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Full Length Research Paper

Response of maize to different organic and inorganic fertilization regimes in monocrop and intercrop systems in a Sub-Saharan Africa Region

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Soil fertility decline is a major constraint to crop production in sub-Saharan Africa due to continuous cropping of maize without an adequate fertilization. The main objective of the present study was to evaluate the effectiveness of several fertilization regimes in monocrop and intercrop systems in a Sub-Saharan Africa region. The study was carried out in a savannah region in D.R. Congo at two locations. The treatments included a control (NoF), inorganic application consisting of nitrogen-phosphorus (NP), organic application of *Entada abyssinica* and *Tithonia diversifolia*, and a combination of organic and inorganic application involving NP with *E. abyssinica* (N + E) and NP with *Tithonia diversifolia* (NP+T). In general, maize mixed with soybean had significantly lower grain yields compared to sole maize plots. Maize in monocrop fertilized with NP combined with *E. abyssinica* (NP + E) or *T. diversifolia* (NP+T) produced the highest grain yields at both sites. Application of *T. diversifolia* and *E. abyssinica* alone increased the grain yield by more than three–fold in monocrop trails and more than twice in the association trials compared to the control. The number of kernels per cob was the main agronomic factor associated to the grain yield differences. Application of organic material, especially *E. abyssinica* and *T. diversifolia* should be recommended to smallholder farmers as a short term cost efficient fertilization practice.

Key words: Inorganic fertilizer, organic fertilizer, *Entada abyssinica*, *Tithonia diversifolia*, sub-Saharan Africa, grain yield.

INTRODUCTION

In sub-Saharan Africa (SSA), continuous cropping of maize, alone or associated to legume without adequate fertilization has led to soil fertility depletion and subsequent low crop yields (Gichuru et al., 2003; Tumuhairwe et al., 2007). Soil fertility degradation has been described as the single most important constraint to food security in SSA. This has been attributed to insufficient nutrient inputs relative to exports, primarily through harvested products, leaching, gaseous losses and soil erosion. In addition to high nutrient depletion, the highlands are dominated by acid P-fixing soils such as ferralsols, Acrisols and Nitosols (Deckers, 1993; Sanchez et al., 1997), and P becomes, beside N, a major limiting nutrient for crop production in many soils. Like in other parts of SSA, negative nutrient balances have been reported for all major farming systems (Smaling et al., 1993, 1996), whereby N is more rapidly depleted than other nutrients (Walaga et al., 2000), and P fixed by Al and Fe.

The smallholder farms in this region practice maize/ legumes association without fertilizer, which is qualified as a backlog crop system. These traditional crop systems, especially maize-legume association, could be improved for sustainable crop yield. But adequate solutions to improve nutrients depletion are often limited in application because of the dynamics and heterogeneity of the African agro-ecosystems in terms of biophysical and socio-economic gradients (Ikerra et al., 2007; Karundiku et al, 2007 ; Kimani et al., 2007 ; Mafuka et al.,

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2007 ; Tabu et al., 2007 ; Waswa et al., 2007). Mineral (inorganic) fertilizers are without doubt part of solutions to reverse environmental degradation and to properly address the rising food demands. Few African countries produce fertilizers. As a consequence, most of the fertilizers that are used in Africa are imported. Fertilizer consumption in SSA has grown during the 1980 to 89 period and the 1996 to 2000 period from 0.83 million tons to 1.10 million tons, a 32.5% increase (IFDC, 2002). However, average fertilizer use in Africa is still very low, about 8 kg/ha (that is, only one-tenth of the world average). Smallholder farmers have limited ability to purchase soil fertility inputs, in particular inorganic fertilizers. While the use of inorganic soluble fertilizers is the obvious means to overcome P limitation, their application in small scale farming systems is limited by their high cost and inaccessibility by the smallholder farms, a result of poor infrastructure (Bekunda et al., 1997; Sanginga et al., 2003). The majority of population in the region is rural and relies on subsistence agriculture. Increased agricultural productivity and improved rural livelihoods cannot occur without investment in soil fertility (Place et al., 2003). Developing low cost technologies for solving P and N limitation to crop production has been the core of several researches in the region. The contribution of locally available resources for correcting P deficiency has been given attention. These include phosphate rocks and organic resources.

According to Lunze et al. (2007), the most affordable agricultural practice for improving soil fertility remains organic manure application alone. This can be difficult to apply at large scale because of insufficient quantities and the poor quality of the available organic resources on farms (Palm et al., 1997). Incorporation of green manure enhances soil organic matter and can improve the soil's physical properties. They also provide ground cover and conserve soil against erosion (Lal et al., 1991). Yet, *Entada abyssinica* L. (A. Rich) a tropical savannah wild species, unknown to scientists for its attributes, but that has been used by farmers of in Eastern Kasai Province, D. R. Congo as an indicator of soil fertility and *Tithonia diversifolia* L. which is largely known for its soil improvement characteristics (Ikerra et al., 2007; Karundiku et al., 2007; Kimani et al., 2007; Mafuka et al., 2007; Tabu et al., 2007; Waswa et al., 2007) could be the available natural resources to improve soil fertility at low cost by the farmers.

Therefore, the main objective of the present study is to compare the response of maize to different organic and inorganic fertilization regimes in monocrop and intercrop systems in a sub-Saharan Africa region.

MATERIALS AND METHODS

Location and site characterization

The study was carried out at two sites in Gandajika (Eastern Kasai) in the D. R. Congo. Site 1 was located 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 25°C and annual rainfall is close to 1500 mm.

Typically, 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.

Experimental design and trial implementation

The study was undertaken during the long rain season in 2009 to 2010. In each site, two trials were conducted one consisting of maize alone and the second was an association of maize and soybean. The experiment design was randomized complete block with six treatments and four replications. Each plot measured 3 × 4 m. The treatments included a control (NoF); NP at 115-63-0; *Entada abyssinica* alone at 8 t ha^{-1}; *Tithonia diversifolia* alone at 8 t ha^{-1}; NP at 57.5-31.5-0 combined with *E. abyssinica* at 4 t ha^{-1} (½ NP+E) and NP at 57.5-31.5-0 combined with *T. diversifolia* at 4 t ha^{-1} (½ NP+T). The experimental plots were left fallow for one year for site 1 (INERA) and only four months (May-September 2008) for site 2 (Mpiana). Fresh *T. diversifolia* and *Entada* leaves were incorporated into the soil to 15 cm depth, three-days before planting. NP (DAP) was banded along the rows and incorporated into the soil 15 days after sowing. This NP treatment was coupled with urea application. Maize seeds (Mus 1 variety) were sown at 0.75 m × 0.50 m and 1 m × 0.5 m in monocrop and association trials, respectively. Three seeds were planted per stand. Maize in association plots were intercropped with soybean at 0.5 m × 0.25 m. Two weeks after planting (2WAP), the maize seedlings were thinned to two plants per stand. For each treatment, the parameters assessed were: cob length, number of rows per cob, number of kernels per cob, grain weight and total yield.

Data analysis

Data were subjected to analysis of variance (ANOVA) using GenStat Discovery Edition 3. Main effects were separated by least significant differences (LSD) at P = 0.05 level.

RESULTS

The cob length for samples from different plots under different fertilizers regimes is described in Table 1. The treatment combining *T. diversifolia* and inorganic fertilizers (NP) significantly (p = 0.05) increased the length of cobs compared to control (NoF) in sole maize and maize - soybean intercropping plots at all sites. At site 1, the best treatments were T+NP and NP, both in sole maize and association trials followed by NP + E and then *E. abyssinica*. The same trends were observed at site 2, where E+NP and T+NP treatments resulted in longer cobs compared to control. Application of *E. abyssinica* organic matter as a treatment resulted in a moderate cob length increase in maize monocrop trail. Fertilization with *T. diversifolia* increased also moderately the cob length in maize and soybean intercropping plots. Overall, the cobs were significantly longer in monocrop trial compared

Table 1. Cob length (cm) under different fertilization regimes with inorganic (Nitrogen-Phosphorus (NP), and organic [(*Entada abyssinica* (E) and *Tithonia diversifolia* (T)] fertilizers in monocrop and maize – soybean intercrop systems in Gandajika, D.R. Congo.

Treatment	Sites			
	Site 1 (INERA)		Site 2 (Mpiana)	
	Sole maize	Association	Sole maize	Association
NoF	13.3[a]	11.7[a]	14.7[a]	12.4[a]
NP	16.3[c]	15.1[bc]	16.0[b]	15.9[bc]
E	14.8[b]	13.9[b]	16.0[b]	15.6[bc]
T	15.4[bc]	15.2[bc]	15.9[ab]	15.0[b]
½ (NP +E)	16.0[c]	14.4[b]	17.9[c]	17.1[c]
½ (NP +T)	17.3[c]	16.4[c]	18.9[c]	17.4[c]

Within a column, means followed by the same letter are not significantly different according to LSD at 5 % probability level. NoF = control without fertilizer; NP = Mineral fertilizer (Nitrogen Phosphorus); E = *Entada* alone; T = *Tithonia* alone; ½ (NP+E) = combination of 50% (Mineral fertilizer + *Entada*); ½ (NP+T) = combination of 50% (Mineral fertilizer +*Tithonia*).

Table 2. The number of rows per cob of maize under different fertilization regimes with inorganic (Nitrogen-Phosphorus or NP), and organic [(*Entada abyssinica* or (E) and *Tithonia diversifolia* or (T)] fertilizers in monocrop and maize – soybean intercrop systems in Gandajika, DR-Congo.

Treatment	Sites			
	Site 1 (INERA)		Site 2 (Mpiana)	
	Sole maize	Association	Sole maize	Association
NoF	16.0[b]	14.0[a]	14.0[a]	14.0[a]
NP	15.0[ab]	15.0[a]	15.5[b]	15.0[a]
E	15.5[b]	14.0[a]	15.5[b]	14.0[a]
T	14.0[a]	14.0[a]	14.0[a]	14.0[a]
½ (NP +E)	15.0[ab]	14.5[a]	14.0[a]	14.5[a]
½ (NP +T)	14.5[ab]	14.5[a]	13.5[a]	14.5[a]

Within a column, means followed by the same letter are not significantly different according to LSD at 5% probability level. NoF = control without fertilizer; NP = Mineral fertilizer (Nitrogen Phosphorus); E = *Entada* alone; T = *Tithonia* alone; ½ (NP+E) = combination of 50% (Mineral fertilizer + *Entada*); ½ (NP+T) = combination of 50% (Mineral fertilizer +*Tithonia*).

to maize/ soybean association plots.

The numbers of kernel rows per cob were significant different among the various treatments investigated (Table 2). At site 1, no treatment produced more kernels rows than the control in the monocrop trial. Moreover, the fertilization with *T. diversifolia* resulted in fewer kernel rows than the control. However, at site 2, the fertilization with NP and the organic treatment with *E. abyssinica* produced more kernel rows than control. Other treatments with inorganic and organic fertilizers did not increase the number of kernel rows.The inorganic fertilization with NP increased significantly the number of kernels per cob in site 1 in the monocrop trial. In the maize and soybean intercropping trial, the inorganic fertilizer (NP) along with the combination treatments NP+E and NP+T resulted in a larger number of kernels per cob compared to control (Table 3). At site 2, all the fertilization treatments increased the number of kernels per cobs compared to unfertilized plots in the monocrop trial. In the intercropping trial on the other hand, the treatment with *E. abyssinica* alone and NP with *T. diversifolia* (NP + T) did increase the number of kernels per cob compared to control (Table 3). In general, the number of kernels per row was higher in monocrop plot compared to the intercropping plot at both sites. All the treatments produced higher values for grain weight of 100 seeds than the control in sole maize and maize and soybean association plots at site 1. The same trend was observed in site 2. However at this site 2 only the treatment with the inorganic fertilizers NP along with NP+E and NP+T increased significantly the grain weight in intercropping trials (Table 4).

In general, grain yields per ha were significantly higher in monocrop than in association at both sites. The application of inorganic or organic fertilizers increased significantly the yield at both sites for monocrop and

Table 3. The number of kernels of maize per cob under different fertilization regimes with inorganic [(Nitrogen-Phosphorus (NP)], and organic [(*Entada abyssinica* (E) and *Tithonia diversifolia* (T)] fertilizers in monocrop and maize – soybean intercrop systems in Gandajika, DR-Congo.

Treatment	Sites			
	Site 1 (INERA)		Site 2 (Mpiana)	
	Association	Sole maize	Association	Sole maize
NoF	388[a]	585[a]	396[a]	600[a]
NP	536[c]	680[b]	452[ab]	720[b]
E	416[ab]	623[ab]	504[b]	700[b]
T	432[ab]	630[ab]	430[ab]	711[b]
½ (NP +E)	514[bc]	632[ab]	463[ab]	714[b]
½ (NP +T)	467[b]	638[ab]	496[b]	715[b]

Within a column, means followed by the same letter are not significantly different according to LSD at 5% probability level. NoF = control without fertilizer; NP = Mineral fertilizer (Nitrogen Phosphorus); E = *Entada* alone; T = *Tithonia* alone; ½ (NP+E) = combination of 50% (Mineral fertilizer + *Entada*); ½ (NP+T) = combination of 50% (Mineral fertilizer +*Tithonia*).

Table 4. 100 maize grain weights (g) under different fertilization regimes with inorganic [(Nitrogen-Phosphorus (NP)], and organic [(*Entada abyssinica* (E) and *Tithonia diversifolia* (T)] fertilizers in monocrop and maize – soybean intercrop systems in Gandajika, DR-Congo.

Treatment	Sites			
	Site 1 (INERA)		Site 2 (Mpiana)	
	Sole maize	Association	Sole maize	Association
NoF	25.0[a]	24.5[a]	25.3[a]	24.5[a]
NP	28.8[b]	28.5[c]	27.5[b]	28.5[b]
E	26.8[b]	26.6[b]	27.4[b]	25.8[ab]
T	27.0[b]	26.5[b]	27.9[bc]	26.5[ab]
½ (NP+E)	28.0[b]	27.0[bc]	29.9[c]	27.0[b]
½ (NP+T)	27.5[b]	27.5[bc]	29.8[c]	27.5[b]

Within a column, means followed by the same letter are not significantly different according to LSD at 5% probability level. NoF = control without fertilizer; NP = Mineral fertilizer (Nitrogen Phosphorus); E = *Entada* alone; T = *Tithonia* alone; ½ (NP+E) = combination of 50% (Mineral fertilizer + *Entada*); ½ (NP+T) = combination of 50% (Mineral fertilizer +*Tithonia*).

association trails. At site 1, inorganic fertilizer NP combined with *E. abyssinica* or *T. diversifolia* resulted in the most grain yield in monocrop plots. NP+T produced the most grain yield in the association trial (Figure 1). This followed by NP + E and NP treatments. Maize monocrop fertilized with NP combined with *E. abyssinica* or *T. diversifolia* (respectively NP+E and NP+T) produced the highest grain yields (7.125 and 7.292 t ha^{-1}, respectively at site 1, and 7.625 and 9.125 t ha^{-1}, respectively at site 2). *T. diversifolia* and *E. abyssinica* alone generated the highest overall grain yields of more than 4.917 and 4.542 for site 1, and 4.510 and 4.530 for site 2, respectively. In site 2, the same treatments, NP+E and NP+T, produced the most grain yield in monocrop and association trials (Figure 2). Like in site 1, *E. abyssinica* and *T. diversifolia* applied alone as organic fertilizers resulted in the same yield increase (Figures 1 and 2).

DISCUSSION

Application of organic or inorganic fertilizers increased significantly cob length compared to unfertilized plots. This can be ascribed to the positive effect of fertilizers in improving soil fertility. This effect is very pronounced when organic manure is combined with inorganic (chemical) fertilizer application (NP+E and NP+T). This could be attributed to the addition from inorganic fertilizer of N which may have been already supplied in sufficient amounts by organic input alone leading to a better synchrony of nutrient release and uptake. De Ridder and Van Kaulem (1990) reported that the use of both inorganic and organic fertilizers often results in synergism and improvement of nutrient and water use efficiency. The inorganic fertilizer provides (a large part of) the nutrients and the organic fertilizer increases soil organic matter status, structure, and buffering capacity (Maatman

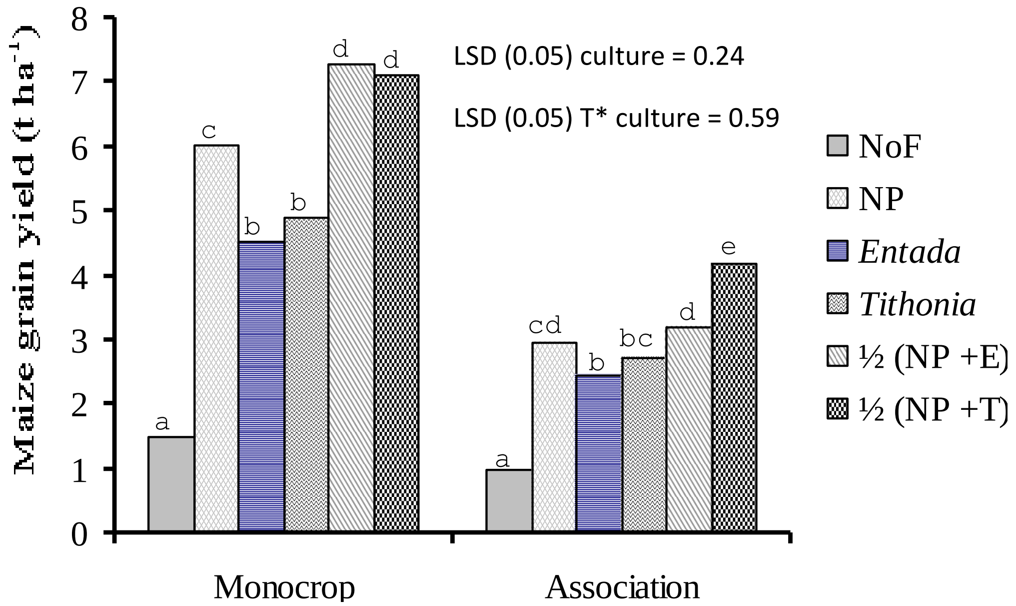

Figure 1. Average grain yields of maize (variety Mus) under different fertilization regimes with inorganic (Nitroge-Phosphorus), and organic (*Entada abyssinica* and *Tithonia diversifolia*) fertilizers in monocrop and maize – soybean intercrop systems in Gandajika – D.R. Congo. (Site 1 – INERA).

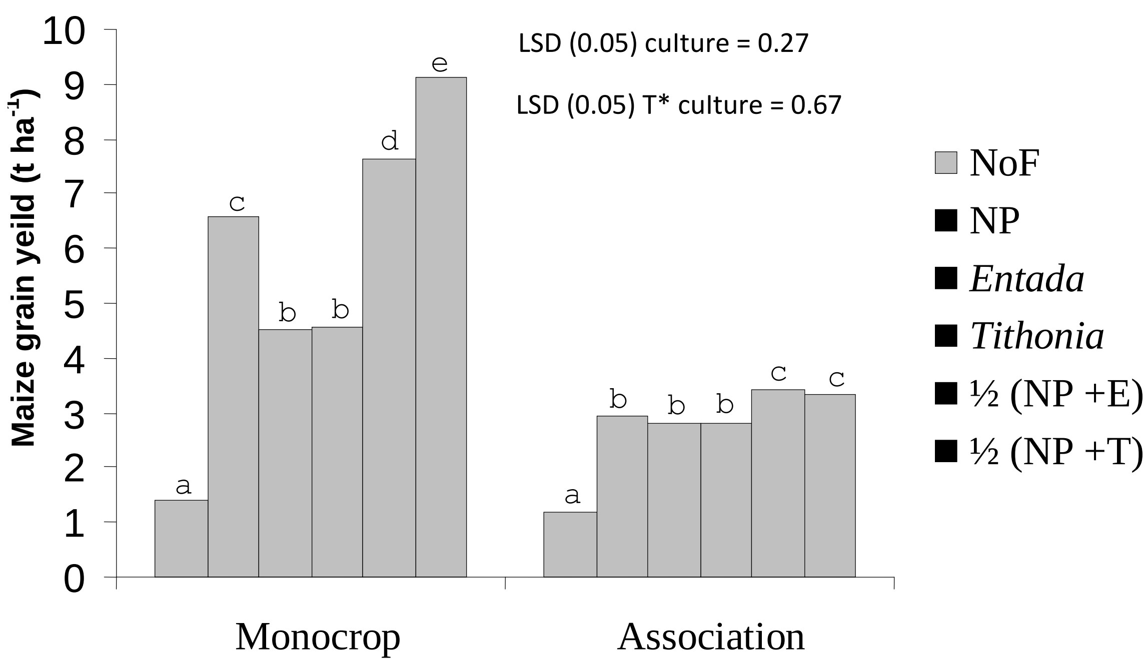

Figure 2. Average grain yields of maize (variety Mus) under different fertilization regimes with inorganic (Nitroge-Phosphorus), and organic (*Entada abyssinica* and *Tithonia diversifolia*) fertilizers in monocrop and maize – soybean intercrop systems in Gandajika – D.R. Congo. (Site 2 – Mpiana).

et al., 2007). The organic matter also improves phosphorus (P) availability through reduction of the P sorption capacities of soil (Easterwood and Sartain, 1990; Nziguheba et al., 2000; Nziguheba, 2007) and supply of the P release during their decomposition (Nziguheba et al., 2002; Nziguheba, 2007). Compared to inorganic fertilizer NP, the application of *T. diversifolia* and *E. abyssinica* alone to the soil did not significantly increase the cob length. High rates of inorganic P fertilizer has been suggested as one of the strategies for managing high P-fixing oils (Sanchez and Jama, 2002) and organic sources of nutrient contents (Maatman et al., 2007).

It was also observed that, the combination of organic (*E. abyssinica* and *Tithonia*) with inorganic (NP) nutrient sources generated higher grain yields than all the others treatments. This was probably due to the increased N and P availability and improvements in other soil parameters. These results are consistent with data reported by Mugendi et al. (1999). As noted by 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 (Kapkiyai et al., 1998; Mugendi et al., 1999). The results concur also with the findings of Mafongoya and Naïr (1997) who reported significant maize yield increases following application of green manure. The leafy pruning incorporated into the soil (as green manure) at the beginning of the season decomposed and released nutrients especially nitrogen, which enhanced crop performance. Ikerra et al. (2007) observed that combining minjingu phosphate rock (MPR) with *Tithonia* application increased maize grain yields than using *T. diversifolia* alone. Kapkiyai et al. (1998) reported that combination of organic and inorganic nutrient sources result into synergy and improved synchronization of nutrient release and uptake by plants (leading to higher yields). It should be noted that the amount of plant nutrients supplied via organic materials is highly dependent on the quantity of the organic materials applied (Matheus et al., 1992).

Tian et al. (1993) reported that nutrient uptake and grain yield of the crop was higher when nitrogen was partially applied as pruning (organic matter), indicating the importance of the combined addition of plant residue and N fertilizer for improving crop production as an integrated soil fertility management strategy (ISFM). Integrated soil fertility management (ISFM) refers to making best use of inherent soil nutrient stocks, locally available soil amendments, and mineral fertilizers to increase land productivity while maintaining or enhancing soil fertility. Increasing outputs from the same pieces of land through agricultural intensification will generally require some use of mineral fertilizers. The rationale behind ISFM is simple. First, organic sources of nutrients have low nutrient contents and are usually not abundantly available. Sustaining soil fertility and increasing productivity using organic resources alone is, therefore, a losing battle. Second, the unique use of inorganic fertilizers may lead to yield grains in the short term but to serious damage to soil fertility and yield declining in the long term. The best strategy to improve productivity and maintain soil fertility in SSA lies, therefore, in a combination of both inorganic and organic fertilizers (De Ridder and Van Keulen, 1990).

In the present study, associating maize with soybean significantly reduced grain yields compared to maize monocrop. This could be due to the competition for uptake nutrient into the soil by maize and soybean plants. These results concur with data reported by Meppe et al., (2007). Francis (1986) pointed out the main disadvantage of crop associations is the reduction of crop yield for different cropping compared to their pure culture. Plant competition for nutrients and water and increased density when the two mixed crops are the main factors attributed to the yield decrease. In the present study, the number of maize per ha was 25% higher in monocrop trial than in the maize intercropped with soybean in this study. But grain yield was more than twice in monocrop plots compared to association trial. The difference in yield between monocrop and association trial was in part the result of a significant high number of kernels per cob and cob length in samples from sole maize plots compared to maize-soybean plots. Other agronomic parameters analyzed were similar.

Conclusion

The application of *E. abyssinica* and *T. diversifolia* biomass appear to improve soil fertility in each site. Sole maize crop fertilized with NP combined with *E. abyssinica* (NP+E) or *T. diversifolia* (NP+T) produced the highest grain yields at both sites. Application of *T. diversifolia* and *E. abyssinica* alone increases the grain yield by more than three–fold in monocrop trails and more than twice in the association trials. Integration of organic and inorganic nutrient sources generated the highest yields. This was attributed to an increased fertilizer use efficiency and provision of more balanced nutrients to the crop. Application of organic material, especially *E. abyssinica* and *T. diversifolia* should be recommended to smallholder farmers.

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