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Integrated Soil Fertility Management: Impact of *Mucuna* and *Tithonia* Biomass on Tomato (*Lycopersicon esculentum* L.) Performance in Smallholder Farming Systems

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Abstract

Many views, paradigms and concepts have been advocated in recent decades on soil fertility and soil conservation across the globe in order to provide sustainable solutions to the rising food and nutrition insecurity while preserving the natural resource base. Meanwhile, food and nutrition security in Sub-Saharan Africa (SSA) is mainly achieved through smallholder farming systems that are characterized by poor and declining soil fertility, which often leads to low crop yields and low income. Hence, a field trial was established to evaluate the impact of integrated soil fertility management (ISFM) practices on tomato yield and the farm-scale income in smallholder farming systems. The ISFM trial comprised a control with no input, mineral fertilizer, and organic treatments comprising sole *Mucuna* and *Tithonia* biomasses as well as their combination (*Mucuna* + *Tithonia*). Generally, tomato performance was better with organic plant biomass amendments, with significantly higher ($P < 0.001$) tomato yield for *Mucuna* + *Tithonia* and sole *Tithonia*, followed by sole *Mucuna* and mineral fertilizer compared to the control. Meanwhile in comparison to the control, *Mucuna* + *Tithonia* and sole *Tithonia* recorded 3.5 and 3.4 t ha^{-1} more yield, respectively, which was about twice the additional yield for sole *Mucuna* and mineral fertilizer with 1.8 and 1.5 t ha^{-1}, respectively (Tukey's HSD, $P < 0.05$). Similarly, the farm-scale income increased significantly ($P < 0.001$) for organic plant biomass, and it was most pronounced for *Mucuna* + *Tithonia* and sole *Tithonia*, followed by sole *Mucuna* and mineral fertilizer, as compared to the control (Tukey's HSD, $P <$

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0.05). A positive Spearman Rank Correlation was recorded between the ISFM treatments and tomato yield or the farm-scale income (r = 0.76, $P < 0.05$), and between tomato yield and the farm-scale income (r = 0.99, $P < 0.05$). These results imply that smallholder farmers in SSA can effectively use the combination of *Mucuna* + *Tithonia* biomass materials or their sole applications as basal mulch to improve tomato production. Thus, these organic amendments could be an alternative and sustainable integrated soil fertility management strategy to boost tomato production and farm-scale income without jeopardizing the sustainability of the environment. However, this requires more efforts to adapt the different ISFM techniques to the specific needs of smallholder farmers, coupled with effective dissemination strategies that facilitate knowledge transfer and technology adoption.

Keywords

Integrated Soil Fertility Management, *Mucuna*, *Tithonia*, Mineral Fertilizer, Tomato

1. Introduction

Sub-Saharan Africa (SSA) accounts for about 9% of global population with high food and nutrition insecurity that is partly due to poor and declining fertility status of the largely acid soils, with nitrogen and phosphorus as the most limiting mineral elements [1] [2]. Although mineral fertilizers are often used to correct soil acidity and improve the soil fertility status, SSA accounts for only 0.1% of global mineral fertilizer production and 1.8% of global mineral fertilizer use, with less than 10 kg ha^{-1} compared to 87 kg ha^{-1} for developed nations [3] [4]. Meanwhile, nutrient losses from arable fields are higher than the natural replenishment capacity of soils in SSA [5] [6]. The poor soil fertility status coupled with low mineral fertilizer inputs in SSA accounts for the low crop yields with huge gaps of over 30% between attainable potential and actual production [7] [8]. Besides exerting a multitude of deleterious effects on the environment, mineral fertilizers are expensive and unaffordable to many resource-poor smallholder farmers in SSA, which necessitates sustainable and affordable alternative soil amendment strategies that are adapted to the needs of smallholder farmers.

The concept of integrated soil fertility management (ISFM) is widely encouraged in SSA, and it is largely considered as a set of agronomic practices adapted to local conditions to maximize nutrient use efficiency and improve crop productivity. The ISFM techniques incorporate mineral fertilizer and locally available inputs (*i.e.* lime and rock phosphate) with organic matter (*i.e.* crop residues and compost) to replenish soil nutrients, improve agronomic efficiency and crop production [9]. Meanwhile, wood ash has been used as additives to mineral fertilizer and compost to improve quality and performances [10] [11]. Ash and ash-derived composts have high liming potential and reportedly improved soil physical and biochemical properties [12]-[15]. However, the reliance on plant materials for soil restoration partly depends on the availability and quality of plant residues. *Tithonia diversifolia* has high biomass and nutrient contents with 3.5% nitrogen, 0.37% phosphorus and 4.1% potassium [16] [17], but contains a few low recalcitrant compounds with 6.5% lignin and 1.6% polyphenol [18]. *Tithonia* demonstrates strong potential for soil rejuvenation [19] [20], and plant health management due to the presence of sesquiterpene lactones (tagitinins-terpene) and other antimicrobial substances that prevent pests and diseases [13]. *Mucuna* spp. has high N-fixing ability and abundant biomass for use in soil rejuvenation [21], and contains up to 3% nitrogen, 0.2% phosphorus and 1.4% potassium [22]-[24]. *Mucuna* exhibits antimicrobial and fauna properties, influences abundance and diversity of soil bacteria and fungi, as well as suppresses nematode populations [25]-[27].

Despite the agronomic importance of different ISFM strategies, their adoption by smallholder farmers has been relatively slow due to a combination of factors, which include poor understanding of the economic benefits, high labour demand and poor technology promotion strategies. Furthermore, most ISFM studies have mainly focused on the direct impact of ISFM on soil restoration parameters rather than the crop productivity and potential economic benefits for farmers. Although many studies have been conducted on the importance of mineral fertilizer and organic amendments as well as on their combinations in various ISFM strategies, few studies have been devoted to the potential benefits of combining different plant biomass materials in ISFM. To the best of our knowledge, there is no specific investigation on the potential benefits of combining *Mucuna* and *Tithonia* biomass materials as basal mulch for integrated soil fertility management in horticultural systems. Hence, this participatory ISFM field trial was intended to adapt and evaluate the potential of combining two plant biomass materials (*Mucuna* + *Tithonia)* as basal mulch to improve soil fertility and plant nutrition, so as to improve tomato yield and farm-scale income for smallholder farmers in Cameroon. Therefore, it is hypothesized that the interaction of organic mulches of *Mucuna* + *Tithonia* will improve tomato yields and farm-scale income as compared to sole *Mucuna* or *Tithonia* biomass applications and mineral fertilizer amendments or the control without any input.

2. Materials and Methods

2.1. Experimental Site and Setup

This study was conducted on a smallholder farm in Lysoka-Buea, located at the foot of mount Cameroon, southwestern Cameroon. The area is situated between latitudes 4˚3'N and 4˚12'N of the equator and longitudes 9˚12'E and 9˚20'E. The soils are mostly derived from volcanic rocks and generally fertile but have poor moisture retaining capacity [28]. The climate is characterized by a mono-modal rainfall and less pronounced dry season, with 85% - 90% relative humidity. Heavy rainfall events are between June and October while the dry season starts from November to May. The mean annual rainfall ranges from 2085 mm at Ekona that is on the leeward side of the mountain to 9086 mm at Debundscha that is on the windward side of the mountain [29]. Lysoka is located between Ekona and Debundscha and had 2875 mm annual rainfall between mid March and mid November [29]. The mean monthly temperature vary from 19˚C to 30˚C, while soil temperature at 10 cm depths decreases from 25˚C to 15˚C with increasing elevation from 200 m to 2200 m above sea level [30] [31].

The field site had been under intensive commercial banana production by the Cameroon Development Corporation (CDC) until 2009. The site was further used for smallholder intercropping system to cultivate subsistence crops like maize (*Zea mays*), (*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 × 4 m) with a 1m buffer zone between plots. All the experimental plots were tilled manually using hoes and a cover crop (*Mucuna cochinchinensis*) was planted in March 2014, at 30 × 30 cm spacing and allowed to fallow for one year in order to establish a homogeneous soil. The *Mucuna* was harvested at maturity in March 2015, and *Mucuna* seeds and shells were separated from the biomass (leaves and stems). The biomass and seeds were sun-dried separately and preserved at room temperature for eventual use as basal mulch and propagation materials, respectively.

2.2. Tomato (*Lycopersicon esculentum* L.) Plants

Hybrid tomato (*Lycopersicon esculentum* L.) seeds (F1 Cobra 26; TECHNISEM® France) were purchased from a local agro-shop in Buea Cameroon. The F1 Cobra 26 is determinate with very good vigour, and combines tolerance/resistance to Tomato Yellow Leaf Curled Virus (YLCV) and Bacterial Wilt (*Ralstonia solanacearum*), which enable very good productivity, and viability to the Sahelian and tropical areas. It also has very good maturity with the first harvest from 65 days after planting, and produces square fruits of medium sizes (80 - 90 g) with uniform coloration. In addition, the fruits have good firmness that allows for good postharvest conservation.

The F1 Cobra 26 seeds were pre-germinated on a nursery bed of 2.5 × 1 m close to the experimental plots, which was prepared by clearing the site with a cutlass and the soil tilled manually using hoes. The tomato seeds were sown on the 26th of March 2015 on the nursery bed at an inter-row spacing of 15 × 15 cm. Vigorous tomato seedlings were transplanted from the nursery bed to the experimental plots on the 21st April 2015. The tomato seedlings were planted at a distance of 1 × 0.5 m on the experimental plots of 20 m^2 (5 × 4 m), with one plant per stand, giving a total of 35 stands per plot. In order to facilitate acclimatisation of tomato plants after transplanting, moisture was immediately provided for each plant via irrigation with tap water, while subsequent moisture was provided by rainfall. Each tomato plant received three litres of water, applied manually by pouring onto the plant-soil interface using watering cans. All 750 plants on the experimental site were staked manually with 1 m wooden sticks and the plants attached firmly to the stakes on the 15th of May 2015 using ropes.

2.3. Soil Fertility Amendments

The field trial was established as a randomized block design with four replicates per treatment. There were five treatment variables comprising a control with no input, mineral fertilizer, and two organic biomass mulches of *Mucuna cochinchinensis* and *Tithonia diversifolia* (Mexican sunflower), as well as their combination (*Mucuna* + *Tithonia*, at 1:1). Organic mulch materials were applied as single basal dose at the rate of 10 kg DW per plot (20 m^2) that is equivalent to 5 t ha^{-1} [32]. The organic mulches were evenly spread on the respective plots immediately after the tomato seedlings were transplanted, mulched and earthed-up three weeks later. The *Mucuna* biomass mulch was harvested from the same field site following one year of *Mucuna* cover crop fallow, while *Tithonia* biomass mulch was harvested from nearby roadsides and abandoned lands, dried in the sun for one week and stored at room temperature prior to field application. Labour for procuring *Mucuna* and *Tithonia* biomasses was provided by farmers who represented family labour according to common smallholder practice. Mineral fertilizer was applied by ring method at 5 cm from plants as two split doses of 90 kg ha^{-1} for each application. The first dose of granular NPK 20:10:10 (ADER® Cameroon) was applied on 14/05/2015 and immediately earthed-up with soil. The second dose of granular NPK 12:14:19 (ADER® Cameroon) was applied on the appropriate plots on 04/07/2015. Overall, a single dose application of 90 kg ha^{-1} fertilizer is approximately 87 kg ha^{-1} reported for developed nations [3] [4]. Considering the cost of 1 US Dollar or 500 FCFA per kg fertilizer, the total cost of mineral fertilizer was applied per hectare is 180 US Dollar or 90,000 FCFA.

2.4. Field Management

In order to facilitate technology appraisal and adoption, a participatory management approach was employed involving the local beneficiary smallholder farmers at all stages of production from field preparation and planting, to harvesting and marketing of produce. Apart from the initial irrigation performed immediately after transplanting of seedlings to the experimental plots, plant growth and performance depended entirely on rain-fed system based on the local rainfall regime. Meanwhile, management practices for weeds, pest and diseases were the same for all treatment plots. Before transplanting the tomato seedlings, the entire field was thoroughly weeded manually using cutlasses and hoes on 16/04/2015. After transplanting of the tomato seedlings, the field was monitored regularly for the emergence of weeds and when necessary, weeding was performed manually using hoes on 14/05/2015, 10/06/2015 and 02/07/2015. In order to maintain plant health and crop damage by pests and diseases within acceptable economic levels, frequent scouting was done for all plots to monitor the emergence of insect pests and diseases. When necessary, all plots were sprayed with appropriate doses of fungicide (Mancozan super; SCPA SIVEX International® France) or insecticides (Garmaline 80, AGROMAF® Cameroon; Cigogne 360, SCPA SIVEX International® France; and Acarius, SAVANA-Horizon Phyto Plus® Cameroon).

2.5. Harvest and Analyses

Since the main focus of this particular investigation was on the tomato yield and potential income gains for the resource-poor smallholder farmers, data on the soil dynamics were not considered in this study. A total of nine tomato harvests were performed within thirty-two days, starting on the 20th of June 2015 and ending on the 27th of July 2015. The tomato fruits were harvested twice a week from each treatment plot, counted and weighed separately using a top loading balance. The harvested tomato fruits were sold in the local markets and the market value was used to determine the farm-scale income generated by each treatment. The farm-scale income was calculated as the total income generated after computing the difference between the total tomato sales and the cost of inputs for the respective plots (*i.e. farm-scale income = total tomato sales – total cost of inputs*). In order to evaluate the direct impact of ISFM treatments, we determined the additional tomato yields and farm-scale income derived from each ISFM treatment by calculating the difference between each ISFM treatment and the control (*i.e. additional yield or income = ISFM treatment – control*). All treatment means were computed and the data sets were subjected to statistical analysis using STATISTICA 9.1 for Windows [33]. The effects of ISFM treatments ($n = 5$) on tomato performance (yield—total fresh fruit weight, number of fruits and the thousand fruit weight) and farm-scale income were assessed by analysis of variance (ANOVA), and significant means were compared by a post-hoc Tukey's HSD test ($P < 0.05$). Additionally, a nonparametric Spearman Rank Order Correlation ($P < 0.05$) was performed to measure the degree of association between the different treatments ($n = 5$) and tomato performance or farm-scale income.

3. Results

The impact of ISFM techniques was mainly evaluated from the perspective of potential benefits for smallholder farmers (*i.e.* crop performance and economic gains) so as to provide greater insight that may facilitate ISFM technology adoption by resource-poor farmers in SSA, since technology adoption is based on knowledge and proven efficacy as well as potential economic gains.

3.1. Tomato Performance

Tomato performance was assessed as yield (fresh fruit weight) and the thousand fruit weight for each treatment. The average tomato yield measured as total fresh fruit weight ranged from 9.7 to 13.2 t ha^{-1} across the different treatments (**Table 1**). Tomato yield was significantly higher with the organic mulch amendments ($P < 0.001$), which is most pronounced for the interaction of *Mucuna* + *Tithonia* biomass and the sole *Tithonia* biomass application, followed by the sole *Mucuna* biomass and mineral fertilizer treatments, as compared to the control (Tukey's HSD, $P < 0.05$; **Table 1**). In comparison to the control, an additional 3.5 and 3.4 t ha^{-1} tomato yield was recorded for the interaction of *Mucuna* + *Tithonia* biomass and the sole *Tithonia* treatments, respectively. This additional increase is more than twice the additional amount recorded for the sole *Mucuna* and mineral fertilizer treatments with 1.8 and 1.5 t ha^{-1} (**Figure 1**). Furthermore, a positive Spearman Rank Correlation was recorded between the different ISFM treatments and tomato yields ($r = 0.76$, $P < 0.05$). Meanwhile, there was no significant difference or correlation between the different ISFM treatments and the thousand fruit weight.

3.2. Impact of ISFM on Farm-Scale Income

The potential for better crop performance and greater economic gains largely drive the interest of smallholder farmers in adopting new technologies against traditional practices. The total farm-scale income ranges between 7223 and 8520 US Dollar (3,128,663 and 4,260,136 FCFA) across the different treatments. The total income

Table 1. The impact of different integrated soil fertility management treatments on tomato performance—yield and thousand fruit weight (mean ± STD); Data within column with different letters are significantly different according to Tukey's HSD, $P < 0.05$.

	Tomato performance	
Treatments	Yield [t ha^{-1}]	1000 Fruit weight
Control	9.7 ± 0.3 c	68.6 ± 16.6 a
Mineral fertilizer	11.2 ± 0.5 b	68.3 ± 16.6 a
Mucuna	11.5 ± 0.4 b	76.1 ± 16.4 a
Tithonia	13.1 ± 1.2 a	70.4 ± 10.1 a
Mucuna + *Tithonia*	13.2 ± 0.2 a	68.2 ± 10.0 a

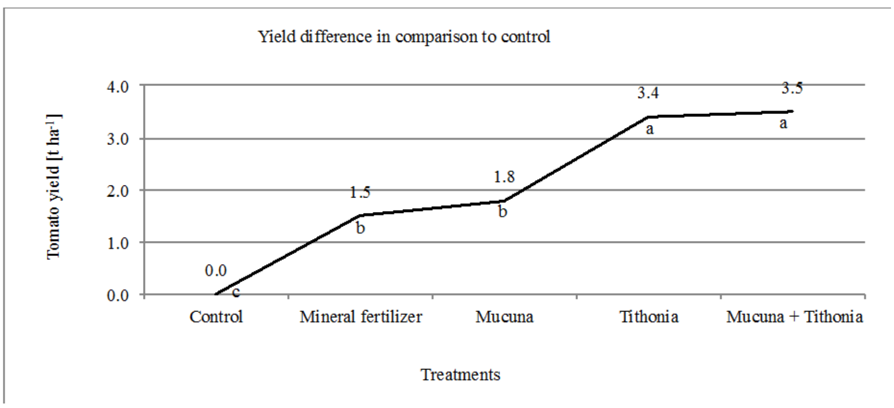

Figure 1. Additional tomato yield derived from the different integrated soil fertility management treatments in relation to the control; Data with different letters are significantly different according to Tukey's HSD, $P < 0.05$.

was significantly higher for the organic mulches ($P < 0.001$), and most pronounced for the interaction of *Mucuna* + *Tithonia* biomass and the sole *Tithonia* treatments, followed by the sole *Mucuna* biomass and mineral fertilizer treatments as compared to the control (Tukey's HSD, $P < 0.05$; **Table 2**). Correspondingly, the interaction of *Mucuna* + *Tithonia* and sole *Tithonia* biomass generated the highest farm-scale income, followed by the sole *Mucuna* biomass and mineral fertilizer treatments, in comparison to the control ($P < 0.001$; **Figure 2**). Furthermore, a significant positive Spearman Rank Correlation was recorded between the tomato yield and farm-scale income ($r = 0.99$, $P < 0.05$) and between the different treatments and farm-scale income ($r = 0.76$, $P < 0.05$).

4. Discussion

According to The Economist [34], feeding nine billion people on earth by 2050 will require gains from narrowing the gap between the worst and best agricultural producers by taking advantage of new technologies. This view is largely supported by technological advancements in agriculture and highlights the need for sustainable integrated soil fertility management strategies. This is particularly important for smallholder farming systems that produce the majority of food that is consume in the low and middle-income countries. Correspondingly, the results of this study demonstrate the potential for ISFM to significantly narrow the gap between potential and actual tomato yields and income for smallholder farmers in SSA.

4.1. Impact of ISFM on Tomato Performance

Crop yield is determined by a combination of environmental factors and farm management practices that in turn

Table 2. Impact of integrated soil fertility management treatments on farm-scale income of smallholder farmers (expressed both in US Dollar and FCFA—local currency of Cameroon); Data within the same column with different letters are significantly different according to Tukey's HSD, $P < 0.05$.

	Farm-scale income	
Treatments	FCFA	US Dollar
Control	3128663 c	6257 c
Mineral fertilizer	3611854 b	7224 b
Mucuna	3688359 b	7377 b
Tithonia	4227923 a	8456 a
Mucuna + *Tithonia*	4260136 a	8520 a

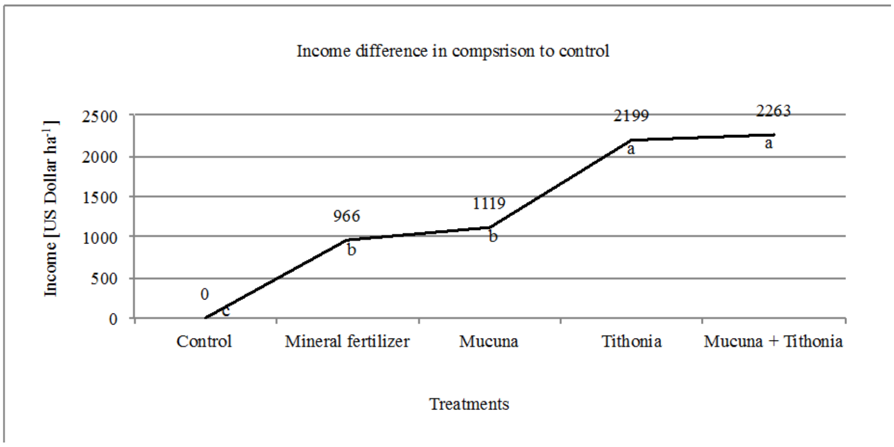

Figure 2. Additional income (US Dollars) derived from integrated soil fertility management treatments in relation to the control; Data with different letters are significantly different according to Tukey's HSD, $P < 0.05$.

influence soil fertility and plant nutrition. Despite applying 180 kg ha^{-1} mineral fertilizer that is more than twice the 87 kg ha^{-1} applied in developed nations [3] [4], organic biomass was better than mineral fertilizer that was only better than the control. The increased tomato yield recorded for *Mucuna* and *Tithonia* treatments is consistent with the results reported in other studies that attributed greater crop yields to improved soil nutrients from organic matter and adequate soil moisture, bulk density and temperature [17] [32]. Hence, the increased tomato yields with organic amendments can be attributed to increased soil nutrient availability and improved plant nutrient uptake resulting from better soil physical, chemical and biological properties [35]. Mulching with plant materials increases yields by stimulating decomposition and mineralisation in the rhizosphere, which improves soil nutrient availability, organic matter content, structure, moisture and temperature [36] [37]. In addition, differences in the quality of plant materials, nutrient content, texture, rate of decomposition, growth and vegetative matter turn over, availability and cost are important for effective ISFM [38] [39].

Besides the influence of *Mucuna* and *Tithonia* on soil properties, they possibly enhanced both root and shoot physiological and morphological developments, which in turn increased productivity. This is consistent with greater root production and lifespan induced by compost and mulching as compared to mineral fertilizer [40]. In addition, mineral fertilizer induces high nitrate (NO_3^-) pulses, which could easily be leached as a result of its high mobility in the soil, coupled with the heavy rainfall condition of the study area. However, organic inputs would have released nitrogen more slowly, which enabled regular supply of nitrogen ions (*i.e.* NH_4^+ and NO_3^-) during a longer period of time to the root system that enhanced branching of axial roots and elongation of lateral roots, leading greater nutrient acquisition [41]. Furthermore, decomposing *Mucuna* and *Tithonia* biomass likely increased humic substances in the rhizosphere that modified root morphology and induced proliferation of lateral roots and root hairs, as well as increased the rate of differentiation for root cells [42] [43]. Hence, greater tomato yields recorded for *Mucuna* and *Tithonia* amendments could be due to the interaction of improved soil properties (*i.e.* physical, chemical and biological) and plant development (*i.e.* root physiology and morphology), which resulted in improved plant nutrition. The lack of significant difference or correlation between the ISFM treatments and tomato fresh weight could be attributed to the fact that some of the potential differences were compensated by water absorption from the soil that supplies all the water that the plant needs. It is suggested that comparison should be done on dry weight basis, which was not applicable in this case as the consumers preferably purchased fresh tomato fruits still having the original water content.

Although ISFM considers combining appropriate micro doses of mineral fertilizer either solely or in combination with locally available organic materials as an important strategy for soil fertility improvement, the use of different organic inputs either solely or combined would be a more sustainable ISFM alternative. Accordingly, the best tomato yield was recorded with the combined biomass of *Mucuna* + *Tithonia* and the sole *Tithonia* biomass application as compared to sole *Mucuna*, mineral fertilizer or the control. This is consistent with [44] who demonstrated advantages of *Tithonia* + Poultry manure compost (4:1) and sole *Tithonia* for improving soil properties and tomato performance (*i.e.* fruit yield and diameter, stem circumference, plant height, leaf area, number of branches and taproot length). The advantage of combining organic inputs is because organic materials differ in their rates of biodegradation. Some organic materials have faster decomposition and mineralization rates that are comparable with the fast rate of nutrient release by mineral fertilizers. Such organic inputs can be associated with materials that have slow rate of nutrient release to produce an effective amendment that is comparable or better than mineral fertilizers. Apparently, *Mucuna* and *Tithonia* biomasses provided fast nutrient release that enabled better tomato performance than mineral fertilizer throughout the plants' life cycle, leading to greater production. The higher tomato yields under combined organic biomass of *Mucuna* + *Tithonia* amendment that is comparable to the sole *Tithonia* biomass application supports our hypothesis of better performance with sustainable ISFM technologies comprising mainly a combination of different organic plant materials that advocates the use of mainly organic biomass in ISFM. Therefore, such fast nutrient release organic biomass materials can be integrated with other organic materials that release nutrients slowly, so as to enable regular and enhanced nutrient supply during the entire crop cycle, leading to improved plant nutrition and greater crop yield.

4.2. Impact of ISFM on Farm-Scale Income

The adoption of integrated soil fertility management technologies largely depends on the confidence of smallholder farmers towards these techniques, which is mainly determined by the crop production and income gained. However, inadequate knowledge on the best-bet ISFM options for specific crops and lack of confidence in the economic returns induces laxity of adopting such technologies by smallholder farmers. Thus, smallholder farmers in SSA have not experienced a significant decrease in yield gap between the actual and expected production per unit area of cultivable land. This is partly due to inadequate supply of the required inputs and high cost, poor technology adoption and lack of knowledge on potential benefits [45] [46]. Meanwhile, knowledge on the economic benefits of ISFM and effective technology dissemination is important for successful adoption. This study demonstrated the potential benefits of combining different organic biomass materials for improving the net productivity and financial gain for smallholder farmers. This strongly supports our hypothesis on better farm-scale gains with ISFM involving a combination of organic plant materials of *Mucuna* + *Tithonia* as compared to sole *Mucuna* biomass or mineral fertilizer applications and the control. Considering that *Mucuna* and *Tithonia* biomass used for this study were obtained via smallholder labour without extra financial cost, any additional yield and economic gains is direct benefit for smallholder farmers who mainly depend on family labour. Interestingly, compared to the current monthly minimum wage of about US Dollar 73 (36,270 FCFA) in Cameroon, the additional income derived from ISFM strategies in this study was more than 100%, ranging from US Dollar 153 to 1297 (76,505 to 648,281 FCFA) for organic biomass as compared to mineral fertilizer. Meanwhile, the opportunity cost for resource-poor farmers with little access to money is often 100% of the actual value due to other high priority uses of available funds and other investment opportunities [47]. Therefore, ISFM options with no extra financial costs like the *Mucuna* and *Tithonia* biomass materials used for this study are the best-bet soil fertility amendment options for the resource-poor smallholder farmers in SSA.

4.3. Mitigating Constraints of ISFM in Smallholder Systems

A plethora of views, paradigms and concepts on sustainable agriculture and natural resource management have arisen in recent decades, which are intended to boost agricultural productivity and provide sustainable solutions to one of the earth's most pressing challenges of preserving the natural resource base. These include integrated soil fertility management, conservation agriculture, integrated nutrient management, organic agriculture, and integrated natural resource management [48] [49]. However, all the diverse concepts and novel titles praise the potential merits of combining different techniques and promoting a combination of different agricultural technologies that are not mutually exclusive or completely overlapping [49] [50]. A major constraint for the use of organic materials in ISFM such as *Mucuna* and *Tithonia* biomass is the huge amount required and the labour cost required for collection, transportation and application [51] [52]. However, we obtained better economic returns for sole *Tithonia* or *Mucuna* + *Tithonia* compared to the control or fertilizer treatments, while *Mucuna* was similar to fertilizer treatment. Hence, *Mucuna* and *Tithonia* biomass are sustainable ISFM alternatives in smallholder farming systems because of their economic returns, coupled with their abundance and adaptability to various environments, rapid growth rate and high vegetative matter turnover [16] [53]. In addition, smallholder farmers can easily cultivate or harvest *Mucuna* and *Tithonia* biomass from abandoned sites or fallow land for use in their fields as soil amendments without any additional cost. It is also possible to plant *Tithonia* along the borders of farmers' fields to serve a dual purpose of land demarcation and for use in soil fertility management. By combining *Mucuna* and *Tithonia* biomasses, farmers can reduce the difficulties of obtaining a particular material by using reduced amounts in combination with other biomass materials that are relatively abundant. There by achieving comparable soil improvement that leads to greater crop yield and farm-scale income.

5. Conclusion

Besides the proven efficacy for *Mucuna* and *Tithonia* biomass for independently improving soil physical, chemical and biological properties, the *Mucuna* + *Tithonia* biomass combination was comparable to sole *Tithonia*, which was better than sole *Mucuna* biomass that displayed a comparable performance with mineral fertilizer in terms of tomato yield and farm-scale gains. This makes *Mucuna* + *Tithonia* biomass a viable and important ISFM alternative for sustainable soil fertility management that is commensurate with the existing plethora of views, paradigms and concepts on sustainable agriculture and natural resource management. Hence, smallholder farmers can effectively adopt *Mucuna* and *Tithonia* biomass applied in combination or solely, to improve net productivity and farm-scale income without any negative externalities. However, this requires more efforts to adapt different techniques to the specific needs of smallholder farmers, with effective dissemination strategies that facilitate technology adoption. Although *Tithonia* is widely distributed on abandoned lands and roadsides in Cameroon, it can be planted on farm boundaries to enhance availability and reduce the associated labour and transport costs. Meanwhile, *Mucuna* biomass can be harvested from fallow sites where they are cultivated as green manure cover crops. Overall, this alternative soil fertility management technique has multiple advantages on soils including decontamination, mineralization, conservation, increased soil biota, erosion control and water conservation within the broader context of sustainable agriculture, and the specific concept of integrated soil fertility management in smallholder farming systems. Nonetheless, more *in situ* based studies are necessary to provide greater insights on the specific impacts of combining *Mucuna* and *Tithonia* biomass materials on the dynamics of soil biota (*i.e.* microbial abundance and diversity, food web ecology or, mycorrhiza dynamics, etc.). Thereby providing a holistic view of soil microorganism and integrated soil fertility management that improves soil fertility and plant nutrition, leading to greater crop productivity and income for farmers.

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