International Scholars Journals

International Journal of Agricultural Extension and Rural Development Vol. 8 (6), pp. 001-008, June, 2020. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Organic based nutrient management strategies: Effect on soil nutrient availability and maize (*Zea mays* L.) performance in Njoro, Kenya

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Accepted 20 January, 2020

A field experiment based on the concept of organic nutrient management (ONM) was conducted in Njoro, Kenya to test the effect of improved legume fallows; crotalaria (CR), lablab (LB), garden pea (GP) and natural fallow (NF, as control) on available soil N and P, and maize performance. The experimental layout was a split plot in a randomized complete block design. The main plots were two cropping systems involving the improved legume fallows and NF preceding sole maize and maize bean (M/B) intercrop. The sub -plots were two residue management types; residue incorporation and residue removal with farm yard manure (FYM) incorporated in its place. Incorporation of LB, CR and GP residues resulted in higher concentrations of N and P in soil than NF residue and FYM incorporation in both cropping systems. Under sole maize, grain yield following LB was significantly higher (51, 28.2 and 52%) than after CR, GP and NF, respectively. In the M/B intercrop, maize grain yield following LB was significantly higher (38.5 and 28.5%) than after GP and NF with no significant differences in yields following CR and LB. Maize dry matter (DM) yields followed a similar trend. Overall, maize grain and DM yields were higher in sole maize cropping system than in M/B intercrop with an additional 0.5 - 0.6 kg ha^{-1} of bean grain yield obtained in the latter cropping system. The improved fallow legumes, with LB being superior, enhanced soil productivity and consequently higher yields of the succeeding crop. The ONM strategy tested is thus a feasible technology that could easily fit into the circumstances of the resource poor farmers within the region.

Key words: Biological nitrogen fixation, farm yard manure, improved legume fallow, residue management.

INTRODUCTION

Maize (*Zea mays* L.) is the most important agricultural commodity and main staple food in Kenya providing about 40% of the populations' caloric requirements (Wekesa et al., 2003; Kandji et al., 2003) . Due to the ever growing human population, coupled with the declining soil fertility, demand for maize continues to outstrip supply (CBS, 2004). Nitrogen and phosphorus are the major nu-trient limiting maize growth in Kenya (Kwabiah et al., 2003). For many cropping systems in the tropics, appli-cation of N and P from organic and inorganic sources is essential to maximize and sustain high crop yield poten-tial in continuous cultivation systems (Hartemik et al., 2000).

In most Sub-Saharan African countries however, ferti-lizer is not readily available and when available the cost is often limiting to small scale resource poor farmers (Smestad et al., 2002). This leads to non-use or use of suboptimal quantities of fertilizer to avoid crop failure, thus posing a threat to food security. It is therefore impe-rative that other sustainable alternatives of soil fertility management are sought to ensure improved crop pro-duction and consequently improved food security.

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Organic nutrient management (ONM), based on biodegradable material is one such alternative. Among the most promising organically based soil nutrient management practices include use of animal manure, incorporation of crop residues and improved legume fallows (Place et al., 2003). Short term improved legume fallow technology is characterized by deliberate planting of fast growing nitrogen fixing legume species in rotation with cereal crops (Niang et al., 2002).

Efficient legume growth and nitrogen fixation is highly dependent on an adequate supply of phosphorus. Minjingu rock phosphate (MRP) which costs about 50% of processed P fertilizers, on elemental P basis, is suitable for use under organic based nutrient management systems (Okalebo and Nandwa, 1997; Lelei, 2004).

The objective of the study was to determine the effect of organic based nutrient management strategies involving improved legume fallows and residue management types in a legume–cereal cropping system on available soil N and P contents and maize performance.

MATERIALS AND METHODS

Site description

The study was conducted at Field 7 station of the Department of Agronomy, Egerton University, Njoro (longitude $35^0 23^1$ and $35^0 36^1$ East and latitude $0^o 13^1$ and $1^o 10^1$ South) during the short (SRS) and long rain seasons (LRS) of the year 2003 and 2004, respectively. The LRS occurs between March/April to August and SRS from September/October to December with peaks in April and November, respectively. The total annual rainfall and mean temperature during the experimental period was 1443.9 mm and 19.6^{o}C, respectively. The soils are well drained, dark reddish in colour and classified as mollic Phaozems (FAO/UNESCO, 1990).

The analyzed chemical and physical characteristics of the top (0 to 0.2 m) soil layer prior to the commencement of the experiment, according to soil fertility rating by Okalebo et al. (2002) were; neutral in pH (pH water 6.8), moderate in organic C (15 g kg^{-1}), high in total N (3.2 g kg^{-1}), low in Olsen extractable P (6.29 mg kg^{-1}) and exchangeable bases (cmol kg^{-1}); Ca (3.8), Mg (0.87) and K (1.12), and clay in texture (%); sand (45), silt (26), and clay (29).

Experimental design and field practices

Treatments and experimental design

The treatments were improved fallow legumes; crotalaria (CR), lablab (LB) garden pea (GP) and natural fallow (NF, as control) with maize as the test crop. The experimental design was a split plot fitted to a randomized complete block. The main plots (3.75 x 4.8 m) were two cropping systems involving improved legume fallows and NF preceding (i) sole maize (M); NF-M, CR-M, LB-M and GP-M, and (ii) maize bean (M/B) intercrop; NF-M/B, CR-M/B, LB-M/B and GP-M/B. The sub-plots were two residue management types; residue incorporation and residue removal with manure (FYM) incorporated in its place. The treatments were replicated four times.

Field practices

The experimental field was previously under a two month weedy fallow. It was cleared of vegetation, tilled and raked using hand tools prior to experimental setup. MRP, at the rate of 290 kg ha^{-1} (40 kg P ha^{-1}), was broadcasted on all plots and mixed well with the top soil, prior to planting of the legumes. The legumes were planted on 10th October 2003 during the SRS at a spacing of 60 cm between rows and 30 cm within rows. Two seeds were planted per hill.

To estimate biological nitrogen fixation (BNF) barley, a reference crop, was sown at a rate of 80 kg ha^{-1} in furrows spaced 20 cm apart. The amounts of nitrogen fixed by LB, CR, GP and NF weeds were then estimated using the difference method (Hauser, 1987);

$$BNF\ (kgha^{-1}) = (ShootN_{leg} + rootN_{leg})kgha^{-1} - (shootN_{ref} + rootN_{ref})\ Kgha^{-1} + (N_{in}\ insoil - N_{in}\ insoil_{ref})\ kgha^{-1})$$

Where; leg = legume; ref = reference crop; in = mineral N. This method assumes that the uptake of soil derived N is the same in the legume and reference crop and hence barley, a crop with simi-lar N uptake characteristics as legumes was chosen (Jensen, 1986; Reining, 2005).

Immediately after grain harvest, the above ground residues of all crops were either completely removed and 5 t ha^{-1} of FYM added in its place (to mimic the farmers' practice of recycling legume residue through livestock as FYM) or chopped into 5 - 20 cm pieces, spread across plots and incorporated during land preparation for the subsequent maize crop. Weed biomass in NF plots was handled similarly as the legume residues.

All plots were planted with H624 maize at the beginning of the LRS of 2004 at a spacing of 75 cm between hill and 30 cm within hills. In the M/B intercrop, beans were sown between two rows of maize. Weeds were controlled by hand hoeing three times during the 2004 LRS.

Soil sampling and analysis

Soil samples for determination of soil available N and P were obtained from the upper soil surface layer (0 - 15 cm) using a 5 cm diameter soil auger. The soil samples were collected at; two weeks after planting, seedling, tasselling, cobbing and maturity stages of maize growth, between the plants within a row in every plot at random. Four augerings were done in every plot and the soil bulked together to get one composite sample.

The samples for analysis of available N (NO_3-N^- + NH_4-N^+) were refrigerated before analysis. For the analysis of available P, soil samples were air dried by placing them in a shallow tray in a well-ventilated area. Soil analysis was done according to the methods described by Okalebo et al. (2002).

Plant sampling and analysis

The maize and legume samples for grain and DM yield determination were obtained from two internal rows of each plot. The weed DM yield was determined from a 1 m^2 area.

The grain yield was adjusted to 13% moisture content while sub samples for DM determination were taken to the laboratory and oven dried at 70°C for 48 h. The grain and DM yields were expressed on hectare basis. Oven dried biomass samples of legumes and weeds were ground to pass through a 0.5 mm sieve and analysed for total N and P using the methods described by Okalebo et al. (2002).

Statistical analysis

The measured soil and plant parameters were subjected to analysis of variance (ANOVA) appropriate for a split plot design. The SPSS software (SPSS Incorporated, 1999) was used for statistical analysis.

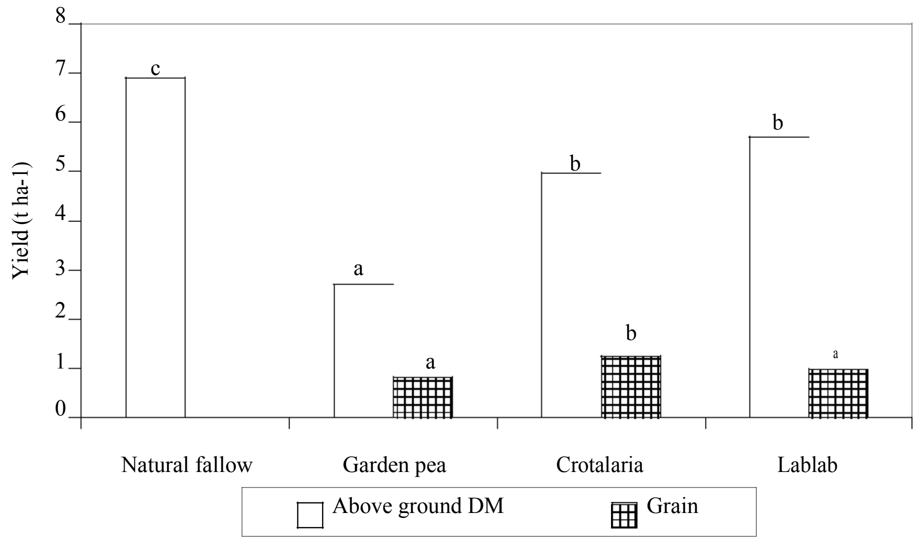

Figure 1. Above ground DM yield of NF weeds and improved fallow legumes and grain yield of improved fallow legumes. Means of pre-maize treatments followed by the same letter are not significantly different according to Turkey mean separation procedure at *P*<0.05.

RESULTS AND DISCUSSION

Dry matter (DM) yields of NF weeds and improved fallow legumes

The DM yield (t ha^{-1}) of the NF weeds (6.9) was signify-cantly higher (P<0.05) than LB (5.7), CR (4.9) and GP (2.7). CR and LB had significantly higher DM yield than GP (Figure 1).

The high DM yield of the NF weeds may partly be attributable to the highly vegetative nature of the weeds present (*Amaranthus hybridus*, *Comelina benghalensis*, *Galinsonga parviflora*, *Digitaria scalarum*, *Cynodon dactylon*, *Pennisetum clandestinum*) coupled with their rapid growth and establishment in comparison to the le-gume species. Gathumbi et al. (2004) studying short term fallows reported highest biomass production in weedy fallow and observed that the type of fallow species greatly influenced biomass production. The differences in legume DM yields may be attributed to increased availa-ble soil P supplied through solubilization of MRP and varietal differences in P uptake and P use efficiency. Ingleby et al. (2001) had also reported that phosphorus application enhanced nodulation, total dry matter and grain yield of legumes.

Grain yield of the improved fallow legumes

Grain yield (t ha^{-1}) of CR (1.25) was significantly higher (P<0.05) than that of LB (0.98) and GP (0.83). The grain yields did not differ significantly between LB and GP (Figure 1). The differences in yields could be in light of the pronounced differences in phenotype and genotypes of the legumes involved with resultant variations in the amounts of nitrogen supplied to the crops through BNF. Nodulation and N_2 fixation in legumes are generally thought to be quantitatively inherited traits (Graham et al., 2004). In terms of DM yields, LB had relatively higher DM yields than CR (Figure 1). This observation indicates that the LB plant tissue developed early in the growing sea-son is not an effective N source for the later reproductive sink that exists during seed development (McConnell et al., 2002).

N and P contents of improved fallow legumes and NF weed residues

The total N and P content of LB and CR residues were significantly higher (P<0.05) than that of the NF weeds and GP (Table 1). The high N and P contents of LB and CR residues may have been due to the high above ground DM produced by the respective legumes (Figure 1) and consequently the higher nutrient accumulation. Gathumbi et al. (2004) reported that CR fallows recorded the greatest total N and P yield due to fast establishment and higher total biomass production. The NF weeds had the highest above ground biomass yield, but a corres-pondingly lower N yield (Table 1). This may be due to their low N content (1.5%) in comparison with GP (2.5%), CR (3.4%) and LB (3.2%). This is in agreement with the findings of Niang et al. (2002) who reported that natural fallow weeds contained low N contents.

N fixation by the improved fallow legumes

The NF weeds fixed low amounts of N in comparison to improved fallow legumes (Table 1). CR and LB fixed sig-

Table 1. N and P contents and BNF by legumes and NF weeds.

Pre-maize treatment	Nutrient content in residue (kg ha^{-1})		BNF, kg ha^{-1}
	N	P	
NF	104^{b}(28)	8^{b}(2)	4^{a*}(2.5)
GP	60^{a}(4)	4^{a}(3)	126^{b}(3)
CR	169^{c}(17)	12^{c}(1)	175^{bc}(31)
LB	180^{c}(14)	12^{c}(1)	196^{c} (30)

Means in a column followed by the same letter are not significantly different according to Turkey mean separation procedure at *P*<0.05. Values in parentheses are standard deviations.

nificantly higher (P<0.05) amounts of nitrogen than GP (Table 1) . This may be attributable to their better genetic potential, coupled with P release by MRP, and hence had a comparative advantage for enhanced N fixation.

LB and CR with high amounts of N fixed also had high aboveground biomass (Figure 1) . The correlation (r^2) between amounts of N fixed and legume DM yield for these legumes was 0.94. This agrees closely with the findings of Kumar and Goh (2000) who reported strong correlations between the amounts of N fixed for both legume DM yield (r^2 = 0.96) and N accumulation (r^2 = 0.97-0.99). Giller (2001) had also reported that larger amounts of N_2 fixed in broad bean resulted from better growth and higher biomass accumulation.

Effect of improved fallow legumes on soil nutrient availability and maize performance

Soil available N

Maize growth stages

There was a decline in soil available-N across maize growth stages for all pre-maize and residue management treatments (Table 2). The observed decline could partly be due to increased crop uptake during growth and development. This is in agreement with Kamoni et al. (2000) who had observed that N was taken up by maize throughout the growing season with maximum uptake recorded at 10 days before tasselling to 25 to 30 days after tasselling. Losses of N would also be due to leaching, because of heavy rains, microbial immobilization and denitrification (Hoeft, 2004).

Low levels of soil available N was recorded two weeks after maize planting in the NF treatment (Table 2) . This suggests depletion of soil available N reserves due to the low N content and poor N fixing ability of the weeds. N uptake thus depended on the residual mineral-N reserve in the soil and the rate of N mineralization. Wortmann (2000) had reported that the rate of N uptake is greater than the rate of mineralization during the growth period and consequently mineral N reserve in the soil is depleted quickly.

Legume residues vs. FYM incorporation

The soil available N was higher in the legume residue than FYM incorporated treatments, except for the NF treatment (Table 2). The FYM treatment had significantly low mineral N in soil at all stages of maize growth (Table 2), for both sole maize and M/B intercrop. This is attributable to manure's slow release of nutrients. Murwira and Kirchman (1993) studying mineralization from organic fertilizers found that mineralization of manure N increased to a maximum of 46% in the third season of application.

Sole maize vs. maize/bean cropping systems

The soil available N was significantly higher (P<0.05) in sole maize than in M/B intercrop (Table 2). The relatively low soil available N in the M/B intercrop compared to sole maize may be due to the competition between beans and maize for limited N and sharing of fixed N_2 with maize crop (Cadisch et al., 2002).

Legume vs. legume

There were variations in soil available N following the different legumes with significantly higher (P<0.05) amounts realized following CR and LB. The variation among the legumes may be attributed to differences in total N yield (Table 1) and mineralization rates after incorporation. Apart from input to the system through BNF, the higher N content following LB and CR may partly be explained by their deep root systems that captured nitrate from the subsoil. This is also consistent with observations made by Wortmann et al. (2000) and Smesad et al. (2002).

Legume vs. NF

Soil available N content was significantly higher (P<0.05) after legumes compared to the NF and this may be attributable to the superior mineralization rate of the incorporated N rich legume residues. Gathumbi et al. (2004) observed higher soil N levels in fallows improved with legumes than in NF. Microbial tie-up of soil inorganic

Table 2. Available nitrogen (kg ha^{-1}) measured at different stages of maize growth.

Pre-maize and residue treatments		Sole maize: Two weeks after planting	Sole maize: Seedling	Sole maize: tasselling	Sole maize: Cobbing	Sole maize: Maturity	Maize/Bean intercrop: Two weeks after planting	Maize/Bean intercrop: Seedling	Maize/Bean intercrop: tasselling	Maize/Bean intercrop: Cobbing	Maize/Bean intercrop: Maturity
NF	RI	36.80(1.56)	15.40(1.52)	17.80(0.93)	19.30(2.35)	17.20(1.46)	34.05(1.00)	14.20(1.00)	12.20(3.36)	10.20(2.00)	9.90(2.00)
	FYM	37.14(2.18)	18.40(2.00)	14.20(1.26)	11.60(2.62)	9.80(1.50)	34.55(1.23)	19.50(2.20)	15.90(2.26)	9.41(0.46)	7.80 (2.40)
LB	RI	65.98(2.56)	22.58(2.24)	18.80(1.47)	14.49(0.93)	12.30(2.30)	62.94(2.36)	17.35(1.28)	14.80(0.58)	12.70(2.42)	11.60(1.62)
	FYM	52.62(1.80)	21.43(2.30)	12.60(1.18)	11.80(1.28)	9.20(1.68)	50.56(1.42)	16.33(1.18)	14.30(2.60)	10.70(2.60)	8.60(1.42)
CR	RI	49.22(2.36)	20.51(2.90)	26.30(1.24)	19.70(1.18)	18.56(2.40)	43.34(2.10)	29.60(0.62)	18.90(2.96)	14.60(0.69)	8.60(2.23)
	FYM	46.70(2.32)	24.80(3.36)	16.70(1.18)	11.10(1.70)	9.38(1.16)	48.18(2.10)	16.42(2.36)	13.70(1.23)	10.62(2.36)	12.50(3.80)
GP	RI	41.26(1.18)	15.39(3.60)	14.90(4.20)	17.30(1.90)	14.80(2.50)	39.79(2.24)	28.74(1.00)	23.60(0.89)	20.08(1.37)	18.58(2.00)
	FYM	40.89(1.00)	14.23(0.62)	12.70(1.00)	14.49(1.62)	12.60(2.28)	36.70(1.12)	17.70(3.26)	20.20(1.14)	15.60(1.24)	14.30(1.24)

Legend: RI = Residue incorporation, FYM = Farm yard manure. Figures in parentheses are standard deviations.

inorganic N may have occurred during the decomposition of low quality weed biomass with wide C/N ratio (27:1) and concomitantly nutrient release was slow.

Kumar and Gor (2000) reported lower soil N mineralization with incorporation of non- leguminous residues and attributed the same to greater immobilization of N because of high C/N ratios. Added organic material with a high C/N ratio (e.g. > 20 kg C (Kg N)$^{-1}$) provides adequate C substrate, but if the C/N ratio of the microbial biomass is lower (3-14 kg C (Kg N)$^{-1}$), N is taken up from the mineral N pool in the soil to meet the short fall.

Soil available P

Soil available P did not vary significantly following the pre- maize treatments and residue management at the different maize growth stages (Table 3). This is partly attributable to the blanket application of P, an immobile element, as MRP on all plots. Furthermore, Niang et al. (2002) had reported that phosphorus recycling by fallow species through deep uptake is likely to be negligible owing to the very low concentration of available P in the subsoil. Conversely, Lelei et al. (2006) argued that increased biological immobilization of P could be responsible for the lack of differences. There were no significant differences in the concentration of soil available P for the pre-maize and residue management treatments. There was however, slight fluctuations and a general decrease in soil available P with crop growth period in all the treatments (Table 3). This is because of plant uptake, which is continuous throughout the growth period (Long et al., 2003).

Maize DM and grain yield in the sole maize and M/B intercrop systems

Sole maize yield

Sole maize grain and DM yields were significantly higher ($P<0.05$) following improved fallow legumes than NF with sole maize yields following LB being the highest (Table 4). Significant differrences were however not observed after CR and GP residue and FYM incorporation (Table 4).

The higher maize grain and DM yields following LB may be attributed to higher biomass produced by the LB coupled with its superior BNF (Table 1) thus leading to high N content in the legume residues. Inspite of the higher weed biomass produced by the NF weeds, the measured N content was low implying that even upon mineralization the N release was equally low and hence the associated low maize yields. Higher maize grain and DM yields following leguminous fallow than natural fallow may be attributed to the supply of N through mineralization of the high quality legume residues. This is also supported by the fact that the amounts of available N in soil were greater after legumes than after natural fallow (Table 2). Fischler and Wortmann (1999) reported 50% higher maize grain yields following one season fallow with LB than maize following maize. Cheruiyot et al. (2003) in a study on the effect of legume managed fallows on

Table 3. Available P (ppm) measured at different stages of maize growth.

Pre-maize and residue treatments		Cropping sequence and stages of maize growth									
		Sole maize					Maize/Bean intercrop				
		Two weeks after planting	Seedling	tasselling	Cobbing	Maturity	Two weeks after planting	Seedling	tasselling	Cobbing	Maturity
NF	RI	1.60(0.20)	2.00(0.20)	1.50(0.12)	1.20(0.26)	0.90(0.52)	3.20(0.56)	1.70(0.20)	2.00(0.75)	1.00(0.26)	0.80(0.10)
	FYM	4.40(0.17)	1.70(0.26)	4.00(0.36)	3.00(0.10)	2.80(0.42)	2.70(0.44)	2.10(0.40)	1.40(0.17)	1.10(0.26)	0.70(0.17)
LB	RI	5.00(0.28)	2.60(0.14)	3.80(0.42)	2.80(0.20)	2.50(0.30)	2.80(0.26)	2.00(0.20)	2.20(0.10)	1.20(0.34)	1.00(0.41)
	FYM	2.70(0.24)	2.00(0.10)	2.90(0.17)	1.90(0.21)	1.60(0.10)	2.20(0.70)	1.70(0.26)	1.60(0.17)	1.20(0.52)	0.90(0.26)
CR	RI	2.70(0.10)	2.10(0.36)	2.20(0.10)	1.20(0.26)	1.00(0.46)	3.80(0.58)	2.10(0.10)	2.90(0.12)	1.90(0.28)	0.56(1.20)
	FYM	1.90(0.23)	1.60(0.50)	1.00(0.26)	0.70(0.46)	0.40(0.33)	2.70(0.24)	2.00(0.10)	1.80(0.17)	1.40(0.21)	1.60(0.10)
GP	RI	2.50(0.36)	2.10(0.10)	2.00(0.20)	1.70 (0.43)	1.20(0.10)	3.20(0.20)	1.50(0.10)	2.90(0.46)	2.40(0.35)	2.00(0.41
	FYM	2.70(0.44)	1.50(0.10)	1.70(0.18)	1.20(0.10)	0.70(0.36)	2.40(0.20)	2.10(0.38)	2.60(0.20)	1.80(0.10)	1.50(0.26)

soil N in the Rift valley highlands of Kenya reported that among the legume species, lablab showed outstanding positive effect on succeeding maize. This was attributed to increased soil nitrate levels and moisture conservation due to legume residue incorporation. According to Barrios et al. (1998) and Cheruiyot et al. (2003), increase in soil moisture conservation, and weed suppression by the residues may have also contributed to the increased maize yields.

Maize and bean yield in the maize/bean intercrop treatment

Maize yield

Intercropping beans with maize reduced the pre-maize fallow crop effect compared to the sole maize system as shown by the higher maize yields in NF-M/B than NF-M treatments (Table 4). This may be explained by an increase in soil N availability to maize resulting from BNF by the beans, mainly in the low-N fallow treatment.

Maize grain and DM yields in the M/B intercrop were relatively lower, with no significant differences, compared to sole maize in both the residue and FYM incorporated treatments. This may be as a result of the competition between beans and maize for limited N and sharing of fixed N_2 with the maize crop. According to Reddy (2001) and Vandermeer (1989), intercropping advantage depends on net effect in trade-off between interspecific competition and facilitation (positive facilitation) in which one plant species enhances the survival, growth, or fitness of another. In both cropping sequences and residue management systems, the yields following the order LB, CR, GP and NF were reflective of the amounts of N fixed and N content of residue incorporated (Table 1).

Bean

Bean grain yield ranged between 0.5 - 0.6 t ha^{-1} (Table 4) for all pre- maize treatments. Although yields of maize were lower in the M/B intercrop (Table 4), the fact that two crops could be harvested from the same plot more than compensated for the higher yields realized in the sole maize cropping system. According to Reddy (2001), the potential advantages of intercropping include over yielding due to improved utilization of growth resources by the crop and improved reliability from season to season.

Conclusion

In this study, LB was most effective in improving soil productivity as indicated by the performance of subsequent maize crop. Though lower maize yields were realized in the M/B intercrop than sole maize cropping system, the M/B intercrop system may be better and preferable to the small scale farmers due to the dual purposes of ensuring food and nutritional security, as two crops are harvested in one season from the same land, and improving soil fertility through BNF.

The yields obtained with the incorporation of legume residues were not significantly different from those of FYM, farmers are therefore at liberty to either directly incurporate the legume residues or recycle them as livestock feed and be brought back to the farm as FYM. Further, LB was found to be superior in performance compared to other improved legume fallows and hence its up scaling to farmers' fields as a promising and feasible means of boosting maize production and conesquently ensuring food security is recommended.

From the results of this study, it is evident that, legumes have the potential to substitute for inorganic fertilizers. This is in view of the fact that, the maize yields realized in the current study is comparable to those obtained in other studies involving use of inorganic fertilizers. This further attests to the fact that ONM strategy is a feasible technology that could easily fit into the circumstances of the resource poor farmers within the region.

ACKNOWLEDGEMENTS

We are grateful to the Agronomy and Soil Science Departments, Egerton University for respectively providing the experimental site and the laboratory facilities. We also thank the ÖAD (Österreichischer Akademischer Austauschdienst) for funding the research.

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