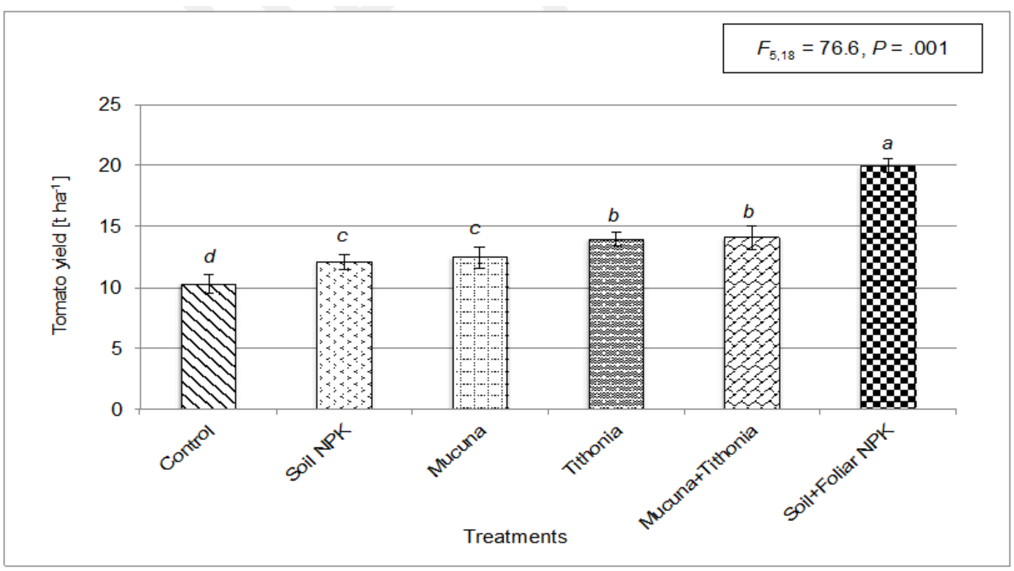

Fig. 5. Effect of treatments on mean tomato yield (t ha^{-1} ± SD); Data with different letters are significantly different according to Tukey's HSD, P = .05

Table 2. Effect of treatments on percentage tomato blight and septoria leaf spot (Mean ± 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 ± 13.6 a	81.4 ± 18.4 a
Soil NPK	19.3 ± 10.3 b	27.1 ± 10.6 b
Mucuna	12.1 ± 8.5 b	22.9 ± 10.4 b
Tithonia	9.3 ± 1.4 b	12.9 ± 3.7 b
Mucuna+Tithonia	6.4 ± 1.4 b	14.3 ± 4.0 b
Soil+Foliar NPK	4.3 ± 1.6 b	10.7 ± 4.9 b

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 also 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 the soil-borne fungus *Septoria lycopersici* is a devastating foliar disease 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 have been used 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 in this study to control leafminer on all the experimental plots [31,32]. However, the highest leafminer infestation in control with the lowest occurred in Soil+Foliar NPK compared to the other treatments is consistent with the first hypothesis of this study. This indicates potential resistance of leafminer to synthetic pesticides and suggests the influence of other resistance-inducing factors in Soil+Foliar NPK treatment that are likely related to chemical elements associated with the NPK foliar fertilizer [36,37]. The resistance-inducing factors likely initiated physical, biological and chemical defence 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 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 and plant nutrition with bio-control potential against pests and diseases [46-51]. The higher tomato yield recorded in Soil+Foliar NPK fertilization is likely due to interaction of improved crop nutrition resulting from enhanced foliar feeding and crop protection via effects of associated chemical elements 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 favours 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 about 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 the water balance [30,33-35]. The recorded tomato performance is consistent with low pest infestation and disease incidence in 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 NPK foliar fertilization compared to soil amendments strongly demonstrates 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 important integrated soil fertility management strategy to simultaneously improve tomato yield and protection 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 fertilizer application. Thereby, necessitating sustainable 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.

REFERENCES

1. Grubben G, Klaver W, Nono-Womdim R, Everaarts A, Fondio L, Nugteren JA, Corrado M. Vegetables to Combat the Hidden Hunger in Africa. Chronica Horticulturae. 2014;54:24-32.
2. Biesalski HK. Hidden Hunger. Springer-Verlag. 2013;245.
3. Thomson B, Amoroso L. Combating micronutrient deficiencies: Food-Based Approaches (eds.). CAB International and FAO. 2011;397.
4. Ntonifor NN, Nsobinenyui DNS, Fokam EB, Fontem LA. Developing an integrated management approach for the fruit fly *Dacus punctatifrons* on tomatoes. American Journal of Experimental Agriculture. 2013;3:470-481.
5. Fontem DA. Survey of tomato diseases in Cameroon. Tropicultura. 1993;11:87-90.
6. Scot WE. Development in the western highlands. USAID-Cameroon. 1980;95.
7. Lebecka R. Host-pathogen interaction between *Phytophthora infestans* and *Solanum nigrum, S. villosum* and *S. scabum*. European Journal of Plant Pathology. 2008;120:233-240.
8. Irzhansky I, Cohen Y. Inheritance of resistance against *Phytophthora infestans* in *Lycopersicon pimpinellifolium* L3707. Euphy. 2006;149:309-316.
9. Yan Z, Reddy MS, Ryu C-M, McInroy JA, Wilson M, Kloepper JW. Induced systemic protection against tomato late blight elicited by plant growth-promoting rhizobacteria. Phytopathology. 2002;92: 1329-1333.
10. Smaling EMA, Braun AR. Soil fertility research in sub-Saharan Africa: New dimensions, new challenges. Communication in Soil Science. 1996;7: 365-386.
11. Bationo A, Hartemink A, Lungu O, Naimi M, Okoth P, Smaling E, Thiombiano L. African soils: Their productivity and profitability of fertilizer use In: Proceedings of the African Fertilizer Summit. June 9-13, Abuja, Nigeria. 2006;29.
12. Bekunda B, Sanginga N, Woomer PL. Restoring soil fertility in Sub-Sahara Africa. Advances in Agronomy. 2010;108:184-236.
13. Sanchez PA. Soil fertility and hunger in Africa. Science. 2002;129:2019-2020.
14. Ngosong C, Mfombep PM, Njume AC, Tening AS. Comparative advantage of Mucuna and Tithonia residue mulches for improving tropical soil fertility and tomato productivity. International Journal of Plant and Soil Science. 2016;12:1-13.
15. Bougnom BP, Knapp BA, Elhottová D, Koubovác A, Etoa FX, Insam H. Designer compost with biomass ashes for

ameliorating acid tropical soils: Effects on the soil microbiota. Applied Soil Ecology. 2010;45:319-324.
16. Laboski CAM, Lamb JA. Changes in soil test phosphorus concentration after application of manure or fertilizer. Soil Science Society of America Journal. 2003; 67:544-554.
17. Parker SK, Nutter Jr. FW, Gleason ML. Directional Spread of Septoria Leaf Spot in Tomato Rows. Plant Disease. 2001;81: 272-276.
18. Lukyanenko AN. Disease Resistance in Tomato. In: Kalloo, G., Ed., Genetic Improvement of Tomato. Monographs on Theoretical and Applied Genetics, Springer, Berlin. 1991;14:99-119.
19. Chaurasia KA, Chaurasia S, Chaurasia S, Chaurasia S. Studies on the development of fruit rot of tomato caused by *Alternaria solani.* International Journal of Pharmacy and Life Sciences. 2013;4:2713-2716.
20. Ganeshan G, Chethana BS. Bioefficacy of pyraclostrobin 25% EC against early blight of tomato. World Applied Science Journal. 2009;7:227-229.
21. Pandey YR, Pun AB, Upadhyay KP. Participatory Varietal Evaluation of Rainy Season Tomato under Plastic House Condition. Nepal Agricultural Research Journal. 2006;7:11-15.
22. Masinde AOA, Kwambai KT, Wambani NH. Evaluation of tomato (*Lycopersicon esculentum* L.) variety tolerance to foliar disease at Kenya Agricultural Research Institute Centre-Kitale in North west Kenya. African Journal of Plant Science. 2011;5: 676-681.
23. Rubin E, Cohen Y. Oospores associated with tomato seed may lead to seed-borne transmission of *Phytophthora infestans*. Phyto parasitology. 2004;32:237-245.
24. Datar VV, Mayee CD. Assessment of losses in tomato yield due to early blight. Indian Phytopathology. 1981;34:191-195.
25. Mehboob A, Zishan G, Mazhar I, BK, Zaheer UK, Muhammad S, Adil R. Comparative study of effect of TYLCV and Septoria blight on F3 tomato lines. International Journal of Biosciences. 2016; 8:229-235.
26. Delahaut K, Stevenson W. Tomato Disorders: Early Blight and Septoria Leaf Spot. A2606: R-0504, The University of Wisconsin, Madison; 2004.
27. Sugha SK, Kumar S. Factors affecting the development of Septoria leaf spot of tomato. Journal of Indian Phytopathology. 2000;53:178-180.
28. Lobos E, Occhionero M, Werenitzky D, Fernandez J, Gonzalez LM. Optimization of a trap *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae) and trials to determine the effectiveness of mass trapping. Neotropical Entomology. 2013; 42:448-457.
29. Leite GLD, Picanco M, Guedes RNC, Zanuncio JC. Role of plant age in the resistance of *Lycopersicum hirsutum* f. glabratum to the tomato leaf miner *Tuta absoluta* (Lepidoptera: Gelichiidae). Journal of Science and Horticulture. 2001; 89:103-113.
30. Wagner D, DeFoliart L, Doak P, Schneiderheinze J. Impact of epidermal leaf mining by the aspen leaf miner on the growth, physiology, and leaf longevity of quaking aspen. Oecologia. 2008;157:259-267.
31. Khidr AA, Gaffar SA, Maha SN, Taman AA, Fathia AS. New approaches for controlling tomato leafminer, *Tuta absoluta* (Meyrick) in tomato fields in Egypt. Egypt Journal of Agricultural Research. 2013;91: 335-345.
32. Oztemiz S. The tomato leaf miner *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae) and it’s biological control. KSU Journal of Natural Sciences. 2012; 15:47-57.
33. Peña JE, Hunsberger A, Schaffer B. Citrus leafminer (Lepidoptern: Gracillnriidae) density: effect on yield of "Tahiti" lime. Journal of Economic Entomology. 2000; 93:374-379
34. Schaffer B, Peña JE, Colis AM, Hunsberger A. *Citrus leafminer* (Lepidoptera: Gracillariidae) in lime: assessment of leaf damage and effects on photosynthesis. Crop Protection. 1997;164.
35. Whittaker JB. Physiological responses of leaves of *Rumex obtusifolius* to damage by a leaf miner. Functional Ecology. 1994;8: 627-630.
36. Gontijo PC, Picanc OMC, Pereira EJG, Martins JC, Chediak M. Spatial and temporal variation in the control failure likelihood of the tomato leaf miner, *Tuta absoluta*. Journal of Applied Biology. 2013; 162:50-59.
37. Arno J, Gabarra R. Side effects of selected insecticides on the *Tuta absoluta* (Lepidoptera: Gelechiidae) predators

Macrolophus pygmaeus and *Nesidiocoris tenuis* (Hemiptera: Miridae). Journal of Pest Science. 2011;84:513-520.
38. Biondi A, Desneux N, Siscaro G, Zappala L. Using organic certified rather than synthetic pesticides may not be safer for biological control agents: Selectivity and side effects of 14 pesticides on the predator *Orius laevigatus*. Chemosphere. 2012;87:803-812.
39. Sarfraz M, Keddie BA. Conserving the efficacy of insecticides against *Plutella xylostella* (L.) (Lep. Plutellidae). Journal of Applied Entomology. 2005;129:149-57.
40. Syed TS, Lu YY, Liang GW. Effect of crude extracts from plants on the oviposition behavior of diamondback moth. Journal of South China Agricultural University. 2003; 24:87-88.
41. Shelton AM, Sances FV, Hawley J, Tang JD, Boune M, Jungers D, Collins HL, Farias J. Assessment of insecticide resistance after the outbreak of diamondback moth (Lepidoptera: Plutellidae) in California in 1997. Journal of Economic Entomology. 2000;93:931-936.
42. Li M, Gao X, Gao Z, Zhao W, Su Z. Insecticidal activity of extracts from forty-eight plants including *Xanthium sibiricum* Patrin. Huanjing Xuebao Jinan. 2008;17: 33-37.
43. Sayyed AH, Saeed S, Noor-Ul-Ane M, Crickmore N. Genetic, biochemical, and physiological characterization of spinosad resistance in *Plutella xylostella* (Lepidoptera: Plutellidae). Journal of Economic Entomology. 2008;101:1658-1666.
44. Liu S, Ji M, Zhao L, Wei S, Wang G, Li X, Li L. Preliminary study on bioactivity of two plants extracts against three kinds of pests. Xiandai Nongyao, Shenyang. 2007; 6:27-29.
45. Rajani KS, Gayatric N. Bio-controlling effect of leaf extract of *Tagetes patula* L. (marigold) on growth parameters and diseases of tomato. Pakistan journal of Biological Sciences. 2017;20:12-19.
46. Mathews J, Leong TT. Performance of two new legume species in oil palm planting. In: Pushparajah, E. (ed.) Proceedings. International Planters Conference on Plantation Tree Crops in the New Millenium: The Way Ahead, The Incorporated Society of Planters, Kuala Lumpur. 2000;1: 325-339.
47. Shaharudin B, Yow TK. Establishment of leguminous cover plant (*Mucuna bracteata*) (Poster Presentation). The Incorporated Society of Planters: Kuala Lumpur, 17-20 May 2000. 2000;317-323.
48. Mathews J, Joseph K, Lakshmanan R, Jose G, Kothandaraman R, Jacob CK. Effect of bradyrhizobium inoculation on *Mucuna bracteata* and its impact on the properties of soil under Hevea. In: 6th International PGPR Workshop, 5-10 October 2003, Calicut, India. 2003;29-33.
49. Chiu SB, Bisad M. *Mucuna bracteata* - biomass, litter and nutrient production. The Planter. 2006;82:247-254.
50. Agbede TM, Afolabi LA. Soil fertility improvement potentials of Mexican sunflower (*Tithonia diversifolia*) and Siam weed (*Chromolaena odorata*) using okra as test crop. Archives of Applied Science Research. 2014;6:42-47.
51. Olabode OS, Sola O, Akanbi WB, Adesina GO, Babajide PA. Evaluation of *Tithonia diversifolia* (hemsl.) A gray for soil improvement. World Journal of Agricultural Sciences. 2007;3:503-507.
52. Agbede TM, Adekiya AO, Ogeh JS. Archives of agronomy and soil science. 2014;60:209-224.
53. Ojeniyi SO, Odedina SA, Agbede TM. Soil productivity improving attributes of Mexican sunflower (*Tithonia diversifolia*) and siam weed (*Chromolaena odorata*). Emirates Journal of Food and Agriculture. 2012;24:243-247.
54. Adoyo F, Mukalam JB, Enyola M. Using Tithonia concoctions for termite control in Busia District, Kenya. ILEIA Newsletter. 1999;13:24-25.
55. Pujari SA, Gandhi MB. Studies on effects of seed and leaf extracts of *Mucuna pruriens* on some common bacterial pathogens. Journal of Environmental Research and Development. 2013;8:50-54.
56. Rayavarapu AK, Kaladhar DSVGK. Evaluation of antimicrobial activity of *Mucuna pruriens* on plant pathogens. Asian Journal Biochemical and Pharmaceutical Research. 2011;2:593-600.
57. Gockowski J, Mbazo'o J, Mbah G, Moulende TF. African traditional leafy vegetables and the urban and peri-urban poor. Food Policy. 2003;28:221-235.

58. Fraser P, Banks H, Brodie M, Cheek M, Daroson S, Healey J, Marsden J, Ndam N, Nning J, McRobb A. Plant succession on the 1922 Lava flow of Mt. Cameroon. In: Timberlake, J. & S. Kativu (eds) African plants: Biodiversity, Taxonomy and Uses. Royal Botanic Garden, Kew. 1999;253-262.
59. Payton RW. Ecology, Altitudinal Zonation and Conservation of Tropical Rainforest of Mount Cameroon. Final Project - Report R4600, ODA, London; 1993.
60. Fraser PJ, Hall JB, Healing JR. Climate of the Mount Cameroon Region, Long and Medium Term Rainfall, Temperature and Sunshine Data, SAFS, University of Wales Bangor, MCP–LBG. Limbe. 1998;56.
61. Agbede TM, Adekiya AO, Ogeh JS. Effects of *Chromolena* and *Tithonia* mulches on soil properties, leaf nutrient composition, growth and yam yield. West African Journal of Applied Ecology. 2013;21:15-29.
62. Ntonifor NN, Okolle JN. Bioecology of the fruit fly *Dacus punctatifrons* on tomatoes and host range expansion. Journal of Tropical Agriculture and Food Science. 2006;34:417-425.
63. Okolle JN, Ntonifor NN. Field ovipositional behaviour and laboratory studies on development of *Dacus punctatifrons* (Diptera: Tephritidae) on tomato. Insect Science. 2005;12:393-398.
64. White IM, Elson-Harris MM. Fruit flies of economic significance: Their identification and bionomics. CAB international, Wallingford. 1992;601.
65. Streets RBSr. The diagnosis of Plant Diseases. The University of Arizona Press, Tucson, Arizona; 1982.
66. Burchill RT. Methods in Plant Pathology (ed.). Commonwealth Mycological Institute, Kew, Surrey, England. 1981;43.
67. Tuite J. Plant Pathological Methods: Fungi ad Bacteria. Burgess Publ.Co. Minneapolis, MN, USA. 1969;239.
68. Fokunang CN, Mbong GA, Manju E, Tembe EA, Rachid H. Screen house and field resistance of taro cultivars to taro leaf blight disease (*Phytophtora colocasiae*). British Biotechnology Journal. 2016;15:1-15.
69. Akhtar KP, Saleem MY, Asghar M, Ali S, Sarwar N, Elahi MT. Resistance of solanum species to *Phytophthora infestans* evaluated in the detached-leaf and whole-plant assays. Pakistan Journal of Botany. 2012;44:1141-1146.
70. Obeng-ofori D, Yirenkyi ED, Ofosu-Anim J. Vegetable and spice crop production in West-Africa. City printers Ltd. 2007;162. ISBN: 9988-7973-3.
71. StatSoft. STATISTICA 9. 1 for Windows. StatSoft Inc., Tusla, USA; 2010.
72. Rajagopal R, Vidyashekaran P. Control of leaf spot diseases of tomato. Pesticides. 1982;16:16.
73. Rajagopal R, Vidyashekaran P. Effect of fungicides control of leaf spot diseases of tomato on the quality of fruits. Indian Phytopathology. 1983;36:352-354.
74. Perez CJ, Alvarado P, Narvaez C, Miranda F, Hernandez L, Vanegas H, Hrusk A, Shelton AM. Assessment of insecticide resistance in five insect pests attacking field and vegetable crops in Nicaragua. Journal of Economic Entomology. 2000; 93:1779-1787.
75. Bharadwaj CL. Efficacy and economics of fungicides spray schedules for the management of foliar and fruit diseases in tomato. Indian Journal of Mycology and Plant Pathology. 1991;21:56-59.
76. Singh NK, Saxena RP, Jaiswal RC, Kumar. Effect of fungicidal seed treatment and foliar sprays on early blight incidence, fruit characters and yield of tomato cv. pusa ruby. Journal of Applied Horticulture. 2000;2:124-126.
77. Girija G. Efficacy of mancozeb formulations for the control of early and late blight of tomato. Pestology. 2000;24: 72-73.
78. Hagan AK, Bowen KL, Campbell HL, Wells L. Calendar based and AU-Pnuts advisory programs with pyraclostrobin and chlorothalonil for the control of early leaf spot and stem rot on peanut. Peanut Science. 2007;34:114-121.
79. Salau AO, Odeleye OM. Antibacterial activities of *Mucuna pruriens* on selected bacteria, African Journal of Biotechnology. 2007;6:2091-92.
80. Shridhar KR, Bhat R. Agrobotanical, nutritional and bioactive potential of unconventional legume – Mucuna. Livestock Research and Rural Development. 2007;19:123.
81. Enespa, Dwivedi Sk. Effectiveness of some antagonistic fungi and botanicals against *Fusarium solani* and *Fusarium oxysporum* infecting Brinjal and Tomato plants. Asian Journal of Plant Pathology. 2014;8:18-25.

82. Hassanein NM, AbouZeid MA, Youssef KA, Mahmoud DA. Control of tomato early blight and wilt using aqueous extract of neem leaves. Journal of Phytopathologea Mediterranea. 2010;49:143-151.
83. Awalin S, Shahjahan M, Roy AC, Akter A, Kabir MH. Response of Bell Pepper (*Capsicum annuum*) to Foliar Feeding with Micronutrients and Shoot Pruning. Journal of Agriculture and Ecology Research International. 2017;11:1-8.
84. Prochnow JT, Schmid LP, Medeiros JC, Mielezrski F. Response to Late Foliar Nitrogen Application in Soybean Productivity. Journal of Experimental Agriculture International. 2017;15:1-5.
85. Pal S, Barad AV, Singh AK, Khadda BS, Kumar D. Effect of foliar application of Fe and Zn on growth, flowering and yield of gerbera (*Gerbera jamesonii*) under protected condition. Indian Journal of Agricultural Sciences. 2016;86:394-398.
86. Tonfack LB, Bernadac A, Youmb E, V. Mbouapouognigni P, Ngueguim M, Akoa A. Impact of organic and inorganic fertilizers on tomato vigor, yield and fruit composition under tropical andosol soil conditions. Fruits. 2009;64:167-177.
87. Shobo BA, Bodunde JG, Akinboye OE, Ayo-Bello TA, Afodu OJ, Ndubusi-Ogbonna LC. Enhancement of Growth and Yield Performance in Tomato (*Solanum lycopersicon L*) through Foliar Application of a Nutrient Supplement. Journal of Experimental Agriculture International. 2016;14:1-6.
88. Neupane MP, Singh SP, Sai Sravan U, Singh A. Effect of Soil and Foliar Nitrogen Application on Growth, Yield and Quality of Baby Corn Cultivars. Journal of Experimental Agriculture International. 2017;16:1-11.
89. Nafiu KA, Chude VO, Ezendu CO. Field Evaluation of Foliar Blend Micronutrient Fertilizer on Cotton (*Gossypium hirsutum*) Production in Katsina State, Nigeria. Journal of Experimental Agriculture International. 2017;17:1-8.

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