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Assessing the Effects of Integrated Soil Fertility Management on Biological Efficiency and Economic Advantages of Intercropped Maize (*Zea* Mays *L.*) and Soybean (*Glycine Max L.*) in DR Congo

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Authors' contributions

This work was carried out in collaboration between all authors. Author GMM designed the study, performed the statistical analysis, and wrote the first draft of the manuscript. Author BDK monitored the field trails and reviewed the manuscript. Author KKN reviewed the experimental design, completed the statistical analyses and the literature review and wrote the final manuscript. All authors read and approved the final manuscript.

Research Article

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ABSTRACT

Interactions among species play an important role in determining the structure and the dynamics of plant communities. The main objectives of the study were (i) to assess and compare different competition indices and their relationship with yield component under different inorganic and organic fertilizers regimes; and (ii), to identify nutrient management regimes options that lead to high yields and incomes in a maize-soybean intercropping system. Effects of integrated soil practices management on crop competition, yields components and economics advantage in maize-soybean intercropping system in a savannah region of the DR-Congo were investigated. Field trials were conducted at two sites in a randomized complete block design with six treatments replicated four times. Grain yield and yield components increased under integrated soil fertility management (ISFM) (inorganic or mineral and organic fertilization combined) than other treatments at

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the two sites of the study. Organic biomass application resulted in similar grain yield production than the inorganic (mineral) fertilizer application. The required land decreased when soil was fertilized compared to the control. Land equivalent coefficient (LEC) values ranged from 0.50 to 0.79. Soybean intercropped with maize resulted in an area-time equivalency ratio (ATER) higher than 1 for all the treatments confirming the intrinsic advantage of intercropping over sole crops. Among all the treatments, integrated nutrient management (ISFM) resulted in higher yields and monetary advantage index (MAI) values for maize/soybean mixture compared to other treatments. The highest MAI of 343891 was generated by the *Tithonia* (organic) – inorganic applications.

Keywords: Cropping system; land equivalent ratio; land equivalent coefficient; area-time equivalency ratio; monetary advantage index; plant competition; maize and soybean yields; DR-Congo.

1. INTRODUCTION

Cereal-legume intercropping plays an important role in food production worldwide. Crop intercropping is commonly practiced [1] because of various advantages such as greater yield stability, greater land-use efficiency, increased competitive ability toward weeds, improvement of soil fertility due to the addition of N by fixation, and some favorable exudates from legume species [1-5]. Lithourgidis et al., [6], demonstrated that yield production under intercropping is higher than in sole cropping systems. This is because resources such as water, light and nutrients can be utilized more efficiently than in the respective sole cropping systems [7]. Almost all reported intercropping combinations with a significant yield advantage involved non legume/legume combinations [8-9].

Maize and soybean are among the main staple foods for several communities in the DR-Congo. Maize based cropping systems are very popular in the tropics. In general, small farmers in the DR-Congo practice maize/legumes association (especially maize-soybean intercropping) without using any fertilizer [10,11,12,13]. In intercropping system, the cereal species are usually taller; they grow faster than the legume species. They also have extensive root system with large mass of fine roots (Lehmann et al., 1998), and they are competitive for soil inorganic N [14-15].

Interactions among species play an important role in determining the structure and the dynamics of plant communities in agriculture [16-17]. According to Ghosh et al. [9], imbalanced nutrient application coupled with low N and P content represent the major constraints that limit crop productivity in intercropping systems in many soils. The continuous use of inorganic fertilizers has been associated with an increased of soil acidity, nutrient imbalances and soil degradations [10]. This shortcoming of inorganic (mineral) fertilizer use has motivated agronomists to explore an ecological approach for soil amendments [10]. Application of organic manure alone to sustain cropping has been reported to be inadequate due to their relatively low nutrient contents and their inability to provide a sufficient amount of nutrients [18]. Integrated nutrient management approaches (Integrated Soil Fertility Management or ISFM), in which both organic manure and inorganic fertilizers are used, have been suggested as an efficient approach for crop production [18]. In ISFM nutrients from the organic manures are supplemented with inorganic nutrients that are readily available to plants [10].

Positive effects of the application of inorganic fertilizers on crop yields and yield improvements had been documented [19]. Senaratne et al. [20] reported improvement in the competitive ability of leguminous plants in legumes/grass mixture with K application. Nutrients are released more slowly from organic manure and they are stored for a longer time in the soil, thereby ensuring a long residual effect [21-22]. It is hypothesized that nutrient application of both organic and inorganic fertilizer, alone or in mixture, could offer some economic and biological advantages for farmers.

The main objectives of the present study are (i) to assess and compare different competition indices and their relationships with yield components under varying sets of nutrient applications and (ii) to identify nutrient management regimes options that lead to a high yield and income.

2. MATERIALS AND METHODS

2.1 Site Characterization

The study was carried out at two sites in Gandajika (Eastern Kasai) in the DR. Congo. Site 1 was locate at INERA research station (23° 57'E, 06° 48'S and 754 m altitude) and site 2 in Mpiana (23° 56'E, 06° 36'S and 685 m altitude). The region falls within the Aw4 climate type according to Köppen classification characterized with 4 months of dry season (from mid-may to august) coupled with 8 months of rainy season, sometimes interrupted by a short dry season in January/February. Daily temperature averages 25ºC and annual rainfall is close to 1500 mm. Gandajika soils consist of a collection of sandy on clay sediment more often based on a shallow lateritic old slab. The adsorption complex is fairly well saturated and there are still some weatherable minerals. The total potassium contents varied from 368 to 1050 mg kg^{-1} for site 1 (INERA) and from 7, 920 to 10,000 mg kg^{-1} for site 2 (Mpiana). For phosphorus, the values ranged from 97 to 113 mg kg^{-1} for site 1 (INERA) and from 456 to 508 mg kg^{-1} for site 2 (Mpiana). The amount of nitrogen was below detectable limits at site 1 (INERA) and varied between 47 to 115 mg kg^{-1} at site 2 (Mpiana). Details of soil chemistry for the targeted sites are described in Muyayabantu et al. [11,12,13].

2.2 Experimental Design and Field Trials

The study was undertaken during the long rain season in 2010-2011. At each site, a trial was conducted with three components. The first component consisted of maize alone, the second of soybean alone and the third was an association of maize and soybean. The experimental design for each was the randomized complete block (RCB) with six treatments and four replications. Each plot measured 3x4 m. The treatments included a control (traditional method) or Without Fertilizer (WF); Conventional method or Mineral (inorganic) Fertilizer (MF) at 115-63-0; Biological method consisting of the application of *Entada abyssinica* biomasses (EAB) alone at 8 t ha^{-1}; *Tithonia diversifolia* biomasses (TDB) alone at 8 t ha^{-1} and integrated soil fertility management (ISFM) method consisting of the application of MF at 57.5-31.5-0 combined with *E. abyssinica* at 4 t ha^{-1} ½ (MF+EAB) and MF at 57.5-31.5-0 combined with *T. diversifolia* at 4 t ha^{-1} ½ (MF+TDB). A short fallow period of four months was left between each cropping cycle. During the long growing rainy season, fresh *T. diversifolia* and E. *Entada* leaves were incorporated into the soil to 15 cm depth, three-days before planting. MF (DAP) was incorporated into the soil 15 days after sowing. This MF treatment was combined with urea application. Maize seeds (Mus 1 variety) were sown at 0.75 m x 0.50 m and 1 m x 0,5 m in monocrop and intercrop, respectively. Three seeds were

sown per hole. Maize in association plots were intercropped with soybean at a spacing of 0.25 m in row. In monoculture, Soybean seeds were sown at 0.5 m x 0.25 m. Two weeks after sowing (WAS), maize and soybean seedlings were thinned to two plants per stand. For each treatment, the parameters assessed include grain yield and yield components, different competition indices such as land equivalence ratio (LER), area x time equivalency ratio (ATER), land equivalent coefficient (LEC), competitive ratio (CR), relative crowding coefficient of both components (K), aggressivity (AGG); intercropping and monetary advantage index and Net benefits.

2.3 Estimation of Agrobiological Parameters

2.3.1 Yield components

Maize and soybean intercropping expected yield were estimated based on the following formula:

$$IEY = \frac{MOY\ x\ DIS}{100} \quad (1)$$

Where, IEY is the intercropping expected yield; MOY is the monocrop obtained yield for each crop and DIS is the crop's density in intercropping system.

Two types of results can be recorded: (1) mutual inhibition and underperformance yield when the intercropping obtained yields for each crop in the association is lower than its corresponding intercropping expected yield, (2) cooperation when the intercropping obtained yields for each crop in the association is higher than its corresponding intercropping expected yield [23]. As it is difficult to compare the performance of two different crops in intercropping system (maize and soybean), maize grain yields were converted to soybean equivalent yield (SEY) as:

$$SEY\ (t.ha^{-1}) = \frac{Yield\ of\ maize\ (intercrop\ or\ sole)\ x\ unit\ price\ of\ maize}{Unit\ price\ of\ Soybean} \quad (2)$$

The current market price of these two crops was used in calculating SEY in intercrop or in sole.

Real intercropping soybean yield (RISY) was estimated as RISY=SEY+ISOY (3)

Where ISOY is the intercropping soybean obtained yield. The difference between RISY and sole soybean obtained yield (SSOY) represent the agronomic intercropping advantage (AIA) over respective sole crops.

2.3.2 Different competition indices

Intercrop advantage was calculated through the determination of land equivalent ratio (LER) based on the following equation:

LER = (Yab/Yaa) + (Yba/Ybb) (4)

Where Yaa and Ybb are yields of sole crops for a and b and Yab and Yba are crop yields in intercrops for a and b. Values of LER greater than 1 are considered advantageous [4].

The relative dominance of one specie (a) over the other (b) in the intercropping trial was estimated by the use of relative crowding coefficient (K). K was calculated as:

$$K = (Ka \times Kb) \quad (5)$$

Where, Ka = Yab x Zba / (Yaa-Yab) x Zab
Kb = Yba x Zab / (Ybb-Yba) x Zba,

Where, Yab and Yba were the yields of maize and soybean in the intercrop, respectively, Yaa and Ybb ,were the yields of maize and soybean in sole crop, respectively and Zab and Zba were the respective sown proportions (based on seed numbers) of maize and soybean in the intercropping systems [3]. There is an intercrop advantage when the value of K is greater than 1.00 and no yield advantage when K is equal to 1. On the other hand, there is intercrop disadvantage when K is less than 1.00.

Land equivalent coefficient (LEC), a measure of interaction related to the relationship strength was calculated as:

$$LEC = La \times Lb \quad (6)$$

Where, La = LER of main crop and Lb = LER of intercrop [24]. For a two crop mixture the minimum expected productivity coefficient (PC) was 25% which means that a yield advantage is obtained if LEC value exceeds 0.25.

Area-time equivalency ratio (ATER), the ratio of number of hectare-days required in monoculture to the number of hectare-days used in the intercrop to produce identical quantities of each of the components, was computed as follows:

$$ATER = \frac{(Ryaxta)+(Rybxtb)}{T} \quad (7)$$

Where, Ry = Relative yield of species ‘a’ or ‘b’ i.e., yield of intercrop (a or b)/yield of main crop, t= duration (days) for species ‘a’ or ‘b’ and T = duration (days) of the intercropping system [25].

Competitive ratio (CR) indicates the number of times by which one crop or species is more competitive than the other. Relative species competition is often evaluated using competitive ratios [26].This was calculated as:

$$Ra = La/Lb \times Zba/Zab \quad (8)$$

$$Rb=Lb/La \times Zab/Zba$$

Where Ra is the competitive ratio of crop a and La and Lb are the partial LERs of crops a and b respectively, Zba is the proportion of crop a in the ab intercrop and Zab is the proportion of crop b in the ab intercrop. If Ra < 1, there is a positive benefit and the crop can be grown in association; if Ra > 1, there a negative benefit. The reverse is true for Rb.

Aggressivity is another index that represents a simple measure of how much the relative yield increase in crop “a” is greater than that of crop “b” in an intercropping system. It was calculated based on the following equation:

$$Aab = (Yab/YaaZab) - (Yba/YbbZba) \quad (9)$$

Where Yaa and Ybb are yields as sole crops of “a” and “b” and Yab and Yba are yields as intercrops of a and b. Zab and Zba are the sown proportions of a and b in intercrop ab, respectively.

If Aab =0, both crops are equally competitive; if Aab is positive, a is dominant; if Aab is negative, a is the dominated crop [9].

Moreover, Banik et al. [27] reported that the actual yield loss (AYL) index for specie a or b provide more precise information about the competition than the other indices between and within the component crops (a and b) and the behavior of each species in the intercropping system, as it is based on yield per plant. The AYL is the proportionate yield loss or gain of intercrops in comparison to the respective sole crop, i.e., it takes into account the actual sown proportion of the component crops with its pure stand. In addition, partial actual yield loss (AYLa or AYLb) represents the proportionate yield loss or gain of each species when grown as intercrops, relative to their yield in pure stand. The AYL is calculated according to the following formula [28]:

$$AYLab = AYLa + AYLb \quad (10)$$

$$AYLa = \{[\frac{Yab/Zab}{Ya/Za}] - 1\} \text{ and } AYLb = \{[\frac{Yba/Zba}{Yb/Zb}] - 1\}$$

Where Ya and Yb are the yields of maize and soybean, respectively, as sole crops and Yab and Yba are the yields of maize and soybean, respectively, as intercrops. Zab and Zba are proportion of maize and soybean, respectively.

The AYL can have positive or negative values to indicate an advantage or disadvantage of the intercropping when the main objective is to compare yield on individual plant basis.

2.4 Estimation of Economic Advantage of Intercropping

The economic performance of the intercropping was evaluated to determine if maize and soybean combined yields are high enough for the farmers to adopt this system. For that purpose, the economic analysis was carried out to estimate the net benefit and benefit cost ratio. Moreover, none of the above competition indices provided any information on the economic advantage of the intercropping system. For this reason, the monetary advantage index (MAI) was calculated as:

$$MAI = \frac{(monetary\ value\ of\ combined\ intercrops)x(LER-1)}{LER} \quad (11)$$

The higher the MAI value the more profitable is the cropping system [29]. Intercropping advantage (IA) was calculated using the following formula [27]:

$$IAma = AYLma \times Pma \quad (12)$$

IAsb = AYLsb x Psb

Where Pma is the commercial value of maize grain yield (the current price is CDF 300 per kg), and Psb is the commercial value of soybean yield (the current price is DCF 900 per kg). It should be pointed out that 1 USD dollar was equivalent to 900 CDF (Congolese Franc) at the time of the present study.

2.5 Data Analysis

Data were subjected to analysis of variance (ANOVA) using GenStat Discovery Edition 3. Treatment means were separated by least significant differences (LSD) at P = 0.05 level. The Weighted Least Squares Linear Regression was calculated to establish the correlation between HY and obtained yield in intercropping for each culture (maize and soybean).

3. RESULTS

Both organic and inorganic treatments produced higher values for expected and obtained soybean grain weight compared to the control at both sites (INERA and at Mpiana (Table 1). ISFM with ½ (MF+EAB) and ½ (MF+TDB) resulted in the highest soybean grain for expected (IESY) and obtained (IOSY) yield than other treatments at all sites. Conventional practice (MF) and EAB and TDB had similar grain weight (Table 1). IOSY was higher than the IESY in both experimental sites, regardless of the treatments.

Maize under any fertilization regimen produced higher values for expected (IEMY) and obtained (IOMY) grain yield than the control. ISFM with ½ (MF+EAB) and ½ (MF+TDB) were the best treatments followed by the conventional agriculture (MF), and the biological agriculture (EAB and TDB), respectively (Table 2). On the other hand, combined organic and inorganic fertilizers (*T. diversifolia* + NP and *E. abyssinica* + NP) increased significantly the expected and obtained yields for maize (Table 2) and soybean (Table 1) in the intercropping treatment.

Table 1. Soybean expected and obtained grain yield following mineral (inorganic) and organic fertilization at INERA (site 1) and Mpiana (site 2) in Gandajika (DR-Congo)

Fertilizer	Sites			
	Site 1 (INERA)		Site 2 (Mpiana)	
	IESY	IOSY	IESY	IOSY
	(t ha-1)			
WF (Control)	0.2650c	0.2875c	0.2950c	0.4225c
MF	0.4650b	0.5325b	0.5425b	0.6575b
EAB	0.4750b	0.4850b	0.5600b	0.6200b
TDB	0.4500b	0.5125b	0.5300b	0.6600b
½ (MF +EAB)	0.5675a	0.7050a	0.6575a	0.8550a
½ (MF +TDB)	0.6000a	0.7300a	0.6750a	0.8650a

Means in columns with a common alphabet are not significantly different at p = 0.05.
IESY=intercropping expected soybean yield, IOSY= intercropping obtained soybean yield.
WF = without fertilization; MF= mineral fertilization; EAB= Entada abyssinica biomass; TDB = Thithonia diversifolia biomass.

Table 2. Maize expected and obtained yield following mineral (inorganic) and organic fertilization at INERA (site 1) and Mpiana (site 2) in Gandajika (DR-Congo)

Fertilizer	Sites			
	Site 1 (INERA)		Site 2 (Mpiana)	
	IEMY	IOMY	IEMY	IOMY
	(t ha-1)			
WF (Control)	1.0500d	0.9750d	1.1875d	0.9850d
MF	4.2300b	2.9625bc	4.6075b	2.9525bc
EAB	3.1800c	2.4450c	3.1500c	2.7900c
TDB	3.5425c	2.7050bc	3.1800c	2.8200c
½ (MF +EAB)	5.1050a	3.1875b	5.3375b	3.4175a
½ (MF +TDB)	4.9875a	4.1850a	6.3850a	3.3175ab

Means in columns with a common alphabet are not significantly different at p = 0.05.
IEMY=intercropping expected maize yield, IOMY= intercropping obtained maize yield.
WF = without fertilization; MF= mineral fertilization; EAB= Entada abyssinica biomass; TDB = Thithonia diversifolia biomass;

At site 1 (INERA), ISFM (EF+EAB and MF+TDB) resulted in soybean yield increases of 33.7% (AYLsb=+0.337) and 30.9% (AYLsb=0.309), respectively in intercrop compared to the sole crop yield. In contrast, there was a decrease in maize yield under MF (-3%) and in MF+EAB mixtures (-13.3%) compared to the sole crop (Table 3).

At site 2 (Mpiana), the same treatments (MF and MAB plus MF+TDB) resulted in a significant decrease in maize yield estimated at 10.5% (AYLma = -0.105), 10.9% (AYLma = -0.109) and 28.4% (AYLma = -0.284) compared to the respective sole crop. AYLsb ranged from + 0.172 (EAB) to 0.370 (WF). The total AYL of maize–soybean intercrop was positive (Table 3), indicating an advantage of intercropping over pure stands.

Table 3. Soybean equivalent yield (SEY) (t ha^{-1}), actual yield loss of maize (AYLm), and actual yield loss of soybean (AYLsb), in an intercropping system following mineral (inorganic) and organic fertilization at INERA (site 1) and Mpiana (site 2) in Gandajika (DR-Congo)

Treatment	Site 1 (INERA)				Site 2 (MPIANA)			
	Actual yield loss			SEY	Actual yield loss			SEY
	Maize	Soybean	Total		Maize	Soybean	Total	
WF(Control)	0.279^{a}	0.154^{b}	0.433^{a}	0.318^{e}	0.370^{a}	0.389^{a}	0.7597^{a}	0.355^{e}
MF	-0.030^{d}	0.228^{b}	0.198^{cd}	0.966^{b}	-0.105^{c}	0.298^{b}	0.1934^{e}	0.963^{c}
EAB	0.070^{c}	0.037^{c}	0.107^{d}	0.797^{d}	0.216^{b}	0.172^{b}	0.3878^{c}	0.910^{d}
TDB	0.087^{c}	0.209^{b}	0.296^{b}	0.882^{c}	0.220^{b}	0.269^{b}	0.4883^{b}	0.919^{d}
½(MF+EAB)	-0.133^{e}	0.337^{a}	0.204^{c}	1.039^{b}	-0.109^{c}	0.383^{a}	0.2744^{d}	1.114^{a}
½(MF+TDB)	0.145^{b}	0.309^{a}	0.455^{a}	1.372^{a}	-0.284^{d}	0.365^{a}	0.0807^{f}	1.082^{b}

Means in columns with a common alphabet are not significantly different at p = 0.05.
WF = without fertilization; MF= mineral fertilization; EAB= Entada abyssinica biomass; TDB = Thithonia diversifolia biomass;

Soybean did compensate the yield loss of maize species indicating an advantage of intercropping (AYL positive). Actual yield loss for soybean (AYLsb) was positive under all the treatments at both sites, while the maize under MF and MF+EAB resulted in a negative actual yield loss at both sites. The lowest actual yield loss for maize (AYLma) was observed under MF+TDB (-0.284). But, total actual yield loss (AYLt) was positive under all the

treatments at both sites. The highest AYLt was observed under MF+TDB (0.455) at site 1 (INERA), but this value was not significantly different from the control (0.433). SEY increased with the application of combined inorganic and organic fertilizers at both sites. MF+TDB resulted in the highest SEY value (1.372 t ha^{-1}) followed by MF+EAB (1.039 t ha^{-1}) at site 1 (INERA). At site 2 (Mpiana site), MF+EAB ranked first (1.114 t ha^{-1}) followed by MF+TDB (1.082 t ha^{-1}). WF decreased significantly the SEY with the lowest value of 0.279 t ha^{-1} and 0.355 t ha^{-1} at site 1 (INERA) and site 2 (Mpiana), respectively.

Positive differences between SSY and RISY were observed under all the treatments at both sites (Table 4). In fact, the highest agronomic intercropping advantage (AIA) was observed when inorganic-organic fertilizers were applied with values of +0.9732 t ha^{-1} and +0.6492 t ha^{-1} for MF+TDB at INERA and at Mpiana, respectively. These values were +0.6523 t ha^{-1} for INERA and +0.7037 t ha^{-1} for Mpiana under MF+EAB treatment. The lowest AIA was observed under the control (WF) with +0.6050 t ha^{-1} at INERA and +0.1773 t ha^{-1} at Mpiana site. Integrated soil fertility management (MF+TDB and MF+EAB) resulted in a significant increase of SSY and RISY values at all sites.

Tables 5 and 6 describe the results of land equivalence ratio (LER), area-time equivalency ratio (ATER), land equivalent coefficient (LEC), competitive ratio of maize (CR ma), competitive ratio of soybean (CRsb), relative crowding coefficient of both components, aggressivity of maize (AGG. ma) and the aggressivity of soybean component (AGG. sb) at INERA and Mpiana sites respectively.

All the treatments resulted in LER values higher than 1.00. MF+TDB treatment resulted in the highest LER value (1.23), but not significantly different from control (WF = 1.22) (Table 5). Soybean intercropped with maize resulted in ATER values higher than 1.00 for all the treatments. MF+TDB resulted in the highest ATER (1.27) value, followed by MF+EAB with an ATER value of 1.21. LEC values ranged from 0.50 (MF+EAB) to 0.79 (WF). The highest LEC values were observed with the WF (0.79) and MF+TDB (0.74) treatments. The lowest LEC (0.50) was observed with the MF+EAB treatments. Maize intercropped with soybean showed a positive K value that was higher than 1.0 for all the treatments. The highest K was observed under MF+TDB (3.36) followed by MF+EAB (2.48) and TDB (2.13). In general, competitive ratio values for maize (CRma) were higher than competitive ratio values for soybean (CRsb), except for the control treatment. Aggressivity of maize (AGG.ma) was generally positive, except for WF, while that of the soybean (AGG.sb) was negative (Table 5).

Table 4. Sole soybean yield (SSY) (t ha^{-1}), reel intercropping soybean yield (RISY) (t ha^{-1}), and agronomic intercropping advantage (AIA) following mineral (inorganic) and organic fertilization at INERA (site 1) and Mpiana (site 2) in Gandajika (DR-Congo)

Fertilizer	Site					
	INERA			MPIANA		
	SSY	RISY	AIA	SSY	RISY	AIA
WF (Control)	0.5107^{c}	0.6050^{e}	0.0943^{e}	0.5677^{c}	0.7450^{d}	0.1773^{e}
MF	0.8943^{b}	1.5025^{c}	0.6082^{b}	1.0410^{b}	1.6225^{c}	0.5815^{bc}
EAB	0.9337^{b}	1.2725^{d}	0.3400^{d}	1.0753^{b}	1.5300^{c}	0.4547^{d}
TDB	0.8663^{b}	1.3950^{cd}	0.5287^{c}	1.0200^{b}	1.5525^{c}	0.5325^{c}
½ (MF +EAB)	1.0920^{a}	1.7425^{b}	0.6523^{b}	1.2663^{a}	1.9700^{a}	0.7037^{a}
½ (MF +TDB)	1.1543^{a}	2.1275^{a}	0.9732^{a}	1.2983^{a}	1.9475^{b}	0.6492^{b}
Mean site	0,91	1.4408	0.5328	1,0447	1.5612	0.5150

Means in columns with a common alphabet are not significantly different at p = 0.05.
WF = without fertilization; MF= mineral fertilization; EAB= Entada abyssinica biomass; TDB = Thithonia diversifolia biomass;

Table 5. Maize-soybean intercropping yield advantage based on different competition indices from field trials at site 1 (INERA) in Gandajika (DR-Congo)

Treatment	LER	ATER	Competitive ratio		LEC	K	Aggressivity	
			Maize	Soybean			Maize	Soybean
WF(Control)	1.22^{a}	1.17^{c}	0.92^{e}	1.13^{a}	0.79^{a}	1.45^{e}	-0.125^{e}	0.125^{a}
MF	1.10^{ab}	1.17^{c}	1.31^{b}	0.84^{d}	0.54^{cd}	1.66^{de}	0.258^{b}	-0.258^{d}
EAB	1.03^{b}	1.18^{c}	1.03^{d}	1.03^{b}	0.58^{c}	2.48^{b}	0.034^{d}	-0.034^{b}
TDB	1.15^{ab}	1.17^{c}	1.13^{c}	0.92^{c}	0.64^{b}	2.13^{c}	0.122^{c}	-0.122^{c}
½(MF+EAB)	1.10^{ab}	1.21^{b}	1.6^{a}	0.65^{e}	0.50^{d}	2.00^{d}	0.470^{a}	-0.470^{e}
½(MF+TDB)	1.23^{a}	1.27^{a}	1.12^{c}	0.89b^{c}	0.74^{a}	3.36^{a}	0.164^{c}	-0.164^{c}

Means in columns with a common alphabet are not significantly different at p = 0.05.
LER= Land equivalent ratio, ATER= area-time equivalent ratio, LEC= land equivalent coefficient, K= relative crowding coefficient. WF = without fertilization; MF= mineral fertilization; EAB= Entada abyssinica biomass; TDB = Thithonia diversifolia biomass;

The same trend was observed at site 2 (Mpiana) (Table 6). All the treatments had LER values higher than 1.00. WF treatment resulted in the highest LER value (1.52), while MF+TDB application generayed in the lowest LER of 1.040. Soybean intercropped with maize (under all treatments) had an ATER value that was higher than 1.00. MF+TDB and MF+EAD had the highest ATER (1.33 and 1.24 respectively) followed by the TDB (1.23) treatment. LEC values ranged from 0.38 (MF+TDB) to 1.29 (WF). Soybean intercropped with maize resulted in LEC values higher than 1 for the control treatment; all others treatments had LEC values of 0.79, 0.75, 0.51 for TDB, EAB, MT and MF+EAB, respectively. The lowest LEC (0.38) was observed in the MF+TDB treatment. Maize combined with soybean showed K values higher than 1.0 for all the treatments. The highest K of 5.32 was observed for the MF+TDB treatment followed by MF+EAB (3.08) and EAB (2.48) treatments. Competitive ratios for maize (CRma) were consistently higher than those for soybean (CRsb). Aggressivity of maize (AGG.ma) was generally positive, while that of soybean (AGG.sb) was negative (Table 6).

Table 6. Maize-soybean intercropping yield advantage based on different competition indices from field trials at site 2 (Mpiana) in Gandajika (DR-Congo)

Treatment			Competitive ratio				Aggressivity	
	LER	ATER	Maize	Soybean	LEC	K	Maize	Soybean
WF(Control)	1.52^{a}	1.20^{d}	0.83^{d}	1.22^{a}	1.29^{a}	1.24^{c}	0.019^{e}	-0.019^{a}
MF	1.10^{bc}	1.20^{d}	1.47^{b}	0.70^{c}	0.51^{d}	1.83^{b}	0.403^{b}	-0.403^{c}
EAB	1.200^{bc}	1.21^{d}	0.97^{cd}	1.04^{b}	0.75^{c}	2.48^{ab}	0.043^{c}	-0.043^{b}
TDB	1.270^{b}	1.23^{c}	1.09^{c}	0.93^{b}	0.79^{b}	1.96^{b}	0.049^{c}	-0.049^{b}
½(MF+EAB)	1.13b^{c}	1.24^{b}	1.61^{ab}	0.63^{cd}	0.51^{d}	3.08^{ab}	0.492^{b}	-0.492^{c}
½(MF+TDB)	1.040^{c}	1.33^{a}	1.97^{a}	0.54^{d}	0.38^{e}	5.32^{a}	0.650^{a}	-0.650^{d}

Means in columns with a common alphabet are not significantly different at p = 0.05.
LER= Land equivalent ratio, ATER= area-time equivalent ratio, LEC= land equivalent coefficient, K= relative crowding coefficient. WF = without fertilization; MF= mineral fertilization; EAB= Entada abyssinica biomass; TDB = Thithonia diversifolia biomass;

The MAI values were positive for all the organic and inorganic fertilization regimes at both sites (Table 7), indicating a yield advantage over the control. The highest MAI values for maize-soybean mixture were observed with *Tithonia*-inorganic fertilizer mixture (343891) followed by MF+EAB application (164565) at site 1 (INERA). The same trend was observed at site 2 (Mpiana). MF+TDB treatment resulted in a significantly ($p \leq 0.05$) higher MAI (298139) compared to other treatments, followed by the MF+EAB (234126) treatment. The total IA for maize and soybean mixture, which is an indicator of the economic feasibility of intercropping systems, revealed the most advantageous mixtures crop under all the organic and inorganic regimes in both sites. The highest IA was observed in MF+TDB treatment with values of +328.11 and +469.23 at sites 1 and 2, respectively, followed by MF+EAB at both sites. Contrary to maize-soybean mixture, a negative partial IA was observed when maize was treated with MF (IA value of -9.09) and MF+EAB (IA value of -39.9) at site 1 (INERA). The same trend was observed at site 2 (Mpiana). However at this site 2, MF+TDB treatment resulted in the lowest negative partial IA (-85.33) in sole maize (Table 7).

Table 7. Monetary advantage index and intercropping advantage of different fertilization regimes in Soybean-maize intercrop system at site 1 (INERA) and site 2 (Mpiana) in Gandajika (DR-Congo)

Fertilizer	INERA				MPIANA			
	IA			MAI	IA			MAI
	Maize	Soybean	Total		Maize	Soybean	Total	
WF(Control)	21.10^{d}	33.65^{c}	54.75^{d}	50735^{d}	64.67^{b}	158.41^{b}	223.08^{c}	58580^{d}
MF	-9.09^{e}	209.69^{b}	200.61^{c}	118793^{c}	-31.38^{c}	274.15^{b}	242.77^{c}	116259^{c}
EAB	83.62^{a}	141.80^{b}	225.42^{c}	99534^{c}	-85.33^{d}	335.96^{a}	250.63^{c}	231196^{b}
TDB	26.08^{c}	192.00^{b}	218.08^{c}	133048^{bc}	65.86^{b}	247.29^{b}	313.16^{b}	204334^{b}
½(MF+EAB)	-39.9^{f}	310.07^{a}	270.21^{b}	164565^{b}	-32.59^{c}	352.35^{a}	319.76^{b}	234126^{b}
½(MF+TDB)	43.56^{b}	284.55^{a}	328.11^{a}	343891^{a}	111.13^{a}	358.10^{a}	469.23^{a}	298139^{a}

Means in columns with a common alphabet are not significantly different at p = 0.05.
MAI=monetary advantage index, IA=intercropping advantage. WF = without fertilization; MF= mineral fertilization; EAB= Entada abyssinica biomass; TDB = Thithonia diversifolia biomass.
Seeding ratio maize: soybean was 51:49,based on seed numbers

Results from Table 8 show the cost-benefit analysis of maize/soybean in sole and intercropping systems at the INERA site, in which the reduction in the maize yield was compensated for by the soybean grain yield. A greater yield was obtained from the ISFM

(MF+TDB and MF+EAB) treatment in intercrop and sole maize and soybean resulting in a higher total income. Crop under MF+TDB ranked first, with gross income values of CDF 1960000 ha^{-1} and CDF1080000 ha^{-1} for maize-soybean intercropping and sole soybean crop, respectively. In sole maize crop, MF+EAB and MF+TDB generated the highest gross incomes. The cost of production was higher when MF was used to produce maize and soybean in monoculture and in intercropping system. The ISFM was second while the control treatment costed the least to produce maize and soybean (CDF 291000 ha^{-1}, CDF 259000 ha^{-1} and CDF 323000 ha^{-1} for maize-soybean intercrop, sole maize, and sole soybean, respectively). Soybean plots treated with MF resulted in a negative net income (CDF-383413 ha^{-1}) indicating a decline of soybean production. The highest net income were observed under MF+TDB (CDF 1130000 ha^{-1}) for maize-soybean intercropping and under MF+EAB and MF+TDB for sole maize, with a net income of CDF 1400000 ha^{-1} and CDF 1380000 ha^{-1}, respectively (Table 8). The costs benefit ratio decreased when the net benefit increase. A negative cost benefit ratio indicates that the cost of production is higher than the corresponding gross income. The same trend observed for cost-benefit analysis at site 1 (INERA) (Table 8) was noted for maize/soybean in sole and intercropping system at site 2 (Mpiana) (Table 9).

A greater net income was obtained from TDB, EAB alone and MF+EAB in intercrop with values of CDF 1040000 ha^{-1}, CDF 1020000 ha^{-1} and CDF 1010000 ha^{-1}, respectively. These values were not statistically different from the values for the MF+TDB treatment. In sole maize crop, ISFM (MF+EAB and MF+TDB) treatments resulted in the highest net income compared with the control. In general the cost of production was higher at site 1 (INERA) compared to site 2 (Mpiana).

Table 8. Cost of production, gross income, and net income (CDF/ha) for soybean intercropped with maize under different mineral (inorganic) and inorganic fertilization regimes at site 1 (INERA) in Gandajika (DR-Congo)

Cropping system	Fertilizer	Cost of production (CDF)	Gross income (CDF)	Cost benefit ratio	Net income (CDF)
Intercropping					
Maize/soybean	WF (Control	291000	556569^{e}	2.1	265569^{d}
Maize/soybean	MF	1174200	1.38E+06^{c}	6.7	205356^{e}
Maize/soybean	EAB	410600	1.17E+06^{d}	1.54	760960^{c}
Maize/soybean	TDB	410600	1.28E+06^{d}	1.5	873698^{b}
Maize/soybean	½ (MF +EAB)	824400	1.60E+06^{b}	2.1	778529^{c}
Maize/soybean	½ (MF +TDB)	824400	1.96E+06^{a}	1.7	1.13E+06^{a}
Sole					
maize	WF (Control)	259000	450000^{d}	2.4	191000^{e}
maize	MF	1142200	1.81E+06^{b}	2.7	670300^{d}
maize	EAB	378600	1.36E+06^{c}	1.4	983900^{c}
maize	TDB	378600	1.47E+06^{c}	1.34	1.10E+06^{b}
maize	½ (MF +EAB)	792400	2.19E+06^{a}	1.6	1.40E+06^{a}
maize	½ (MF +TDB)	792400	2.17E+06^{a}	1.6	1.38E+06^{a}
Sole					
soybean	WF (Control)	323000	469813^{e}	3.2	146813^{d}
soybean	MF	1206200	822787^{c}	-2.15	-383413^{e}
soybean	EAB	442600	858973^{c}	2.1	416373^{a}
soybean	TDB	442600	797027^{d}	2.25	354427^{a}
soybean	½ (MF +EAB)	856400	1.00E+06^{b}	6.75	148240^{c}
soybean	½ (MF +TDB)	856400	1.08E+06^{a}	4.7	228587^{b}

Means in columns with a common alphabet are not significantly different at p = 0.05. WF = without fertilization; MF= mineral fertilization; EAB= Entada abyssinica biomass; TDB = Thithonia diversifolia biomass;

Note that the conversion rate between the Congolese franc (CDF) and USD dollar was $1USD = 900 CDF during the experimental period

Table 9. Cost of production, gross income, and net income (CDF/ha) for soybean intercropped with maize under different mineral (inorganic) and inorganic fertilization regimes at site 2 (Mpiana) in Gandajika (DR-Congo)

Cropping system	Fertilizer	Cost of production (CDF)	Gross income (CDF)	Cost benefit ratio	Net income (CDF)
Intercropping					
Maize/soybean	WF (Control	263800	683013^{e}	1.63	419213^{b}
Maize/soybean	MF	1147000	1.49E+06^{c}	4.33	344249^{c}
Maize/soybean	EAB	383400	1.41E+06^{d}	1.4	1.02E+06^{a}
Maize/soybean	TDB	383400	1.43E+06^{cd}	1.4	1.04E+06^{a}
Maize/soybean	½ (MF +EAB)	792800	1.81E+06^{a}	1.8	1.01E+06^{a}
Maize/soybean	½ (MF +TDB)	792800	1.79E+06^{b}	1.8	998053^{a}
Sole crop					
maize	WF (Control)	240800	467500^{e}	2.1	226700^{d}
maize	MF	1124000	1.98E+06^{c}	2.33	851000^{c}
maize	EAB	360400	1.35E+06^{d}	1.4	989600^{b}
maize	TDB	360400	1.36E+06^{d}	1.4	1.00E+06^{b}
maize	½ (MF +EAB)	769800	2.29E+06^{b}	1.5	1.52E+06^{a}
maize	½ (MF +TDB)	769800	2.74E+06^{a}	1.4	1.97E+06^{a}
Sole crop					
soybean	WF (Control)	286800	522253^{e}	2.22	235453^{c}
soybean	MF	1170000	957720^{cd}	- 4.5	-212280^{d}
soybean	EAB	406400	989307^{c}	1.7	582907^{a}
soybean	TDB	406400	938400^{d}	1.8	532000^{a}
soybean	½ (MF +EAB)	815800	1.17E+06^{b}	3.4	349227^{b}
soybean	½ (MF +TDB)	815800	1.19E+06^{a}	3.14	378667^{b}

Means in columns with a common alphabet are not significantly different at p = 0.05.

WF = without fertilization; MF= mineral fertilization; EAB= Entada abyssinica biomass; TDB = Thithonia diversifolia biomass

Note that the conversion rate between the Congolese franc (CDF) and USD dollar was $1USD = 900 CDF during the experimental period

4. DISCUSSION

The intercropping obtained maize yield under each treatment was higher than the corresponding intercropping expected maize yield. Such transgression has been reported by Huxley and Maingu, [30]. There was an over-performance for the maize-soybean intercrops compared to other treatments. This is consistent with data described by Willey [23] and Willey and Rao [30]. The decline in soybean yield recorded was then offset by the surplus of maize yield that was recorded.

De Ridder and Van Kaulem [32] reported that the use of both inorganic and organic fertilizers often results in synergism and improvement of nutrient and water use efficiency. This might be the case for some fertilizers regimes such as ISFM [½ (MF +EAB) and ½ (MF +TDB)] that resulted in the highest soybean expected (IESY) and obtained (IOSY) compared to other treatments. In fact, Ghosh et al. [9] reported an increase in seed yield of soybean intercrop with sorghum under integrated use of organic and inorganic fertilizers and a decrease of intercrop soybean yield under inorganic fertilizer (N–P–K) application. As reported in many studies, the integration of organic and inorganic nutrient inputs increases fertilizer use efficiency and provides a more balanced supply of nutrients to the crop [33]. The results of this study are consistent with the findings of Mafongoya and Naïr ([34] who reported significant maize yield increases following application of green manure.

In the present study, expected and obtained yield for soybean and maize under MF, TDN and EAB application were similar. Based on previous reports, the inorganic fertilizer may have provided a large part of the nutrients and the organic fertilizer may have increased soil organic matter status, structure, and buffering capacity in the fertilized sites [12, 35]. In general, the organic matter also improves phosphorus (P) availability through reduction of the P sorption capacities of soil and supply of the P release during their decomposition [36-37]. High rates of inorganic P fertilizer have been suggested as one of the strategies for managing high P-fixing oils [38].

It was also revealed that ISFM (EF+EAB and MF+TDB) increased intercrop soybean yield at site 1 (INERA). The increase of soybean yield could be attributed to positive interaction effects of organic and inorganic mixture (ISFM). However, the positive AYL for maize-soybean recorded for all the treatments at both sites indicate an intercropping advantage over corresponding pure stands. Soybean could compensate the yield loss of maize for MF and MF+EAB treatments at site 1 (INERA) and for MF, MF+EAB, and MF+TDB at site 2 (Mpiana) (AYLma negative). These results corroborate the data reported by Dhima et al. [3] on competition indices of common vetch and cereal intercrops in two seeding ratios. AYL index can provide more accurate information than the other indices on inter- and intra-specific competition of the component crops and the behavior of each species involved in the intercropping systems.

The superiority of SEY, ISFM [½ (MF +EAB) and ½ (MF +TDB)] applications for crop yields for both maize and soybean could be explained by the synergism of organic and inorganic fertilizers and its ability to improve the availability of nutrient into the soil and water use efficiency. The results are consistent with Ayoola and Makinde [10] who reported a better maize growth with enriched cow dung compared to the sole inorganic fertilizer application. This suggests that organic manure from EAB and TDB can be enriched with inorganic nutrients to generate an initial and fast release of nutrients to plants. Comparable yields were reported with N-enriched cow dung [10]. Ayoola and Agboola ([39] reported that maize performed better in terms of growth, yield and yield components with fortified organic

manure than either sole organic or sole inorganic fertilizers. Similar responses have been also observed on maize, rice and sorghum [40-42]. Murwira and Kirchmann [43] observed that the nutrient use efficiency of a crop is increased through a combined application of organic manure and inorganic fertilizer.

The agronomic intercropping advantage (AIA) results are consistent with these findings. This could be due to a higher RISY obtained under these fertilizer regimes compared to the respective sole soybean yield (SSY). But, in general, all treatments resulted in a higher RISY than their respective SSY at both sites. Yield advantages have been recorded in many nonlegume/legume intercropping systems compared to corresponding sole crops. This includes maize (Zea mays L.) / soybean [44], sorghum/soybean [45], wheat (*Triticum aestivum L*.) / mungbean [*Vigna radiata* (L.) R. Wilczek] [46], barley (*Hordeum vulgare* L.) / medic (Medicago spp.) [47], canola (*Brassica spp.)* / soybean [48], groundnut (*Arachis hypogaea* L.) / pearl millet [*Pennisetum glaucum* (L.) R. Br.] [49], maize/faba bean (*Vicia faba* L.) [50], pearlmillet/cluster bean [*Cyamopsis tetragonoloba* (L.) Taub. [51], groundnut/cereal fodders [29], barley/pea (*Pisum sativum* L.) [52], and faba bean / barley [53].

The LER provides an accurate assessment of the biological efficiency of the intercropping situation. The trade-off between increasing the yield of suppressing species and decreasing that of the suppressed species has three possible outcomes for intercropping systems, i.e., yield advantage (LER > 1), yield disadvantage (LER < 1), and the intermediate result (LER = 1) [54]. The results of the present study revealed crop complementarities in maize/soybean intercropping and yield advantage, as LER and K values were greater than unity. This corroborated with the data described by Ghosh et al. [9].

The results reported herein also indicate that between 5% and 23% more land would be required under sole systems to get the same amount of grain yield compared to the intercropping at site 1 (INERA) and 4% - 53% more land would be required at site 2 (Mpiana site). Specifically, at site 1 (INERA), the land required in monocrop were 22 % for WF, 23 % for MF+TDB, 15 % for TDB and 10 % for MF+EAB and MF. Therefore, a surface excess of only 5 % is required for EAB. At site 2 (Mpiana), the required lands were 53 % (WF), 27 % (TDB), 20 % (EAB), 13 % (MF+EAB), 10 % (MF) and 4 % for MF+TDB. However, these results show that, the required land decreases when soil is fertilized compared to the control without any fertilization.

In general, the non legume crop is considered a suppressing crop in legume/non legume associations like sorghum/pigeon pea [55], groundnut/cereal fodders [29], and soybean/sorghum [9]. This was true in maize/soybean intercropping in the present study as indicated by the aggressivity analysis. Maize is a dominant species (positive aggressivity) and soybean a dominated species (negative aggressivity) except under WF (control) where the reverse was observed. This could be attributed to the poor initial fertility level responsible of slow growth of maize, favoring soybean component which has the ability to fix atmospheric nitrogen.

According to Willey and Rao [31], CR gives a better measure of competitive ability of the crops and can be a better index compared to K and aggressivity. The CR of maize for most treatment was > 1, and the CR value of soybean for most treatments was < 1. This indicates an advantage in yield compared with sole crops under these treatments. This further suggests that maize in the intercropping system is less competitive than the associated soybean.

Land equivalent coefficient (LEC) was greater than 0.25 under all treatments at both sites. According to Adetiloye et al. [24], for a two-crop mixture, the minimum expected productivity coefficient (PC) is 25%. This indicates that soybean can grow in mixture with maize under all treatments without major adverse effects. In fact, in the present study, intercropping yield advantage was observed under all the treatments in both sites, indicating an absolute yield advantage of soybean when intercropped with maize. Yilmaz et al. [56] had reported similar findings in maize- legume intercropping systems in the East Mediterranean region.

ATER values produced under all the treatments were higher than 1.0, confirming further advantage of intercropping of soybean with maize at both sites. The ATER values obtained in this study implied that between 17% to 27% more hectare days would be required under sole cropping than when the soybean was intercropped with maize at site 1 (INERA). At site 2 (Mpiana), 20% to 33% more hectare-days would be required under sole cropping than when soybean was intercropped with maize.

A definite yield advantage was observed under all the treatments with a positive MAI value. But among all treatments, integrated nutrient management (MF+TDB and MF+EAB) resulted in a higher MAI value for maize/soybean mixture at both sites (INERA and Mpiana). The results of the present study corroborate with the findings of Ghosh et al. [57]. They reported that under integrated use of organic- and inorganic-fertilizers, the soybean equivalent yield and monetary advantage index were higher than for the control and the inorganic-fertilizer treatments. The IA which is also an indicator of the economic feasibility of intercropping systems, also confirmed that the most advantageous treatments in the maize/soybean mixtures were integrated nutrient management followed by MF, TDB and EAB application. The fact that MAI and IA values were positive suggests that these fertilizer applications had the highest economic advantage in the intercropping systems [3] whereas all the others, which had negative values, showed an economic disadvantage.

Intercropped maize/soybean generated higher values of GI and net benefits than their respective sole systems under integrated nutrient management. This is probably because of the additional yield and values of the two components. Egbe [58] had made similar observations in pigeon pea/sorghum and pigeon pea-/maize intercropping studies. Njoroge et al. [59] estimated the net benefit of intercropping coffee with food crops by subtracting the total variable costs from the gross profits. Similarly, Egbe [58] had estimated the total profit and the marginal benefit; cost ratio from investments on different farm inputs used in pigeon pea/sorghum intercropping systems by computing returns per naira invested (RI). The use of TDB and EAB alone can be justified as fertilizer to generate greater net benefits than the application of inorganic fertilizers in maize/soybean intercropping and sole crops. This could be due to the fact that, mineral fertilizer cost more than organic fertilizer. The large profit generated in maize/soybean intercropping compared to respective sol crop might probably be the result of the high yield and price of soybean compared to maize. MF+TDB and MF+EAB were indeed more profitable treatments than the other treatments. Based on the data from the present study, organic fertilizer application can be recommended because of its reasonable cost compared to the inorganic fertilizer. The results are consistent with previous soil chemical analyses that revealed that site 2 (Mpiana) is more fertile than site 1 (INERA) [12-13]. This explained the relative increase in the GI observed at this site 2.

5. CONCLUSION

Integrated nutrient management (MF+TDB and MF+EAB) resulted in a significantly higher grain yield than the control. There was a significant variability in competitive index among the various treatments. Land equivalent ratio (LER), area–time equivalency ratio (ATER), decreased with fertilizer application at both sites. Land equivalent coefficient (LEC) was higher than 0.25 for all the treatments, an indication of yield advantages over the control. Relative crowding coefficient (K) was higher under integrated soil fertility management than under other treatments. In general, aggressivity was negative for soybean and positive for maize indicating that maize is a dominant crop and soybean a dominated crop at both sites. Soybean intercropped with maize resulted in a high yield components, high gross income and net benefits under MF+TDB and MF+EAB. Application of MF resulted in the lowest and negative net benefit for sole soybean crop indicating the disadvantage of this application. These results suggest that maize/soybean intercropping system is biologically and economically efficient and more profitable under ISOM with MF+EAB and MF+TDB. However, application of *Entada* and *Tithonia* alone could be sufficient to produce a moderate production, compared to inorganic fertilizer, in this intercropping system when farmers lack possibility to purchase inorganic fertilizer.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1 Francis CA. Multiple cropping systems. Vol. 1. Macmillan Publishing Co., New York; 1986.

2 Jensen ES. Grain yield, symbiotic N2 fixation and interspecific competition for inorganic N in pea–barley intercrops. Plant Soil. 1996;182(1):25–38.

3 Dhima KV, Lithourgidis AS, Vasilakoglou IB, Dordas CA. Competition indices of common vetch and cereal intercrops in two seeding ratio Field Crops Research. 2007;100:249–256.

4 Ofori F, Stern WR. Cereal –legume intercropping systems. Adv.Agron. 1987;41:41-90.

5 Hauggaard-Nielsen H, Ambus P, Jensen ES. Interspecific competition, N use and interference with weeds in pea–barley intercropping. Field Crops Res. 2001a;70:101-109.

6 Lithourgidis AS, Vasilakoglou IB, Dhima KV, Dordas CA, Yiakoulaki MD. Forage yield and quality of common vetch mixtures with oat and triticale in two seeding ratios. Field Crops Res. 2006;99:106–113.

7 Li L, Sun JH, Zhang FS, Li XL, Yang SC, Rengel Z. Wheat/maize or wheat/soybean strip intercropping I. Yield advantage and interspecific interactions on nutrients. Field Crop Res. 2006;71:123-137.

8 Morris RA, Garrity DP. Resource capture and utilization in intercropping: Non-nitrogen nutrient. Field Crops Res. 1993;34:319–334.

9 Ghosh PK, Manna MC, Bandyopadhyay KK, Ajay Tripathi AK, Wanjari RH, Hati KM, Misra AK, Acharya C, Subba Rao A. Interspecific interaction and nutrient use in soybean/sorghum intercropping system. Agron. J. 2006;98:1097-1108.

10 Ayoola OT, Makinde EA. Farming Systems Research and Extension Programme, Institute of Agricultural Research and Training, Obafemi. Afric. J. Plant Sci. 2008;2(3): 019-022.

11 Muyayabantu GM, Kadiata BD, Nkongolo KK. Response of maize to different organic and inorganic fertilization regimes in monocrop and intercrop systems in a sub-Saharan Africa region. Journal of Soil Science and Environmental Management. 2012a;3(2):42-48.

12 Muyayabantu M, Kadiata BD, Nkongolo KK. Evaluation of biological soil fertility management practices for corn production in oxisols. American Journal of Plant Sciences. 2012b;3:1654-1660.

13 Muyayabantu M, Nkongolo KK, Kadiata BD. Effects of organic and inorganic fertilization on soil nutrient dynamics in a savannah region (DR Congo). Chemistry and Ecology. //dx.doi.org/10.1080/02757540.2013.770480. 2012c.

14 Lehmann J, Peter I, Steglich C, Bebauer G, Huwe B, Zech W. Below ground interaction in dryland agroforesty. For. Ecol. Manage. 1998;111(2–3):157–159.

15 Carr PM, Horsley RD, Poland WW. Barley oat and cereal–pea mixture as dryland forages in the northern Great Plains. Agron. J. 2004;96:677–684.

16 Crawley MJ. Plant ecology. Blackwell Sci. Publ., Cambridge, UK. Dauro, D., and M.A. Mohamedsaleem. Shoot and root interactions in intercropped wheat and clover. Trop. Agric. Trinidad. 1997.

17 Aerts R. Interspecific competition in natural plant communities: Mechanisms, trade-offs and plant–soil feedbacks. J. Exp. Bot. 1999;50:29–37.

18 Palm CA, Myers RJK, Nndwa SM. Combined use of organic and inorganic nutrient sources for soil fertility replenishment. In: Buresh R, editor. Replenishing soil fertility in Africa. SSSA Special publication Number 51. USA: SSSA; 1997.

19 Carsky RJ, Iwuafor ENO. Contribution of soil fertility research and maintenance to improve maize production and productivity in sub-Saharan Africa. In: B. Badu-Apraku, MAB Fakorede, M Ouedraogo, FM Quin, editors. Strategy for Sustainable Maize Production In West and Central Africa. Proceedings of Regional Maize Workshop 21-25. . IITA-Cotonou: Benin Republic; 1999.

20 Senaratne R, Liyanage NDL, Ratnasinghe DS. Effect of K on nitrogen fixation of intercrop groundnut and the competition between intercrop groundnut and maize. Fert. Res. 1993;34:9–14.

21 Sharma A.R, Mittra BN. Effect of different rates of application of organic and nitrogen fertilizers in a rice-based cropping system. J. Agric. Sci. 1991;117:313-318.

22 Abou El-Magd MM, Hoda MA, Fawzy ZF. Relationships, growth, yield of broccoli with increasing N, P or K ratio in a mixture of NPK fertilizers. Ann. Agric. Sci. 2005;43(2):791-805.

23 Willey RW. Intercropping its importance and research needs: Part I. Competition and yield advantage. Field Crop Abstr. 1979;32:1–10.

24 Adetiloye PO, Ezedinma FOC, Okigbo BN. A land equivalent coefficient concept for the evaluation of competitive and productive interactions on simple complex mixtures. Ecol.modelling. 1983;19:27-39.

25 Hiebisch CK, McCollum RE. Area x time equivalency ratio: a method of evaluating productivity of intercrops. Agron. J. 1987;79:15-22.

26 Putnam DH, Herbert SJ, Vargas A. Intercropped corn soybean density studies. 1. Yield complementarity. Expl. Agric. 1984;21:41-51.

27 Banik P, Sasmal T, Ghosal PK, Bagchi DK. Evaluation of mustard (Brassica campestris var. Toria) and legume intercropping under 1:1 and 2:1 row-replacement series systems. J. Agron. Crop Sci. 2000;185:9–14.

28 Banik, P. Evaluation of wheat (T. aestivum) and legume intercropping under 1:1 and 2:1 row-replacement series system. J. Agron. Crop Sci. 1996;176:289–294.

29 Ghosh PK. Growth, yield, competition and economics of groundnut/cereal fodder intercropping in the semi-arid tropics of India. Field Crops Res. 2004;88:227-237.

30 Huxley PA, Maingu Z. Use of a systematic spacing design as an aid to the study of intercropping: some general considerations. Experimental Agriculture. 1978;14:49-56.

31 Willey RW, Rao MR. A competitive ratio for quantifying competition between intercrops. Expl. Agric. 1980;17:257-264.

32 De Ridder N, Van Keulen H. Some aspects of the role of organic matter in sustainable intensified arable farming systems in the West African semi-arid tropics (SAT). Fertil. Res. 1990;26:299-310.

33 Mugendi DN, Nair PKR, Mugwe JN, O'Neill MK, Woomer PL. Calliandra and Leucaena alley cropped with maize. Part 1: Soil fertility changes and maize production in the sub-humid highlands of Kenya. Agrof. Syst. 1999;46:39-50.

34 Mafongoya PL, Naïr PKR. Multipurpose tree prunings as a source of nitrogen to maize under semiarid conditions in Zimbabwe. Agrof. Syst. 1997;35:31-46.

35 Maatman A, Wopereis MCS, Debrah KS, Groot JJR. From Thousands to millions: Accelerating agricultural intensification and economic growth in Sub-Saharan Africa. In: Bationo A, Waswa B, Kihara J, Kimetu J, editors. Advances in integrated soil fertility management in Sub-Saharan Africa: Challenges and opportunities. The Netherlands: Springer; 2007.

36 Easterwood GW, Sartain JB. Clover residue effectiveness in reducing orthophosphate sorption on ferric hydroxide coated soil. Soil. Sci. Soc. Am. J. 1990;54:1345-1350.

37 Nziguheba G. Overcoming phosphorus deficiency in soils of Eastern Africa: recent advances and challenges. In: Bationo A, Waswa B, Kihara J, Kimetu J, editors. Advances in integrated soil fertility management in Sub-Saharan Africa: Challenges and opportunities. The Netherlands: Springer; 2007.

38 Sanchez PA, Jama BA. Soil fertility replenishment takes off East and Southern Africa. In: Vanlauwe B, editor. Integrated plant nutrition management in Sub-Saharan Africa from concept to practice. CABI International; 2002.

39 Ayoola OT, Agboola AA. Influence of cassava planting pattern and organic – inorganic fertilizer sources on the growth and yield of maize in cassava-maize-melon intercrop in South – west Nigeria. Moor J. Agric. Res. 2002;3(2):161 – 168.

40 Adeniyan ON, Ojeniyi SO. Effect of poultry manure, NPK 15-15-15 and combination of their reduced levels on maize growth and soil chemical properties. Niger. J. Soil Sci. 2005;15:34-41.

41 Satyanarayana VM, Vera PPV, Murphy VRK, Boots KJ. Influence of integrated use of farmyard manure and inorganic fertilizer on yield and yield component of irrigated lowland rice. J. Plant Nutrition. 2002;25(10):2081– 2090.

42 Bayu W, Rethman NFG, Hammes PS, Alemu G. Effects of Farmyard Manure and Inorganic Fertilizers on Sorghum Growth, Yield and Nitrogen use in a Semi-arid area of Ethiopia. J. Plant Nutrition. 2006;29(2):391-407.

43 Murwira HK, Kirchmann H. Carbon and nitrogen of cattle manures, subjected to different treatments, in Zimbabwean and Swedish Soils. In: Mulongoy K, Merckx R, editors. Soil organic matter dynamics and sustainability of tropical agriculture. UK: Wiley-Sayce, Chichester/Exeter; 1993.

44 Ghaffarzadeh M, Prechac FG, Gruse RM. Grain yield response on corn, soybean and oat grown in a strip intercropping system. Am. J. Alternative Agric. 1994; 9:171–177.

45 Elmore RW, Jackobs JA. Yield and nitrogen yield of sorghum intercropped with nodulating and non-nodulating soybeans. Agron. J. 1986;78:780–782.

46 Chowdhury MK, Rosario EL. Comparison of nitrogen, phosphorus and potassium utilization efficiency inmaize/mungbean intercropping. J. Agric. Sci. 1994;122:193–199.

47 Moynihan JM, Simmons SR, Sheaffer CC. Intercropping annual medic with conventional height and semi dwarf barley grown for grain. Agron. J. 1996;88:823–828.

48 Ayisi KK, Putman DH, Vance CP, Russelle MP, Allan DL. Strip intercropping and nitrogen effects on seed, oil and protein yields of canola and soybean. Agron. J. 1997;89:23–29.

49 Ghosh PK, Devi Dayal. Effect of varying levels of nitrogen in three groundnut-based intercropping systems. In: Punia MS, Dhankar S, Pahuja SK, Yogesh J, editors. Proc. Int. Conf. on Food Security and Crop Sci., CCS Haryana Agricultural University, Hissar-125 004, India; 1998.

50 Li L, Yang SC, Li XL, Zhang FS, Christie P. Interspecific complementary and competitive interactions between intercropped maize and faba bean. Plant Soil. 1999; 212(2):105–114.

51 Yadav RS, Yadav OP. The performance of cultivars of pearlmillet and clusterbean under sole cropping and intercropping systems in arid zone conditions in India. Exp. Agric. 2001;37:231–240.

52 Chen C, Malvern W, Karnes N, David W, Martha K. Row configuration and nitrogen application for barley–pea intercropping in Montana. Agron. J. 2004;96:730–738.

53 Trydemanknudsen M, Hauggaard-Nielsen H, Jornsgard B, Steenjensen E. Comparison of interspecific competition and N use in pea–barley, faba bean–barley, and lupin–barley intercrops grown at two temperate locations. J. Agric. Sci. 2004;142:617–627.

54 Vandermeer J. The ecology of intercropping. New York: Cambridge Univ. Press; 1989

55 Tobita S, Katayama K, Matsunaga R, Adu-Gyamfi JJ, Ito O, Rao TP. Soil nitrogen as a limiting factor in the intercropping system of soybean and pigeonpea. In: Ito O, Katayama K, Johansen C, Kumar Rao JVDK, Adu-Gyamfi JJ, Rego TJ, editors. Dynamics of roots and nitrogen in cropping system of the semi-arid tropics. Ser No 3. Japan: JIRCAS Int. Agriculture; 1996.

56 Yilmaz S, Atak M, Erayman M. Identification of advantages of maize-legume intercropping over solitary cropping through competition indices in the East Mediterranean region. Turk. J. Agric.For. 2008;32:111-119.

57 Ghosh PK, Tripathi AK, Bandyopadhyay KK, Manna MC. Assessment of nutrient competition and nutrient requirement in soybean/sorghum intercropping system. Europ. J. Agronomy. 2009;31:43–50.

58 Egbe OM. Evaluation of agronomic potentials of some pigeonpea genotypes for intercropping with maize and sorghum in Southern Guinea Savanna. Ph.D thesis, University of Agriculture, Makurdi, Nigeria; 2005.

59 Njoroge JM, Waithaka K, Chweya JA. Effects of intercropping young plants of the compact Arabica coffee hybrid cultivar. Ruiru Iwith potatoes, tomatoes, beans and maize on coffee yields and economic returns in Kenya. Expl. Agric. 1993;29:373-377.

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