Open Access Library Journal
2023, Volume 10, e10337
ISSN Online: 2333-9721
ISSN Print: 2333-9705

No-Till Systems: Why Not for Bush Beans (*Phaseolus vulgaris* cv. HM 21-7) Intercropped with the East African Highland Banana?

Tony M. Muliele[1,2]

[1]Institut National pour l'Etude et la Recherche Agronomiques, Kinshasa, The Democratic Republic of the Congo
[2]Faculté des Sciences Agronomiques, Département de Phytotechnie Université Pédagogique Nationale (UPN), Kinshasa, The Democratic Republic of the Congo
Email: tonymuliele@yahoo.fr

How to cite this paper: Muliele, T.M. (2023) No-Till Systems: Why Not for Bush Beans (*Phaseolus vulgaris* cv. HM 21-7) Intercropped with the East African Highland Banana? *Open Access Library Journal*, **10**: e10337.
https://doi.org/10.4236/oalib.1110337

Received: June 4, 2023
Accepted: July 18, 2023
Published: July 21, 2023

Abstract

Manual tillage is usually practiced in small-scale banana-beans intercropping systems in the Eastern Democratic Republic of Congo (DR Congo). This study tested the hypothesis that manual tillage in banana-beans intercropping systems may increase bean yield. The study was carried out at INERA Mulungu Research Station in the Eastern DR Congo, from February 2014 to May 2017. Four treatments with repetitions were applied under a completed randomized blocs design. Tillage with hand hoe + beans + mulch exportation (T0 or common local system); no Tillage + beans + self-mulch (T1), Tillage with hand hoe + beans + self-mulch (T2), and no Tillage + beans + mulch exportation (T3). Bean yield and banana leaf area index (LAI) were assessed during three bean growing seasons. The relationship between bean yield and banana LAI was computed using a boundary line analysis approach. Bean yield ranged between 187 and 394 $kg \cdot ha^{-1}$ with higher values during the first two seasons. Treatments did not significantly affect bean yield, but the overall means of bean yield decreased in the order of T0 (324.8 $kg \cdot ha^{-1}$) > T1 (294.4 $kg \cdot ha^{-1}$) > T2 (291.2 $kg \cdot ha^{-1}$) > T3 (273.2 $kg \cdot ha^{-1}$). Banana LAI ranged from 0.96 to 1.56, and treatments were not significantly different. The relationship between banana LAI, and bean yield shows a cut-off at LAI equals to 1.18, above it bean yield decreases sharply. The specific effects of tillage (T0 versus T2) and soil cover (T1 versus T3) show only a slight increase in bean yield, 34 $kg \cdot ha^{-1}$ and 21 $kg \cdot ha^{-1}$ respectively. Manual tillage did not significantly improve bean yield, farmers in the study area are encouraged to use no-till with self-mulch in banana-beans intercropping systems. However, to improve beans' performance, banana LAI should be below 1.18.

Subject Areas

Agriculture Science

Keywords

Manual Tillage, Beans, Yield, Intercropping Systems, Highland Banana

1. Introduction

Intercropping systems are commonly practiced by small-scale farmers in Eastern Africa for several decades [1] [2] [3]. Numerous studies reported the benefits of intercropping systems. There are, among others, crop diversification and food security, maximizing land use and intensity of crop production [4] [5] [6].

In South Kivu in the Eastern DR Congo especially, banana is generally intercropped with beans [2] [6]. In fact, bananas and beans are important foods and sources of income for farmers [7]. Beans support better lower sunlight intensity than other crops. Except for K, bean is lesser competitive to banana for nutrients [8].

Based on crop systems, Muliele *et al.* [9] reported that manual tillage with a hand hoe or fork and export of crop residues is the common local banana-beans intercropping management system in South Kivu. Twice a year (February and September), the soil between bananas is tilled in order to prepare beans seedbed. The authors demonstrated that manual tillage 1) affected negatively banana roots in the 10 cm upper soil and may reduce plant growth in a young banana plantation; 2) improved soil physical properties (penetration resistance, and bulk density) during the first months after manual tillage. They also reported that no-till with mulch had no negative effect on banana root and growth, and bean yield.

In a mono-cropping system, Muliele [10] evaluated the short effect of no-till with mulch on the yield of beans, in the Eastern DR Congo. Results show that the conversion of tilled plots without mulch to no-till with mulched plots decreased significantly bean yield in the first season. During the second beans season, however, beans in no-till plots with Tripsacum mulch yielded relatively greater than tilled plots without mulch. [11] [12] [13] reported that no-till systems with mulch (conservation agriculture) are more efficient in the long term.

Besides, the above-mentioned studies [2] [9] compared no-till plots with mulch and tilled plots without mulch. Even though these studies compared the banana-beans management systems as applied by farmers in the study area, the results of such studies are ambiguous since from the scientific viewpoint, they could not discriminate tillage and mulching effects on banana and bean growth and yield. All things considered, in order to select appropriate bananas-beans intercropping systems in the study area, a specific effect of tillage and mulch on bananas and beans still be needed. Therefore, this study aimed at assessing the specific effect of tillage and mulching on bean yield in bananas-beans intercropping systems. Banana growth (Leaf area index, LAI) and bean yield from tilled plots without mulch were compared with those from tilled plots with mulch and no-till plots or without mulch. Based on higher land pressure related to high population density (300 - 350 inhabitants per km^2 [3]) in the study area, this study may contribute to developing sustainable banana systems in order to increase crop productivity and land use efficiency in smallholder banana farms.

2. Material and Methods

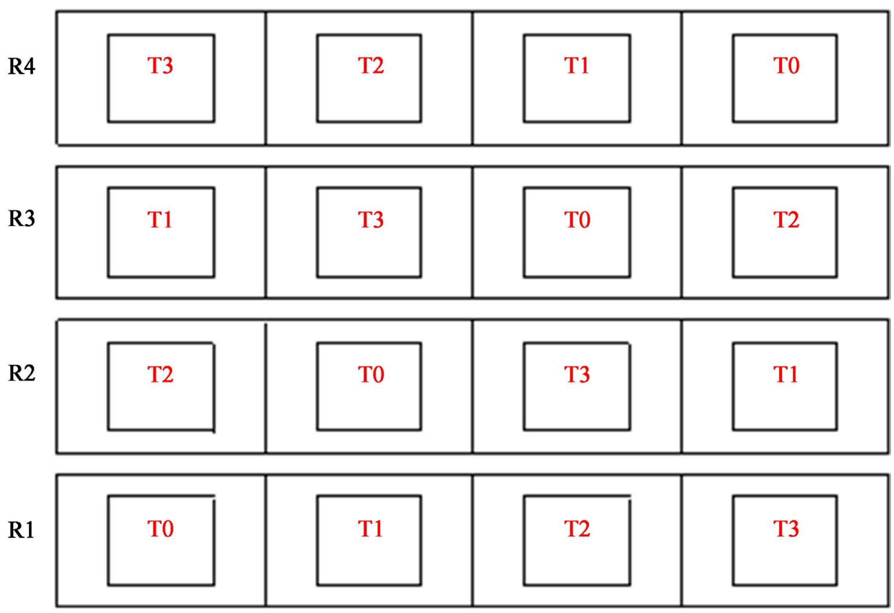
2.1. Study Site

This study was carried out at the INERA Mulungu Research station (2.335˚S, 28.788˚E, 1699 m above sea level), located in the Eastern Democratic Republic of Congo (DR Congo). The climate and soil properties of the study site were reported with details by [9] [2]. Concisely, Mulungu climate is Aw3 according to the Köppen [14], this a tropical climate with two contrasting seasons: a rainy season, and a dry season of three months. Precipitation average varies between 1500 - 1800 mm and the growing season extends to over 325 days a year [9]. Soils are fertile (e.g. pH = 6.3; topsoil (0 - 20 cm) with high organic carbon (5.2%) and bases content, and lower bulk density (0.86 $g\cdot cm^{-3}$) and soil penetration resistance (<10 $kg\cdot cm^{-2}$), and classified as Nitisols developed on volcanic ashes [2].

2.2. Experience Layout

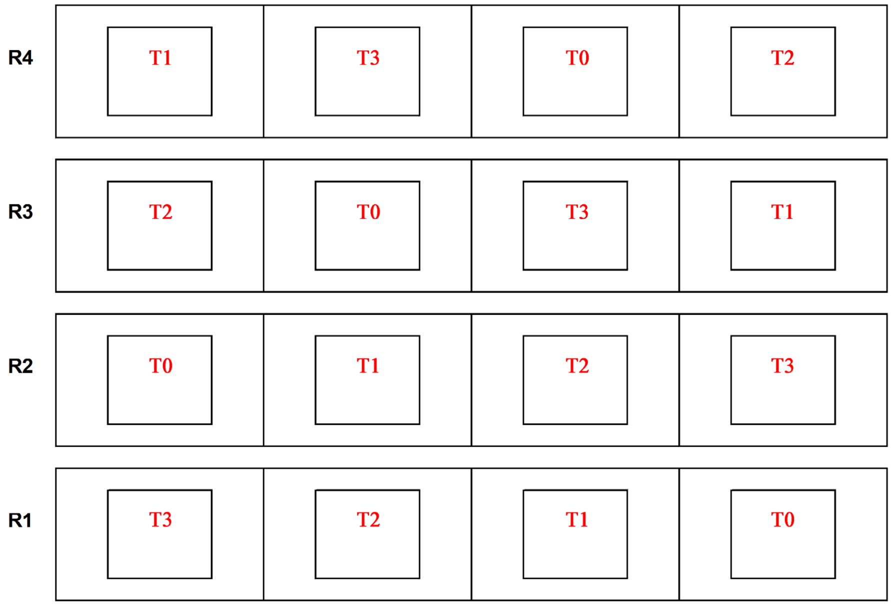
The experiment was installed in April 2008 in order to assess tillage effects on banana-beans intercropping systems. A randomized complete block design with four treatments and four replications was applied: Conventional manual tillage (CMT) with export of crop residues (=T0), no-till (NT) with self-mulch (T1), NT with self-mulch + Hyparrhenia diplandra grass mulch (T2), and NT with self-mulch + Tripsacum laxum grass mulch (T3) (**Figure 1**). Sword suckers of the local banana cultivar "Ndundu" (AAA-EA beer banana) were planted at a 2 m x 2 m spacing (2500 $plants\cdot ha^{-1}$). Self-mulching consisted in leaving crop residues (banana and beans after harvest) in the field. External mulches (T2 and T3) were applied at the rate of 25 $t\cdot ha^{-1}$ dry matter (DM) in the first year, and 12.5 t $DM\cdot ha^{-1}$ in the second year. A single application of banana residues mulch (22 t $DM\cdot ha^{-1}$ based on banana crop residues in the study area) was applied in T1 plots at planting only. Since external mulches (Hyparhenia grass in T2 and Tripsacum grass in T3) did not affect significantly banana yield in the first and second cycles, no additional external mulch was applied thereafter. The T0 plots were tilled at the onset of each bean growing season (September and February) to prepare the seedbed for beans. Bush beans (cv. "Ngwaku-Ngwaku") were sown in all treatments at a density of 250,000 $plants\cdot ha^{-1}$. No mineral fertilizers, organic manure or pesticides were applied. Cultural practices consisted of de-suckering, male bud removal and weeding. Banana bunch weight was recorded through four consecutive cycles, and banana yield ($t\cdot ha^{-1}$) was then calculated for each cycle. Bean yield was assessed during height growing seasons, but was not affected by treatments.

Based on the treatments above-mentioned and the experiment design (**Figure 1**), our trial has compared tilled plots without much (T0) and no-tilled with mulch (T1, T2 and T3). Even weather treatments in this study compared banana-beans systems as applied in the study area, such experimental layout (**Figure 1**) could not discriminate tillage and mulching effects on banana and beans yield. Then, mulch was removed from mulched plots (T1, T2, and T3) and all treatments (T0, T1, T2, and T3) were tilled with hand hoe during 4 beans growing (seasons 2013B, 2014A, 2014B, 2015A). Thereafter, the trial layout was modified and included tilled plots with mulch and non-tilled plots without mulch (**Figure 2**). Bush beans (cv. Bio-fortified HM21-7) was planted under banana during three seasons (2015B, 2016A, and 2016B), and bean yield was assessed at the harvest. At each bush bean harvest, banana leaf parameters (length and width) of the third young leaf and the number of functional banana leaves were measured. Leaf total area was computed using the model developed by Kumar et al. [15]. The banana leaf total area was divided by the plant spacing (2 m × 2 m) to find the banana leaf area index (LAI). Data statistical analysis was performed using the SPSS 20 software with one-way analysis of variance (ANOVA). The tillage system was considered as the independent variable whereas beans yield and banana LAI were dependent variables. Descriptive statistics were used to compute LAI means and standard deviation. The effect of bananas on bush bean yield was assessed throughout the relationship between bean yield and banana LAI using a boundary line analysis approach as described by [16]. The steps followed are 1) construction of the scattered plot diagram between bush bean yield



T0 = Tillage with hand hoe + beans + mulch exportation; T1 = No Tillage + beans + self-mulch; T2 = No Tillage + beans + self-mulch + *Hyparrhenia diplandra* grass mulch; T3 = No Tillage + beans + self-mulch + *Trypsacum laxum* grass mulch.

Figure 1. First experimental layout design.



T0 = Tillage with hand hoe + beans + mulch exportation; T1 = No tillage + beans + self-mulch; T2 = Tillage with hand hoe + beans + self-mulch; T3 = No tillage + beans + mulch exportation; R1: Replication 1; R2: Replication 2; R3: Replication 3; R4: Replication 4.

Figure 2. Second (modified) experimental layout design.

and banana LAI, 2) fitting the boundary-line curve with a quadratic polynomial equation ($y = ax^2 + bx + c$), 3) Then computing of predictor value that resulting in maximum mean bush bean yield, using the differential equation when the value of the derivative is zero ($2ax + b = 0$) [17].

3. Results

Bush beans yielded on average around 300 kg·ha^{-1} at the two first bean cropping seasons (2015B and 2016A, Figure 3(a), and Figure 3(b)), and 250 kg at the 2016B season (Figure 3(c)). Within a treatment, yield sometimes varied strongly between replicates. Whatever bean crop seasons, and the overall bean yield mean (Figure 3(d)), statistical analysis did not show a significant difference between treatments. However, bean yield increase slightly in T0 and T1 (347 kg·ha^{-1}) compared to T2 (330 kg·ha^{-1}) and T3 (303 kg·ha^{-1}) at the 2015B season. During the second bean cropping season (2016A), bean yield in T0 is higher by 38 to 92 kg·ha^{-1} compared to other treatments. The last bean cropping season (2016B) shows lower values in all the treatments, with 188 kg·ha^{-1} in T2 plots, and an increase of 8; 19 and 45 kg under T1, T3 and T0 plots respectively (Figure 3(c)).

Table 1 shows higher values of LAI at the season 2015A which tend generally to decrease across the crop seasons. On average LAI values ranged from 0.98 to 1.61, but no significant difference was observed between treatments whatever crop seasons. The scatter plot and the boundary line relating bean yield to LAI are presented in Figure 4. Seven data points were used to generate the boundary line and to represent the equation. This shows an increase in bean yield up to a

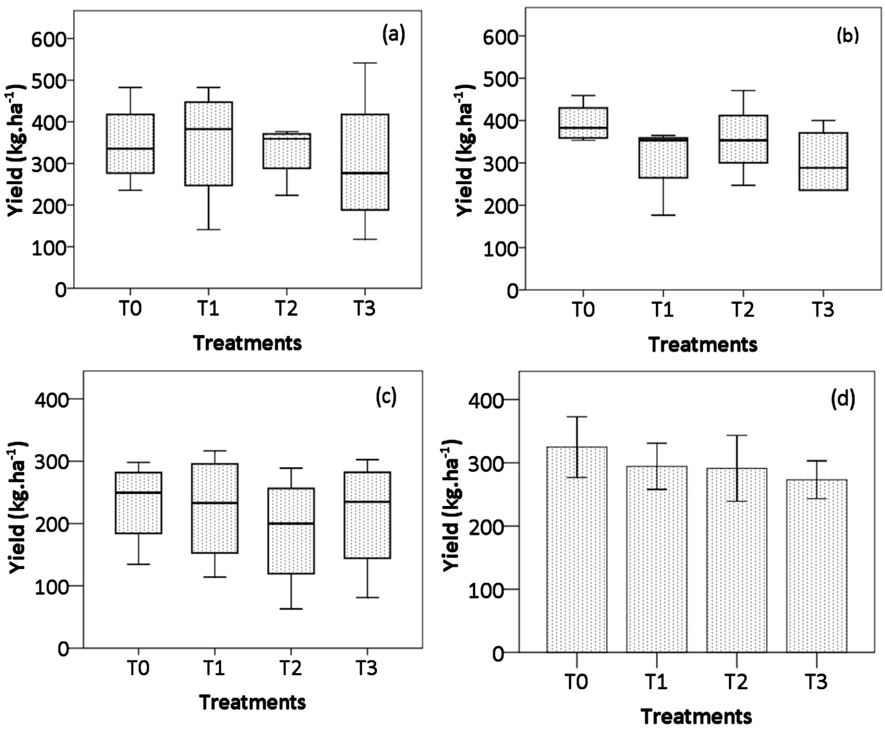


Figure 3. Bean yields as affected by tillage systems, (a) season 2015B, (b) season 2016A, (c) season 2016B, and (d) overall bean yield mean.

Table 1. Leaf area index (LAI) of 6th and 7th banana crop cycles according to treatments applied and bush bean crop seasons. Values are means ± standard deviation.

Treatments	Season 2015B	Season 2016A	Season 2016B
T0	1.56 ± 0.43	1.00 ± 0.25	0.98 ± 0.23
T1	1.26 ± 0.27	1.11 ± 0.53	1.08 ± 0.40
T2	1.61 ± 0.29	1.04 ± 0.23	0.99 ± 0.31
T3	1.60 ± 0.61	1.02 ± 0.40	1.14 ± 0.38

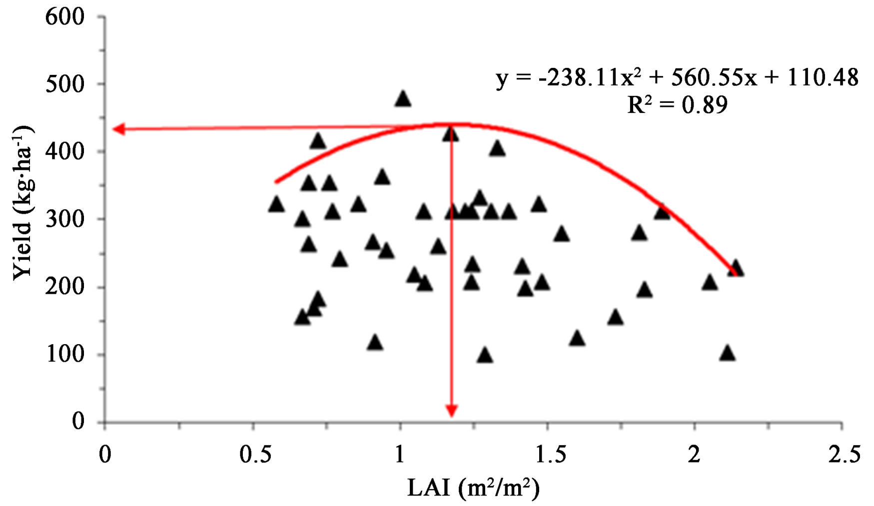


Figure 4. Boundary-line showing bean yield response to leaf area index (LAI).

LAI cut-off of 1.18 and thereafter bean yield decreased irrecoverably. Based on boundary line equation, the optimum bean yield associated with LAI cut-off in this study was 435 kg·ha^{-1}.

The specific effects of soil cover (T0 vs T2, **Table 2(a)**) and manual tillage (T1 vs T3, **Table 2(b)**) on bush bean yields are summarized in **Table 2**. In the short-term (3 cropping seasons), soil cover and manual tillage did not affect significantly the bean yield. In fact, differences in bean yields between tilled plots without mulch (T0) and tilled plots with mulch (T2), and no-till plots with mulch (T1) and no-till plots without much (T3) are only 33.62 and 21.25 additional kg, respectively.

4. Discussion

This study shows that bean yield across crop seasons varied from 189 to 437 kg·ha^{-1} (**Figure 3**). These yields seem to be lowers compared to those reported for beans sole culture on-station trial (1.2 - 1.5 t·ha^{-1}), but are similar to those obtained in banana-beans intercrops systems in the study area [6] [7]. Treatments did not significantly affect bean yield (**Figure 3**), indicating that a common local management system (Tillage with mulch export or T0) did not improve bean yields compared to no-till with (T1) and without mulch (T3). Similar results were reported by [10] for sole bush beans crops (cv. "Ngwaku Ngwaku"). Besides, tilled plots with mulch (T2) did not also affect positively bean yields. Even though tillage and crop residue retention (T2 treatment) are not among bananas-beans intercropping management systems in the study area, a full factorial experiment including this management system revealed the specific effects of tillage and mulching on bean yield. As for treatments, tillage (T0 vs T2) and soil cover (T1 vs T3) had no significant specific effect on bean yields. In fact,

Table 2. Manual tillage versus soil cover effect on the yield of bush bean intercropped with banana. (a) Tillage effect on bean yield; (b) Soil covers effect on bean yield.

(a)

Season	T0	T2	ΔT0 − T2
2015B	347.25	329.56	17.69
2016A	394.32	356.07	38.25
2016B	232.86	187.95	44.91
Overall mean (kg·ha^{-1})	**324.81**	**291.19**	**33.62**

(b)

Season	T1	T3	ΔT1 − T3
2015B	347.25	303.12	44.13
2016A	311.93	303.10	8.83
2016B	224.12	213.32	10.80
Overall mean (kg·ha^{-1})	**294.43**	**273.18**	**21.25**

bean yield increase only for 34 kg·ha^{-1} and 21 kg·ha^{-1} respectively (Table 2) between tilled and no-till plots, and between plots with and without mulch. However, retention crop residues may be more efficient on no-till plots than tilled plots. Several studies (e.g. [9] [10] [12]) demonstrated that conversion tilled plots to no-till plots had generally, in the short-term, no significant affect or negative on crop yields. In the other hands, difference between tilled and non-till plots with mulch tend to increase in the long-term [12].

Banana LAI was not affected by treatments (Table 1). Based on the first experiment layout design in the same experiment site (Figure 1), Bizimana [7] observed earlier that treatments had no significant effect on the banana total leaf area. This may be related to better soil properties (high nutrients, and organic contents, moderate pH, lower soil penetration resistance) [2] [7] of the experiment site that improves banana performance regardless of treatments applied.

The relationship between banana LAI and bean yields (Figure 4) shows a cut-off at LAI = 1.18. This value may be considered the upper LAI threshold value. Based on the first trial design layout (Figure 1), Bizimana [7] reported a sharply decrease in bean yields when the total leaf area exceed 4.5 m^2 (LAI = 1.13). For banana-legumes (beans, soybeans), [18] [19] show that legumes yields are negatively affected when the LAI value is greater than 1.10. In fact, when the LAI equals 1.10, fifty-five percent (55%) of the solar radiation is intercepted [18] [20]. This corresponds to a significant drop in the light resource and PAR (photosynthetic active radiation) [18] [19] that may negatively affect bean yield. Based on the findings of this study, farmers interested in bean yields in banana-beans intercropping systems should keep banana LAI < 1.1.

The negative effect of banana canopy shade on bean yield is well-known by farmers in the study area since banana leaf pruning is a common practice in bananas-beans intercropping systems. For example, [3] [19] and [20] assessed the effect of four-and seven-banana leaf retention compared to all-leaf retention on banana and legume yields. Results show that legume grain and biomass yields increased with banana leaf pruning levels. With respect to plots under four-banana leaf retention that negatively affected banana performance, retention of 7 leaves (moderate leaf pruning) did not in most cases significantly depress yields and resulted in a higher land use efficiency than the banana monocrop all-leaf treatment.

Studies conducted by [2] [9] reported a negative of manual tillage with crop residue exportation in banana-beans intercrops (common local management system) on banana rooting system. Immediately after manual tillage, more severe cord root fresh weight reductions occurred (94% and 74% in young and old banana plantations respectively) in the 10 cm upper topsoil. Banana root pruning in the topsoil could reduce below-ground competition between bananas and beans for water and nutrients, and improve beans' performance, but had a negative effect on banana growth, especially in young plantations (<4 years). Therefore, the tillage manual with exportation of crop residues is considered an unstainable management system since practiced twice a year (at the onset of beans cropping season), it results in soil fertility depletion and decreasing soil aggregate stability, and thus increasing soil loss by erosion. In the study area, erosion is one of the main soil constraints to plant production [2]. Manual tillage with crop residues combined with banana leaf pruning as practiced by some farmers in the study area is another unsustainable management system for banana-beans intercrops.

Based on the findings of this study, it is recommended therefore to farmers interested in bananas-beans intercrop systems in the study area to 1) avoid manual tillage and crops residues exportation, 2) adopt the no-till system, 3) and when needed, apply moderate banana leaf pruning (7 leaves retained in the study area [20]), or 4) decrease banana density in order to improve sunlight penetration to beans. A 2 m × 2 m banana plantation (2500 plants·ha^{-1}) applied for this study [2] is not suitable for improving beans' performance and yield.

5. Conclusion

This study assessed the effect of manual tillage on the yield of bush beans (cv. HM21) intercropped with the East-African highlands bananas. In the short-term, results show that tillage with the exportation of crop residues (Common local system) did not improve bean yield compared with no-till systems (No-till with crop residues). Similarly, the specific effect of tillage (tillage plots compared to no-tills plots) and mulching (plots with mulch compared to plots without mulch) did not significantly affect bean yield. However, the relationship between banana leaf and bean yield shows a cut-off at LAI = 1.18, the threshold that negatively affects bean yield. We conclude that farmers interested in banana-beans intercropping systems should avoid tillage and crops residues exportation, and adopt a no-till system and appropriate banana plant density in order to improve bush beans performance.

Acknowledgements

The author gratefully thanks the Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA) that with the Belgian Directorate General for Development Cooperation (DGDC) funds supported the trial establishment. The help of misters CIZUNGU NAMAGABE André and CIMINANI Jean-Marie is sincerely appreciated for data collection.

Conflicts of Interest

The author declares no conflicts of interest.

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