International Journal of Plant & Soil Science
12(3): 1-13, 2016; Article no.IJPSS.28093
ISSN: 2320-7035

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Comparative Advantage of *Mucuna* and *Tithonia* Residue Mulches for Improving Tropical Soil Fertility and Tomato Productivity

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Authors' contributions

This work was carried out in collaboration between all authors. Author CN designed the study, wrote the protocol, conducted plant and soil analyses and wrote the first draft of the manuscript. Author PMM coordinated field and laboratory exercises and managed literature. Author CAN managed the field site, sampling and data collection. Author AST managed literature searches and supervised the study. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2016/28093
Editor(s):
(1) Marco Trevisan, Institute of Agricultural Chemistry and Environmental Research Centre BIOMASS, Faculty of Agriculture, Catholic University of the Sacred Heart, Italy.
Reviewers:
(1) Fahmida Khan, National Institute of Technology, Raipur, India.
(2) Maria Jose Alves Bertalot and Eduardo Mendoza, Instituto Elo de Economia Associativa– Botucatu, Sao Paulo, Brazil.
(3) Mohan Krishna Balla, Tribhuvan University, Institute of Forestry, Pokhara, Nepal.
Complete Peer review History: http://www.sciencedomain.org/review-history/15714

Original Research Article

Received 1st July 2016
Accepted 1st August 2016
Published 9th August 2016

ABSTRACT

Aims: To evaluate the suitability of *Mucuna cochinchinensis* and *Tithonia diversifolia* residue mulches for improving tropical soil fertility and tomato productivity, by determining the residue quality and their effect on specific soil properties and crop yield.
Methodology: Experimental plots were treated with inorganic and organic inputs (i.e. comprised a control with no input, mineral NPK fertilizer, residues of *Mucuna* and *Tithonia,* and mixture of *Mucuna* and *Tithonia*).
Results: Soil available P increased from 81.3 to 148.3 mg/kg across treatments, with the highest for mineral fertilizer that differed from the plant residues and control, followed by the plant residues

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that differed from control (Tukey's HSD, *P* = .05). Soil exchangeable K increased from 1.3 to 1.9 cmol/kg across treatments, with the highest recorded for plant residues and mineral fertilizer compared to the control (Tukey's HSD, *P* = .05), and correlated with treatments (r = 0.51, *P* = .05). Soil organic C increased from 2.3 to 2.7% across treatments, with the highest recorded for plant residues compared to mineral fertilizer and control (Tukey's HSD, *P* = .05), and positively correlated with treatments (r = 0.75*, P* = .05). Soil pH increased from 4.7 to 5.8, with the highest for mineral fertilizer that differed from the control (Tukey's HSD, *P* = .05), and correlated with the soil available P (r = 0.72, *P* = .05). Tomato yield increased from 9.5 to 13.5 t ha^{-1} with the highest recorded for sole *Tithonia* and *Mucuna*+*Tithonia*, followed by sole *Mucuna* and mineral fertilizer as compared to the control, and correlated with soil organic C (r = 0.71, *P* = .05) and exchangeable K (r = 0.67, *P* = .05).

Conclusion: *Mucuna* and *Tithonia* residue mulches are sustainable organic alternatives to improve tropical soil fertility, either singly or in combination, but *Tithonia* residue has a better impact on tomato productivity due to the higher content of exchangeable K.

Keywords: Tropical soils; mulches; Mucuna and Tithonia; fertilizer; tomato.

1. INTRODUCTION

Low crop productivity in Sub-Saharan Africa (SSA) is partly due to poor and declining fertility of the largely tropical acid soils, with nitrogen (N) and phosphorus (P) as the most limiting elements [1,2]. Meanwhile, nutrient losses from arable soils are higher than the natural replenishment capacity of soils in SSA [3]. Although mineral fertilizers are often used to improve soil fertility and correct soil acidity, SSA accounts for only 0.1% of global mineral fertilizer production and 1.8% of global mineral fertilizer use. Hence, SSA accounts for less than 10 kg ha^{-1} fertilizer use compared to 87 kg ha^{-1} for some developed nations [4]. Hence, poor soil fertility coupled with low mineral fertilizer inputs accounts for the low crop performance in SSA, with huge yield gaps of over 30% between the attainable potential and actual production [5,6]. Besides the high cost, mineral fertilizers exert negative environmental externalities, which necessitates sustainable alternative soil improvement strategies.

Organic matter input is considered an essential practice for improving soil fertility, and plant residues reportedly improved soil properties and organic matter content, as well as reduced the P sorption capacity of soils [7,8]. However, adding the appropriate plant residue is vital for soil fertility improvement, since some residues have higher nutrient contents and liming potential [9,10]. *Tithonia diversifolia* is known to produce abundant biomass with high nutrient contents comprising 3.5% N, 0.37% P and 4.1% K, and few low recalcitrant compounds with 6.5% lignin and 1.6% polyphenol [11,12]. Furthermore, *Tithonia* demonstrated strong potential for soil rejuvenation and mitigating field pests and diseases due to the presence of sesquiterpene lactones (tagitinins-terpene) and antimicrobial substances [13,15]. Meanwhile, *Mucuna* species also reportedly produced abundant biomass comprising about 3% N, 0.2% P and 1.4% K [16-19]. Additionally, *Mucuna* residues demonstrated strong antimicrobial and faunal properties, which affected the functions, diversity and abundance of soil bacteria, fungi and nematodes [20-22].

Meanwhile, tillage practices may also influence soil physical and chemical properties, and eventually affect crop yield [23,24]. Although tillage positively affected soil properties and tomato performance, the impact may be fostered by additionally mulching with nutrient rich plant residue inputs [25]. This investigation was aimed at evaluating the suitability of *Mucuna* and *Tithonia* residue mulches as sustainable alternative amendments to improve soil fertility and tomato productivity. Therefore, the influence of *Mucuna* and *Tithonia* residue mulches on soil properties was compared with mineral fertilizer addition and a control without any input. It was hypothesized that *Mucuna* and *Tithonia* residue mulches shall improve the soil fertility, reduce soil acidity and P sorption, hence releasing more soil available P and exchangeable K for plant use, leading to greater tomato productivity.

2. MATERIALS AND METHODS

2.1 Experimental Site and Setup

The study was conducted at Lysoka-Buea, located at the foot of mount Cameroon, in the South West Region of Cameroon, situated between latitudes 4º3'N and 4º12'N of the equator and longitudes 9º12'E and 9º20'E. The soil type is generally derived from weathered volcanic rocks, and analysis of the field site indicated the dominance of silt with 51.6% (31.1 fine silt and 20.5 coarse silt), followed by clay with 42% and sand with 6.4%. Buea has a mono-modal rainfall regime with less pronounced dry season and 85 - 90% relative humidity. Heavy rainfall occurs between June and October while the dry season starts from November to May, with annual mean rainfall of 2085 mm to 9086 mm, with Lysoka recording about 2875 mm annual rainfall between March and November [26]. The mean monthly air temperature ranges from 19℃ to 30℃, while soil temperature at 10 cm depths decreased from 25℃ to 15℃ with increasing elevation from 200 m to 2200 m above sea level [27,28].

The experimental setup was a completely randomized block design with five treatments (control with no input, mineral fertilizer-NPK, two plant residues of *Mucuna* and *Tithonia*, and a combination of *Mucuna*+*Tithonia* at 1:1). Meanwhile, each treatment was replicated four times (Fig. 1). Prior to establishment of this long-term experimental site, the field had been under intensive commercial banana production by the Cameroon Development Corporation (CDC) until 2009. The field was further used for subsistence intercropping of maize (*Zea mays*), cassava (*Manihot esculenta*), okra (*Abelmoschus esculentus*), ginger (*Zingiber officinale*), beans *(Phaseolus spp)* and cowpeas (*Vigna unguiculata*) until 2013. In 2014, the site was cleared manually using cutlasses and partitioned into experimental plots of 20 m^2 (5 m×4 m), with a 1 m buffer zone separating the plots (Fig. 1). All the experimental plots were tilled (i.e. about 20 cm depth) manually using hoes, seeded with a green manure cover crop (*Mucuna cochinchinensis*) at 30 cm×30 cm spacing in March 2014, and allowed to fallow and homogenised the soil for one year. At maturity in March 2015, the *Mucuna* cover crop was harvested as biomass (leaves and stems). The *Mucuna* seeds were separated from the shells, and the separated biomass and seeds were sun-dried and preserved at room temperature for use as basal mulch and propagation materials, respectively.

2.2 Soil Amendments

Following the establishment of this long-term integrated soil fertility management field site in March 2014, the first experiment was conducted in April 2015 to determine the potential impact of the different treatments on tomato performance and profitability of smallholder farmers [29]. The experiment was repeated the following planting season in August 2015, with focus on the impact of the different treatments on soil physical and chemical properties and the dynamics of essential plant nutrients. Accordingly, the control experimental plots received no fertilizer input, inorganic treatment plots were amended with mineral fertilizer (NPK), while the organic plots were amended with plant residues of *Mucuna cochinchinensis,* or *Tithonia diversifolia,* or combination of *Mucuna* and *Tithonia* at 1:1 ratio. Meanwhile, all treatment plants were earthed-up with the surrounding soil three weeks after transplanting.

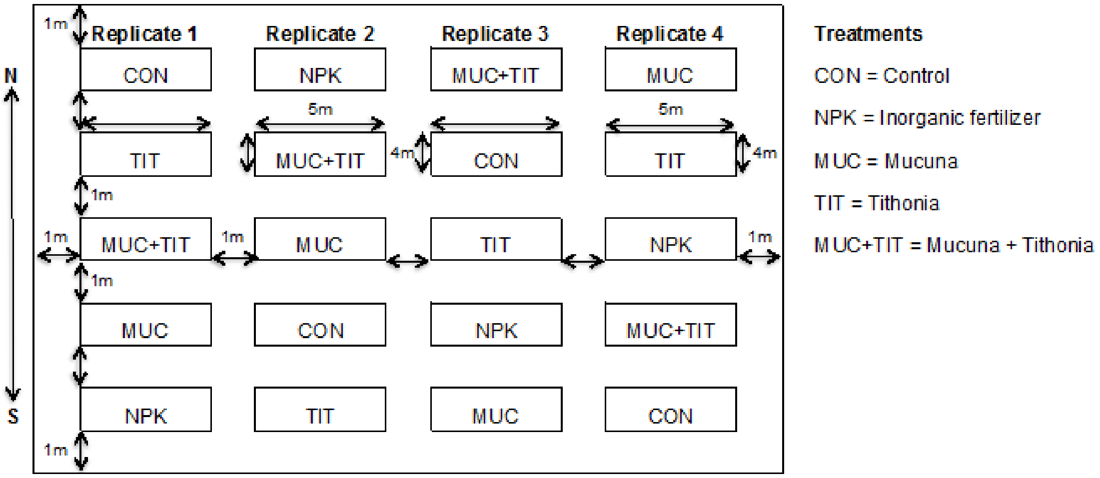

Fig. 1. Experimental setup with five completely randomised treatments within four replicates, and 1 m buffer strips separating all treatment plots

The mineral fertilizer was applied on the respective plots as two split doses of 90 kg ha^{-1} granular NPK 20:10:10 + CaO (ADER® Cameroon) each, using the ring method at 5cm from plants. The first fertilizer application was performed immediately after transplanting, while the second application was performed three weeks later and immediately earthed-up with the surrounding soil. This fertilizer application rate was comparable to about 87 kg ha^{-1} reported for some developed nations [4].

Meanwhile, the plant residues were mulched on the respective organic plots as single basal dose at the rate of 5 t ha^{-1} DW, which is equivalent to 10 kg DW per 20 m^2 plot [30]. The plant residues were evenly spread on the respective plots immediately after tomato seedlings were transplanted, mulched around the plants and earthed-up with the surrounding soil three weeks later. The *Mucuna* residue was obtained from a cultivated field the previous season, while *Tithonia* residue was harvested from roadsides and abandoned fields. The residues were sun-dried for one week and stored at room temperature prior to field application. Before field application of the plant residues, three sub-samples were randomly collected for laboratory analysis to determine the relative composition of the essential elements (N, P and K) that are necessary for plant nutrition and optimum tomato performance.

2.3 Tomato Plant *(Lycopersicon esculentum L.)*

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 on a nursery bed of 2.5 m×1 m beside the experimental field, at an inter-row spacing of 15 cmx15 cm. The nursery bed was prepared by clearing with a cutlass and tilled manually with a hoe. All seedlings in the nursery bed were regularly treated with appropriate fertilizers and plant health management practices (i.e. fungicides, pesticides and insecticides). Vigorous tomato seedlings were transferred from the nursery to 20 m^2 experimental plots (5m×4m) three weeks later, and planted at distance of 1 m×0.5 m. One plant was planted per stand, giving a total of 35 stands per plot. Three weeks after transplanting, 1m wooden sticks were used to stake all plants on the experimental plots, and ropes were used to assist the staking of plants.

2.4 Field Management

Soil moisture during the entire experimental period depended entirely on rain-fed system according to the local rainfall regime. The management practices for weeds, pest and diseases were the same for the nursery and all treatment plots. Before transplanting the tomato seedlings, the entire field was weeded manually using cutlasses and hoes. After transplanting tomato seedlings, the experimental site was monitored regularly for the emergence of weeds and weeding was carried out manually using hoes. The site was monitored regularly for the emergence of insect pests and diseases, and sprayed with appropriate doses of fungicide (Mancozan super; SCPA SIVEX International® France) and insecticides (Garmaline 80, AGROMAF® Cameroon; Cigogne 360, SCPA SIVEX International® France; and Acarius, SAVANA-Horizon Phyto Plus® Cameroon).

2.5 Soil Sampling and Harvest

Eight weeks after transplanting, soil samples were collected at 0-15 cm depths from each plot. Ten soil cores were sampled per plot and bulked into a single composite sample, and immediately transported in plastic bags to the laboratory where they were air-dried and stored prior to analyses. For tomato yield, mature fruits from individual plots were harvested and weighed using a top loading balance. A total of nine harvests were recorded from each treatment plot within a period of 32 days, with two harvests per week.

2.6 Laboratory and Statistical Analyses

Both *Mucuna* and *Tithonia* residues were analysed to determine the relative composition of essential elements (N, P and K). The soil particle size analysis was determined using the pipette method with sodium hexametaphosphate as the dispersing agent [31]. Soil pH was determined potentiometrically in both water (H_2O) and 1 M potassium chloride (KCl) solutions after 24 h in soil suspension (soil/liquid = 1/2.5 w/v). Exchangeable bases were extracted with neutral ammonium acetate solution. Calcium (Ca) and Magnesium (Mg) were determined by atomic absorption spectrophotometry, while Potassium (K) and Sodium (Na) were determined by flame photometry [32]. Exchangeable acidity was determined by KCl extraction method [32]. The total nitrogen content was determined by macro-kjeldahl digestion method [33], while available phosphorus (P) was determined by Bray II method [32]. Meanwhile, the soil organic carbon content was determined by Walkley-Black method [34].

Data sets were subjected to statistical analyses using STATISTICA 9.1 for Windows [35]. Tomato yield and soil properties such as pH [H_2O and KCl], organic carbon, C/N, total N, available P, exchangeable K, sodium [Na], magnesium [Mg], calcium [Ca], aluminum [Al], cation exchange capacity [CEC], and moisture) were subjected to univariate analysis of variance (ANOVA, *P* = .05) as response design variables to test effects of soil treatments (*n*=5) as categorical predictors. Significant data means were compared by post-hoc Tukey's HSD test (*P* = .05), and Pearson's Correlation coefficient (*P* = .05) performed to determine the degree of association between treatments and soil properties or tomato yield.

3. RESULTS

3.1 Essential Elements in Plant Residues

Contents of the three essential elements (N, P and K) in the plant tissues varied within and between the different residues, ranging from 0.35% to 4.18% for *Mucuna* and 0.55% to 4.52% for *Tithonia* (Table 1). This percentage elemental composition corresponds to a total of 274 kg ha^{-1} NPK for *Mucuna* and 415 kg ha^{-1} NPK for *Tithonia*. Meanwhile, the NPK amendment rates of *Mucuna* and *Tithonia* residues per hectare was dominated by the N content with 209 kg and 226 kg, followed by K with 48 kg and 161 kg, and P with 18 kg and 28 kg, respectively. However, the most notable difference between *Mucuna* and *Tithonia* residues is the K content, with 114 kg NPK ha^{-1} for *Tithonia,* followed by N with of 17 kg ha^{-1}, and P with 10 kg ha^{-1}. Therefore, considering the application rate of 87 kg ha^{-1} mineral fertilizer NPK that was used for this study, *Mucuna* and *Tithonia* residues received a total of 187 kg and 328 kg more NPK per hectare, respectively, compared to the mineral fertilizer.

3.2 Impact of Soil Amendments on Essential Nutrients

Overall, the different soil treatments favoured some soil properties such as P, K and organic C, which differed significantly (*P* = .05; Fig. 2, 3 and 4), whereas nitrogen and sodium exhibited trends to differ (*P* = .05) between treatments (Table 2).

3.2.1 Phosphorus

The content of soil available P ranged from 81.3 to 148.3 mg/kg and differed significantly (ANOVA: $F_{4,15}$ = 325.7, *P* = .001; Fig. 2). The highest P content was recorded for mineral fertilizer input that differed significantly (*P* = .05) from the plant residue mulches and control, followed by the plant residue mulches (*Mucuna, Tithonia* and *Mucuna*+*Tithonia)* that only differed significantly from the control (Tukey's HSD, *P* = .05; Fig. 2).

3.2.2 Potassium

Soil exchangeable K content ranged between 1.3 and 1.9 cmol/kg DW soil, and differed significantly between treatments (ANOVA: $F_{4,15}$ = 7.4, *P* = .01; Fig. 3). The highest K content was recorded for plant residue mulches and mineral fertilizer inputs, as compared to the control (Tukey's HSD, *P* = .05; Fig. 3), but there was no significant difference between the plant residue mulches and mineral fertilizer. Meanwhile, both mineral fertilizer and plant residue mulches enhanced the soil K content, as corroborated by the positive correlation between soil treatments and K content (r = 0.51, P = .05).

Table 1. Content of essential elements (% NPK) in the residues of *Mucuna cochinchinensis* and *Tithonia diversifolia*, and the quantity of NPK applied (kg ha^{-1})

Essential elements [%]	**Content of mineral elements in plant residue**	
	Mucuna	***Tithonia***
Total nitrogen	4.18	4.52
Available phosphorus	0.35	0.55
Exchangeable potassium	0.95	3.22
Total NPK	5.46	8.26
Quantity of essential elements applied [kg ha^{-1}]		
Total nitrogen	209	226
Available phosphorus	18	28
Exchangeable potassium	48	161
Total NPK	274	415

3.2.3 Organic carbon

The percentage of soil organic C content ranged between 2.3 and 2.7 DW soil, and differed significantly between treatments (ANOVA: $F_{4,15}$ =13.1, *P* = .001; Fig. 4). The highest organic C was recorded for plant residue mulches, as compared to the mineral fertilizer and control (Tukey's HSD, *P* = .05; Fig. 4). Meanwhile, the increase in soil organic C with plant residue mulches was corroborated by the positive correlation between treatments and soil organic C (*r* = 0.75, *P* = .05).

3.3 Impact of Soil Amendments on pH

The soil pH (H_2O) ranged between 3.54 and 5.96, and differed significantly between treatments (ANOVA: $F_{4,15}$ =3.8, *P* = .05; Table 2), with the highest pH recorded for mineral fertilizer that only differed with the control (Tukey's HSD, *P* = .05; Table 2). The plant residue mulches were neither significantly different from the control nor from the mineral fertilizer treatment. Meanwhile, the increase in soil pH (i.e. decreasing soil acidity) with mineral fertilizer inputs increased the content of soil available P, as corroborated by the positive correlation between soil pH and available P (*r* = 0.72, *P* = .05).

Meanwhile, the soil pH (KCl) ranged between 4.14 and 4.71, and differed significantly between treatments (ANOVA: $F_{4,15}$ = 3.8, *P* = .001; Table 2), with the highest pH recorded for mineral fertilizer that differed from the control and plant residue mulches (Tukey's HSD, *P* = .05; Table 2). Meanwhile, pH (KCl) was only positively correlated with the content of soil available P (*r* = 0.55, *P* = .05).

3.4 Influence of Soil Amendments on Tomato Yield

The average tomato yield ranged between 9.5 and 13.5 t ha^{-1} across treatments, which increased significantly (ANOVA: $F_{4,15}$ = 4.3, *P* = .01; Fig. 5) for the plant residue mulches. The highest yield occurred for sole *Tithonia* and *Tithonia*+*Mucuna*, followed by sole *Mucuna* and mineral fertilizer, as compared to the control (Tukey's HSD, *P* = .05; Fig. 5). Meanwhile, the increased tomato yield under plant residue mulches and mineral fertilizer inputs was influenced by the increase in soil organic C and exchangeable K. This is corroborated by the positive correlation between tomato yield and organic C (*r* = 0.71, *P* = .05), and between tomato yield and exchangeable K (*r* = 0.67, *P* = .05).

4. DISCUSSION

4.1 Impact of Soil Amendments on Essential Nutrients

The application of mineral fertilizer increased the content of soil available phosphorus compared to the plant residue mulches and control. This is due to the slow mineralization rate of the plant

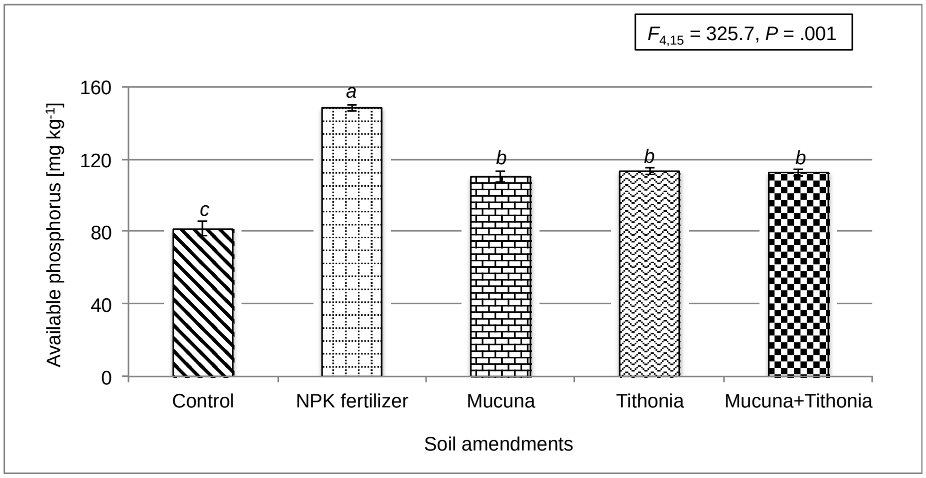

Fig. 2. Impact of soil amendments (i.e. control with no input, mineral fertilizer-NPK, plant residue mulches of *Mucuna* and *Tithonia,* and a combination of *Mucuna*+*Tithonia* at 1:1) on soil available P (mg/kg, Mean ± SD); Values with different letters are significantly different according to Tukey's HSD, *P* = .05

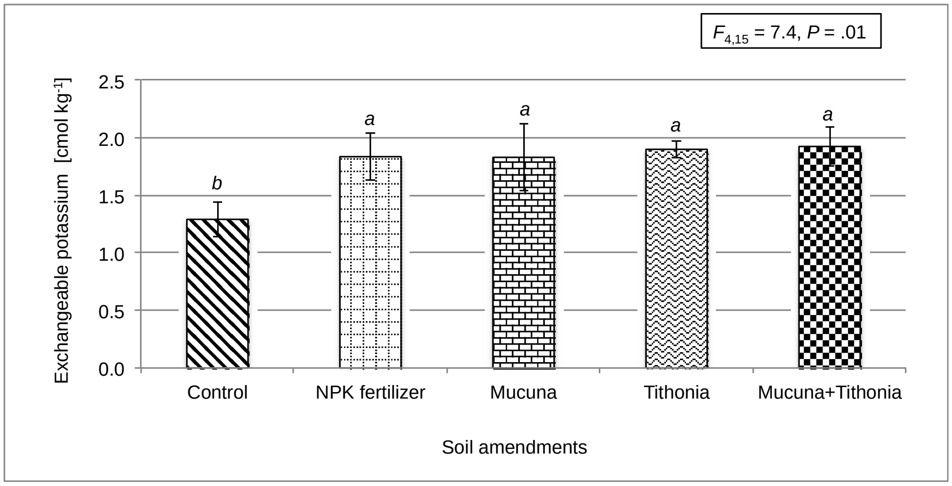

Fig. 3. Impact of soil amendments (i.e. control with no input, mineral fertilizer - NPK, plant residue mulches of *Mucuna* and *Tithonia,* and a combination of *Mucuna*+*Tithonia* at 1:1) on soil exchangeable K (cmol/kg, Mean ± SD); Values with different letters are significantly different according to Tukey's HSD, *P* = .05

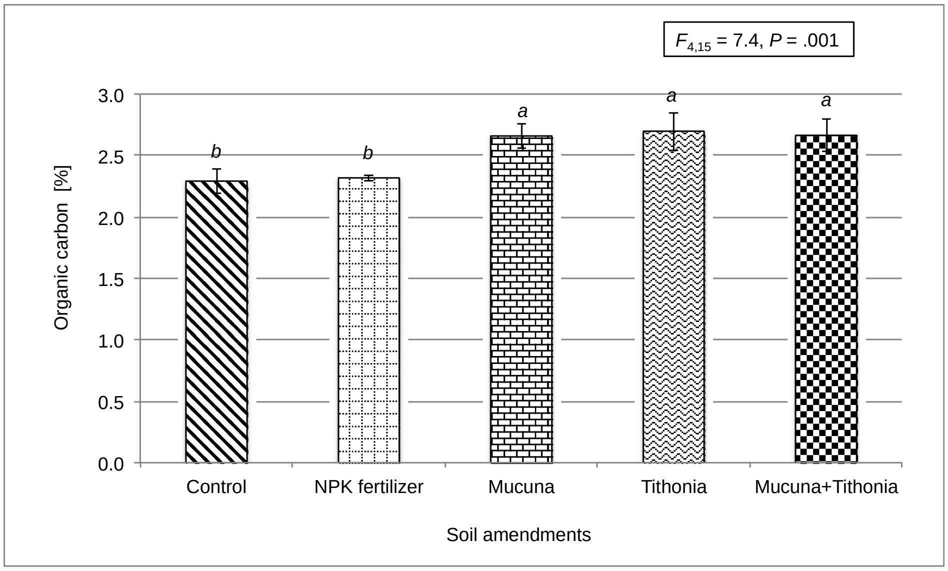

Fig. 4. Impact of soil amendments (i.e. control with no input, mineral fertilizer - NPK, plant residue mulches of *Mucuna* and *Tithonia,* and a combination of *Mucuna*+*Tithonia* at 1:1) on soil organic C (%, Mean ± SD); Values with different letters are significantly different according to Tukey's HSD, *P* = .05

biomass materials to release the essential elements compared to the readily available NPK status of mineral fertilizers. The strong increase in soil exchangeable K against the control is commensurate with the high content of K in the plant residues. Nonetheless, there was no difference in soils amended with the different residues despite the very high K content in *Tithonia* compared to *Mucuna*. However, the K content for soils amended with *Mucuna* and *Tithonia* residues is comparable to soils that are amended with mineral fertilizer, which is likely due to the slow mineralization rate that does not allow a rapid increase in soil K content in relation to that of the plant residue amendment. Hence, the higher K content of the plant residue inputs as compared to mineral fertilizer K does not necessarily translates into a higher K content for the residue-amended soils in comparison to soils amended with mineral fertilizer.

Table 2. Impact of soil amendments (control with no input, mineral fertilizer-NPK, plant residues of *Mucuna* and *Tithonia,* and a combination of *Mucuna*+*Tithonia* at 1:1) on soil physical and chemical properties (Mean ± SD); Values with different letters are significantly different according to Tukey's HSD, *P* = .05

Soil properties	**Soil amendments**				
	Control	**NPK**	**Mucuna**	**Tithonia**	**Mucuna+Tithonia**
pH [H_2O]	3.54±0.79b	5.96±0.33a	5.16±0.21ab	5.33±0.12ab	5.19±0.15ab
pH [KCl]	4.24±0.13b	4.71±0.33a	3.96±0.15b	4.14±0.08b	4.14±0.07b
Moisture [%]	13.18±0.58	13.59±1.29	13.22±0.32	14.08±0.47	12.25±0.62
Total nitrogen [%]	0.24±0.02	0.27±0.08	0.22±0.01	0.21±0.04	0.25±0.06
Carbon/Nitrogen (C/N)	9.79±0.46	9.81±2.26	11.59±0.42	12.76±3.63	11.28±3.08
Sodium [cmol/kg]	0.15±0.01	0.19±0.05	0.15±0.05	0.19±0.01	0.19±0.01
Magnesium [cmol/kg]	3.05±0.45	1.99±0.39	1.98±0.82	2.54±0.41	2.11±0.33
Calcium [cmol/kg]	5.42±1.03	7.87±2.09	6.42±4.45	8.62±0.74	7.78±0.30
Aluminium [cmol/Kg]	0.29±0.40	0.61±0.18	1.11±0.39	0.66±0.26	0.61±0.31
Cation exchange capacity [cmol/Kg]	8.65±0.45	9.23±0.91	8.65±1.65	10.15±0.60	9.02±0.50

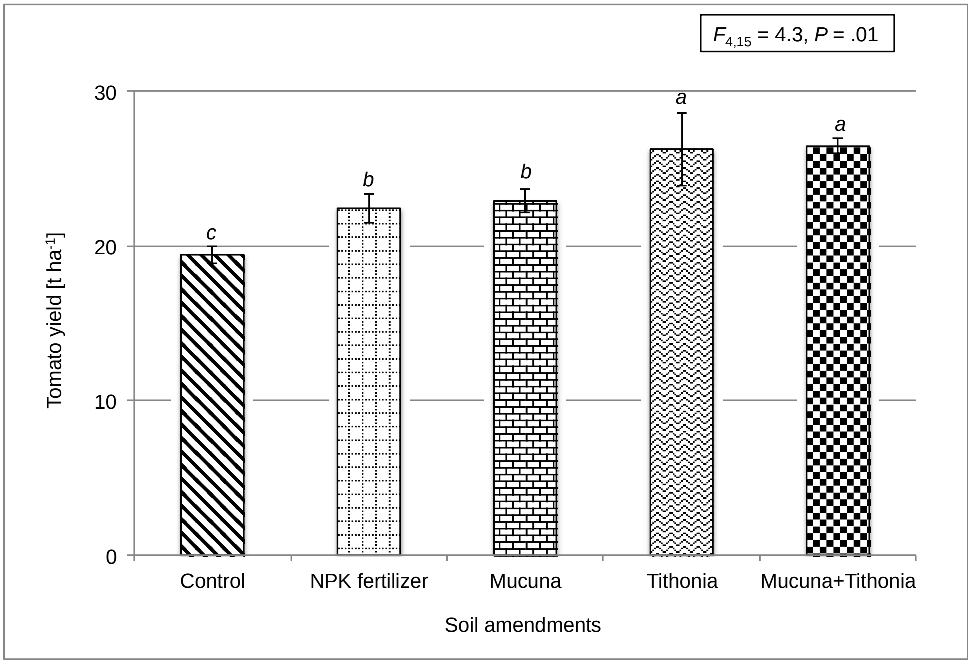

Fig. 5. Influence of soil amendments (i.e. control with no input, mineral fertilizer - NPK, plant residue mulches of *Mucuna* and *Tithonia,* and a combination of *Mucuna*+*Tithonia* at 1:1) on tomato yield (t ha^{-1}, Mean ± SD); Values with different letters are significantly different according to Tukey's HSD, *P* = .05

However, the increased soil available P recorded for plant residue mulches compared to the control corresponds to the release of soluble P by both *Mucuna* and *Tithonia*. The net P mineralization rate likely increased because both plant residues have higher P concentration than the critical level required for P mineralization [7]. The increased soil available P for *Mucuna* and *Tithonia* residue mulches is consistent with reports of increased P availability due to faster mineralization of soil organic P to inorganic P, than soil P sorption [8,36]. The low P content recorded for the control soil is likely due to high P sorption capacity of the acidic soil with 42% clay composition, since clay particles were strongly correlated to P sorption [37]. The positive correlation observed between soil pH and available P possibly led to increased soil P solubility that was favoured by the increase in soil pH. This is likely due to the interactive effects on soil biota, plant residue type and source, and decomposition, as well as soil properties [38]. It has been observed that phosphorus sources and soil types influence P availability differentially [39]. Hence, the differences between *Mucuna* and *Tithonia* residue mulches were likely due to differential rate of decomposition and nutrient release resulting from the residue quality [40]. The rate of soil organic matter decomposition increased with decreasing soil clay content [41]. Furthermore, Odhiambo [42] reported reduced N mineralization in soils with high clay content, while the biochemical composition of plant residue influenced net N immobilization or mineralization [43,44]. The trend for increased N observed in this study coupled with the high clay content (42.1%) of the investigated soil is consistent with the effect of clay on plant residue decomposition and N mineralization [45]. In sum, these findings corroborate the hypothesis that *Mucuna* and *Tithonia* residue mulches improve soil properties and increase soil available P for plant use.

4.2 Impact of Soil Amendments on pH

The increased soil pH recorded for the mineral fertilizer compared to the control and plant residue mulch treatment is due to the liming effect of the CaO in the mineral fertilizer. Meanwhile, the trend of plant residue mulches compared to the control is likely due to N transformations and the release of cations, as well as the oxidation of organic acid anions from decomposing plant residues [46,38]. In addition, ammonification of organic N and specific adsorption of organic molecules produced during residue decomposition and reduction reactions induced by anaerobiosis [47]. Hence, corroborating the hypothesis that *Mucuna* and *Tithonia* shall increase the soil pH, reduce soil acidity and P sorption capacity, leading to more soil available P.

4.3 Influence of Soil Amendments on Tomato Yield

The increased tomato yield for *Mucuna* and *Tithonia* residue mulches is consistent with reports attributing greater crop yields to improved soil physical, chemical and biological parameters [12,15,48]. Plant residues reportedly improved soil organic matter, available P and exchangeable K contents that improved tomato yield [49-51]. Differences in tomato yield between *Mucuna* and *Tithonia* residue mulches are likely due to differential quality of the plant materials, nutrient content and decomposition rate [52,53]. This is further supported by the variation in NPK data of the *Mucuna* and *Tithonia* residues.

The higher tomato yield recorded for *Tithonia* residue mulch can be attributed to its higher nutrient status, fast decomposition and nutrient release [7,14]. In particular, there is likely a strong relationship between the soil exchangeable K content and higher K content in *Tithonia* residues [51]. Differences in plant residue mulches likely influenced soil biology, root growth and nutrient acquisition, leading to greater yield [54-56]. Additionally, the plant residue mulches enabled constant nutrient supply that possibly favoured root growth and nutrient acquisition [57]. Besides, mineral fertilizers might have induced high nitrate pulses that were easily leached because of their high mobility in soil, couple with high rainfall regime of the experimental site. Furthermore, results for combined *Mucuna* and *Tithonia* are consistent with Babajide et al. [58] who reported advantages of composted *Tithonia*+Poultry manure and sole *Tithonia* mulch for improving soil properties and crop performance. This is due to greater nutrient use efficiency, since some plant residues have faster decomposition and mineralization rates that are commensurate with the readily available nutrient release capacity of mineral fertilizers.

Nonetheless, the higher soil available P recorded for mineral fertilizer than plant residue mulches, coupled with comparable pH and exchangeable K does not reflect the lower tomato yield that was recorded. These discrepancies strongly suggest the influence of other contributing factors. Meanwhile, the higher soil organic C content recorded for the plant residue mulches corresponds to the higher tomato yield. In sum, higher tomato yield for plant residue mulches is likely due to improved soil fertility and plant nutrition resulting from the interaction of soil pH, available P, exchangeable K, and soil organic carbon that likely influenced soil physical, chemical and biological status.

5. CONCLUSION

This investigation provides justifiable insights for the enhanced tomato yields recorded for plant residue mulches, and demonstrates the suitability of *Mucuna* and *Tithonia* residue mulches as suitable sustainable alternative integrated soil fertility management strategy to enhance soil nutrient dynamics and plant nutrition under tropical soil conditions. These observed differences are due to the rich NPK content and slow nutrient release of the plant residues that enhanced nutrient availability and plant nutrition, as compared to the mineral fertilizer and control. Meanwhile, the higher K content recorded for *Tithonia* residues was a major determinant for enhanced tomato yields compared to *Mucuna* residues. Overall, mulching with *Mucuna* and *Tithonia* residues is a suitable and sustainable strategy to improve tropical acid soils with poor and declining fertility status and limited available P.

ACKNOWLEDGEMENTS

This study was supported by the Research Grant of the Faculty of Agriculture and Veterinary Medicine of the University of Buea, and the Research and Modernization Allowance of the Ministry of Higher Education of Cameroon.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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