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Using mucuna and P fertilizer to increase maize grain yield and N fertilizer use efficiency in the Coastal savanna of Togo

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Abstract

To reduce severe soil degradation associated with agriculture, intensified land-use system is being promoted in West African countries. Most soils of the West African savanna zones are so poor that the efficiency of mineral fertilizers, if applied is very low. Many small-scale farmers are therefore reluctant to apply fertilizer also because of their high cost and unavailability. This work investigates a fertilizer management strategy using integrated soil fertility management with a leguminous cover crop (mucuna) so as to improve the soil fertility and increase the use efficiency of fertilizer. The experiment was conducted in the coastal savanna of Togo at Djaka Kopé. The aim was to evaluate the effectiveness of mucuna short fallow (MSF) in increasing maize grain yield through an improved use efficiency of mineral fertilizer. A 2-year maize-mucuna relay intercropping system was compared with continuous sole maize cropping. Fertilizer treatments were factorial combinations of 0, 50 and 100 kg nitrogen (N) ha^{-1} and 0, 20 and 40 kg phosphorus (P) ha^{-1}. While maize grain yield was significantly increased by N fertilization, P did not show any important effect on grain yield. With no N and P applied, grain yield after MSF was on average 40 % (572 kg ha^{-1}) higher than without. The response to N was much greater than the response to MSF, indicating that N was undoubtedly the key element for maize yield building. P fertilization and MSF together influenced positively the apparent N recovery fraction (NRF). N uptake alone did not reflect on its own the yield obtained, and the relationship between grain yield and N uptake is shifted by MSF with the grain yield increase per unit of N uptake being higher with than without MSF. Combining MSF and P fertilization may therefore lead to improved N use efficiency, making the application of fertilizer N (lower rates) more attractive to small-scale farmers.

Introduction

The main constraint to the achievement of high maize yields in the savanna zone of West Africa is the increased deficiency of major nutrients and particularly nitrogen (N) (Piéri 1989; Elemon 1993). Although high crop yields can be obtained with judicious fertilizer use, agriculture with high chemical inputs has not been widely adopted in many West African countries. Various factors have contributed to the low fertilizer use, including scarcity of resources, and inefficient fertilizer use. Regarding the latter, only a fraction of the fertilizer applied to the soil is taken up by the crop, the rest either remains in the soil or is lost through leaching and erosion (Christianson et al. 1990).

N is one of the most difficult nutrients to manage efficiently, as it is water soluble and therefore easily translocated in the soil by infiltrating water, resulting in N losses. The judicious application of organic materials such as green manure, crop residues, compost or animal manure counteracts the negative effects of fertilizers like for instance soil acidification, and maintains particularly in combination with mineral fertilizers, a relatively high production level (Piéri 1989; Vlek 1990). Such a judicious combination of fertilizers and organic sources is being promoted by researchers in West Africa (Keatinge et al. 2001). Emphasis is put on the contribution of organic matter to increase the mineral fertilizer use efficiency, thereby minimizing the losses of the plant nutrients added through the fertilizers (Breman 1998). However, crop residues use may not be practical and even conflicting in the coastal savanna of Togo where they are often used as building materials, fuel and fodder during the dry season. Therefore much is being expected from unpalatable green manure.

Mucuna (*Mucuna pruriens* (L.) DC var. utilis) is prominent among the herbaceous legumes being promoted and adopted in the moist savanna of West Africa, and particularly in Togo and Benin, for use as green manure for soil fertility improvement (Versteeg and Koudokpon 1990; Tarawali et al. 1999). Many authors have drawn attention to the N (Carsky et al. 1998; Tian et al. 2000) as well as non-N benefits of mucuna fallowing including improvement of physical, chemical, and biological soil properties (Becker and Johnson 1998; Hulugalle et al. 1986), and weed and nematode control (Fujii et al. 1992; Reddy et al. 1986).

Most of the previous mucuna research has focused on subsequent increases in crop yield, identifying the mechanisms mentioned above. The present study pays attention to the effectiveness of the MSF in increasing the mineral fertilizer use efficiency as component of the subsequent increase in crop yield. Given the fact that mucuna does not contribute appreciably to the soil organic matter build up as it decomposes fast (Tian et al. 1992), it may not be the best choice for an effective integrated soil fertility management strategy. The objectives of this study are to (i) evaluate the response of maize to fertilizer N applied after MSF, (ii) examine the synergistic effect of P and MSF on N use efficiency and uptake in order to develop a mucuna-based soil fertility management for southern Togo.

Materials and methods

Site and climate

The field trial was carried out on-farm in Djaka Kopé (6^o28'N, 1^o38'E), a village in southern Togo. The mean temperature is 27 ^oC and the annual weather is subhumid with bimodal rainfall distribution. The first rainy season lasts from March to July and the second from September to November, allowing two crops a year (Figure 1). The annual rainfall in the experimental area was 968 in the first cropping year (1999) and 680 mm in the second (2000) with the effective rainfall for maize cropping being 596 mm (April-August) and 403 mm the first and second year, respectively. Prior to the experiments, farmers used the fields for maize or maize-cassava mixed cropping. The soil is a degraded Rhodic Ferralsol (FAO 1991) representative of those of southern Togo locally called "Terres de Barre". Soil texture is predominantly sandy, with a clay content of about 9 % in the surface and 37 % in the subsoil (Tossah 2000). At the start of the experiment in 1999, topsoil (0 to 30 cm) properties of plots with continuous sole maize cropping (without MSF) were a pH (H_2O) of 5.7, 4.9 g kg^{-1} organic carbon and 2.8 cmol kg^{-1} CEC. The nutrient status of the soil was 0.36 g kg^{-1} total nitrogen, 3.1 mg kg^{-1} Olsen P, 1.6 cmol kg^{-1} exchangeable Ca, 0.12 cmol kg^{-1} K and 0.9 cmol kg^{-1} Mg. The analyses were done according to the standard methods used at IITA (IITA 1982). The properties of the topsoil of plots with previous MSF (1997 and 1998) were similar to those without MSF, except the extractable P and the CEC, which were reduced to 0.6 mg kg^{-1} and 2.3 cmol kg^{-1}, respectively. With the maize-mucuna relay intercropping system, farmers sow mucuna between maize plants of about 6 weeks old. After maize harvest, mucuna grows throughout the short rainy season and covers the soil, smothering weeds and leaving thick mulch at the end of its cycle (Figure 1).

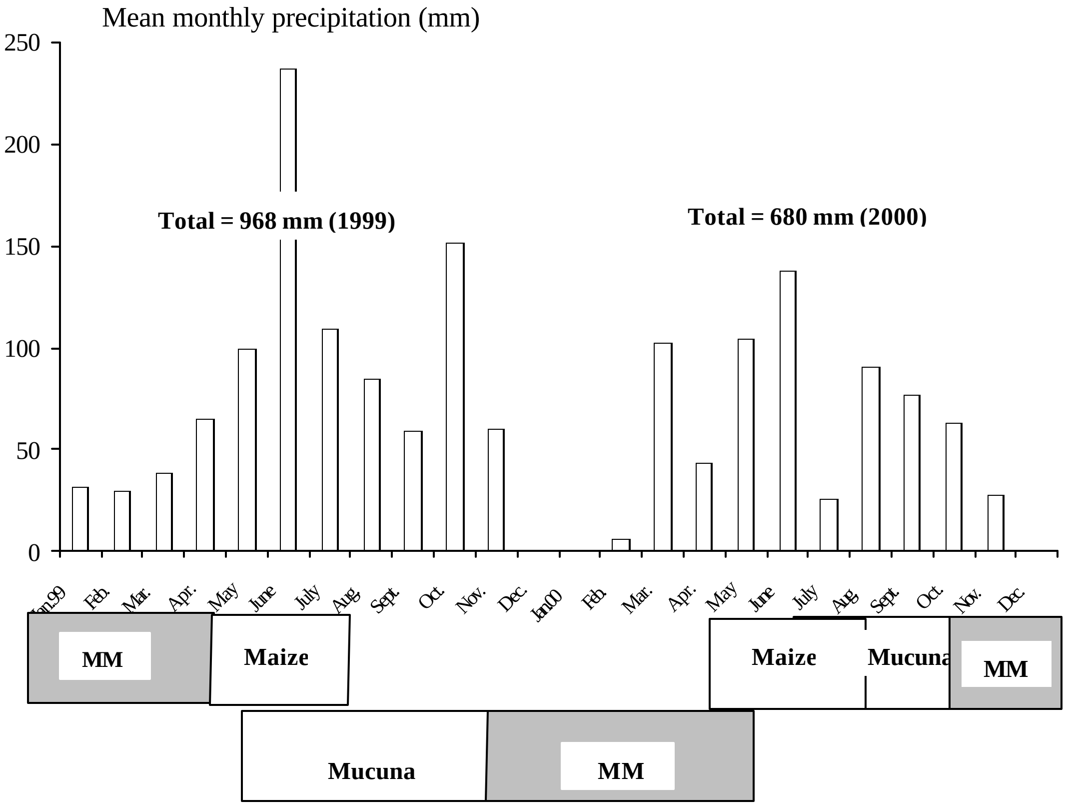

Figure 1. **Maize-mucuna relay intercropping and rainfall pattern (1999-2000) (MM) mucuna mulch.**

As the incorporation of mucuna and maize biomass requires substantial labor, farmers don't completely incorporate them into the soil. Consequently, a part of residues is left on the soil surface as mulch.

From 1999 to 2000 the same maize-mucuna relay intercropping system was imposed on the same plots while the control plots (without mucuna) were left fallow during the short rainy season. Fertilizer treatments were modified as described below in the heading "treatments". During the land preparation, mucuna residues (about 6 t ha^{-1} dry matter of leaves and stems) were hand cleared and incorporated (0-10cm soil depth) with maize stover (2 t ha^{-1} dry matter) by hand hoeing. Maize stover and mucuna residues were half incorporated and a part was left on the soil surface as mulch. At the onset of the rainy season (in late April to mid-May), maize (Ikenne 81-49-SR) was planted. Six weeks after planting maize, mucuna was sown in alternate rows in between maize plants. Distances between rows and hills within rows were 80 cm x 40 cm (2 plants hill^{-1}) for maize and 80 cm x 80 cm (1 plant hill^{-1}) for mucuna. Plots were weeded at 15 and 45 days after sowing (DAS). Maize was harvested in late July to early August and the land was left to mucuna, which prevents farmers from cropping the land during the second short rainy season (September to November). In the dry season, usually in December, at the end of its life cycle, mucuna leaves a thick mulch free of weeds, allowing for the subsequent maize crop during the major rainy season with little or no land preparation or weeding (Vissoh et al. 1998).

Treatments

The experiment was a randomized complete block design with four replicates. The factors were N at 0, 50 and 100 kg ha^{-1} and P at 0, 20 and 40 kg ha^{-1}, with and without MSF, resulting in 72 experimental plots of 6 x 6 m. In order to avoid possible potassium (K) or sulfur (S) limitation, all plots received every year 100 kg K ha^{-1} and 45 kg S ha^{-1} band applied to maize as K_2SO_4. N and K were split in two equal quantities and band applied to maize every year 15 DAS and at flowering (45 DAS), with the objective of reducing nutrient losses. Phosphate rock was not applied to the experimental plots like in the previous years where the plots were used for demonstration. During the experiment (from 1999 to 2000), triple superphosphate (20 % P) was, however, band applied to maize every year 15 DAS.

Plant and soil sampling

The maize plants in an area of 20 m^2 within the middle rows of each plot were harvested at maturity and separated into cob and stover. Grain and stover samples were oven-dried at 60 ^{o}C, weighed, ground to pass 0.5 mm, and then analyzed for total N and P (IITA 1982). Soil samples were taken on the plots prior to land preparation. Six cores per plot were taken diagonally across the plot to a depth of 0 to 30 cm, and mixed to form a composite sample. Soil samples were sun-dried, then after removal of coarse organic debris, crushed and sieved to pass through a 2 mm screen. The sieved soil samples were thereafter chemically analysed for organic carbon, total N, pH (H_2O), pH (KCl) and CEC (IITA 1982).

Estimation of the efficiency of mineral fertilizers

In order to study the effect of MSF and P fertilizer on the N use efficiency of mineral fertilizers, nitrogen agronomic efficiency (NAE) and apparent recovery fraction (NRF) were calculated. NAE was calculated as kg additional grain yield (GY) produced by kg fertilizer N applied at constant P rates. NRF was expressed as a ratio (in percentage) of fertilizer N uptake (NU) by the maize crop (stover + cobs) to fertilizer N applied at constant P rates. These terms are widely used when evaluating the use efficiency of mineral fertilizer and are defined as followed:

NAE (kg kg^{-1}) = (GY with N applied – GY without N applied)/fertilizer N applied

NRF (%) = (NU with N applied – NU without N applied)/nutrient N applied * 100

Statistics

Analysis of variance (ANOVA) was carried out on grain yield, NAE, N uptake, NRF, and P uptake for the two years separately and for both years combined. Prior to analysis of variance, data were examined for normal distribution using Shapiro-Wilk's-test of "Statistica for Windows, release 4". NAE was log–transformed to remedy the variance heterogeneity. When a significant treatment effect was found then comparisons of treatment means were carried out using the least significant difference (LSD) test at 5 % probability level (Gomez and Gomez 1984). Regression analyses were performed to estimate the response in grain yield to soil and fertilizer N uptake and its significance. Testing the homogeneity of regression coefficients (slope) was done to determine whether the regression coefficients in the relationship between grain yield and N uptake with and without MSF are the same or not (Gomez and Gomez 1984).

Results

Dry grain yield of maize

In 1999, average grain yield with no N applied (across P levels) was about 350 kg ha^{-1} without and 524 kg ha^{-1} after a previous MSF (Fig. 2). In 2000, no-N yield was approximately 1832 kg ha^{-1} without MSF and 2200 kg ha^{-1} after the third cycle of MSF (Fig. 3). Significant grain yield increases were obtained at 50 kg N ha^{-1} compared with no N applied, and higher N rate application resulted especially in the year of 2000 in negligible yield increases.

N fertilization after MSF increased ($P \leq 0.001$) grain yield in both years, with the MSF effect being statistically highly significant in 2000 (Fig. 3). This led in 2000 to an interaction ($P = 0.04$) between N fertilization and MSF. With no N and P fertilizer applied, grain yields after MSF were on average 38 % and 41 % higher than without MSF in 1999 and 2000, respectively (Fig. 2A and 3A). In both years, yield response to P application was negligible. Analysis of variance combined over both years showed that P and N fertilizer, MSF and trial year were significant factors, with the mean grain yields in the second year being significantly higher that in the first.

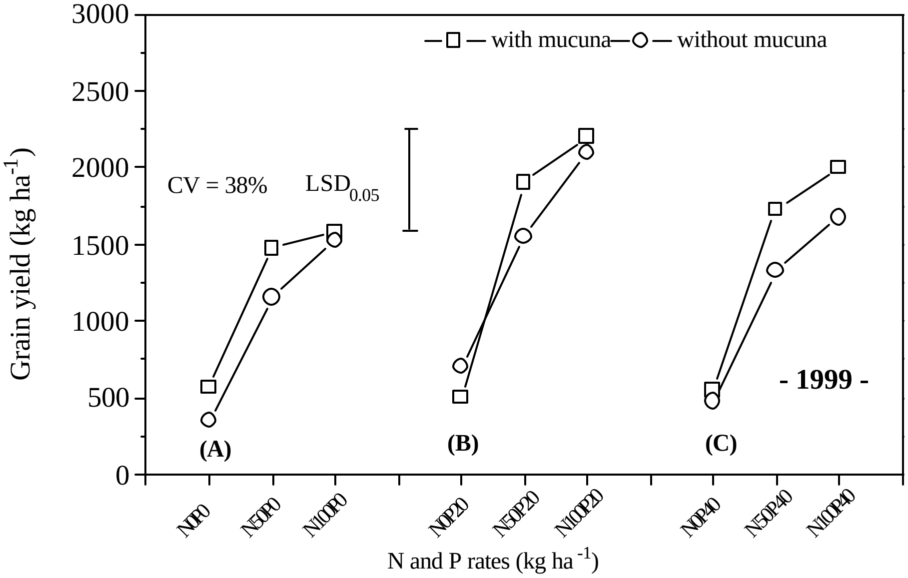

Figure 2. **Response of maize grain yield to N and P (A, B and C) fertilizer application after or without mucuna short fallows.**

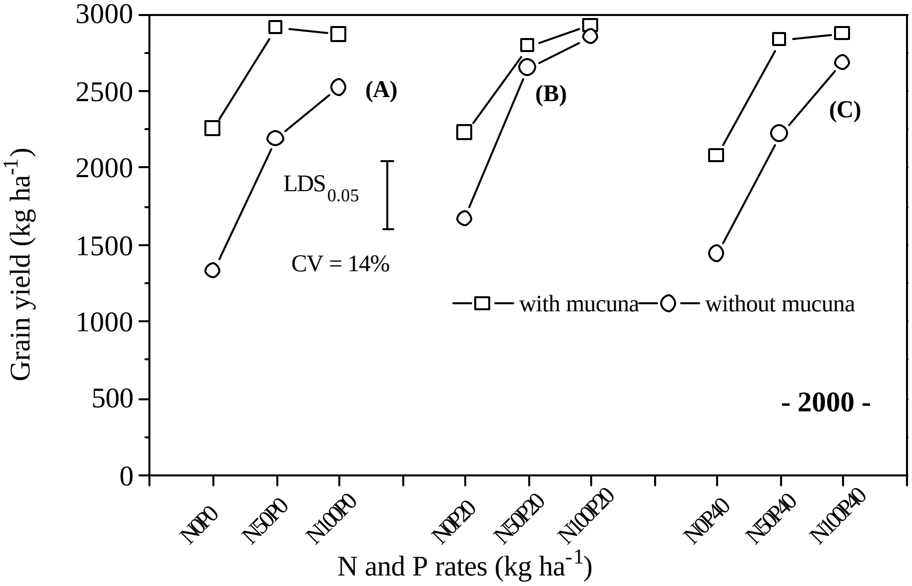

Figure 3. **Response of maize grain yield to N and P (A, B and C) fertilizer application after or without mucuna short fallows.**

Mean values of apparent N agronomic efficiency (NAE) across all N and P rates ranged from 11 to 28 kg kg^{-1} in 1999 and from 7 to 20 kg kg^{-1} in 2000. Without MSF average NAE values for both years did not change. However, with MSF, NAE mean values decreased in the second year (*data not shown*).

Nutrient uptake

Nitrogen

There were significant effects of N and P fertilizer on N uptake by maize in both years. Total N uptake increased up to highest level of N fertilizer applied (Table 1). The mean values of N uptake ranged from 9.3 kg ha^{-1} to 45.6 kg ha^{-1} in 1999 and from 27.6 kg ha^{-1} to 63.8 kg ha^{-1} in 2000. While significant increases in N uptake were obtained from application of 50 kg N ha^{-1}, N uptake levels at 100 kg N ha^{-1}, especially after MSF were not different from those at 50 kg N ha^{-1}.

Table 1. **Total N uptake by maize (kg ha^{-1}) as affected by NP fertilizer and mucuna short fallows (1999 and 2000).**

		Year 1999					
P rate (kg ha^{-1})		P 0		P 20		P 40	
Amendment		-M	+M	-M	+M	-M	+M
N rates (kg ha^{-1})							
N 0		9.3	11.4	14.2	10.6	10.3	10.7
N 50		22.6	23.8	31.5	36.2	28.4	33.5
N 100		32.1	30.6	44.1	45.6	41.7	41.0
[a] LSD$_{0.05}$	12.0						
CV (%)	32.0						
		Year 2000					
N 0		27.6	39.6	38.0	35.2	34.5	34.1
N 50		48.0	52.3	55.1	42.3	47.6	63.0
N 100		55.6	53.1	58.2	57.1	63.8	60.8
[a] LSD$_{0.05}$	9.5						
CV (%)	14.0						

- M without mucuna, +M with mucuna, [a] mucuna x nitrogen x phosphorus interaction

Apparent N recovery fraction (NRF)

Data of average apparent recovery fraction are given in Figure 4. The mean values of NRF ranged from 17 % to 41 % with MSF and from 24 % to 34 % without MSF. NRF was generally higher with 50 kg N ha^{-1} applied than with 100 kg N ha^{-1}.

This is commonly observed when the yield increase from the second increment of fertilizer is less than the first.

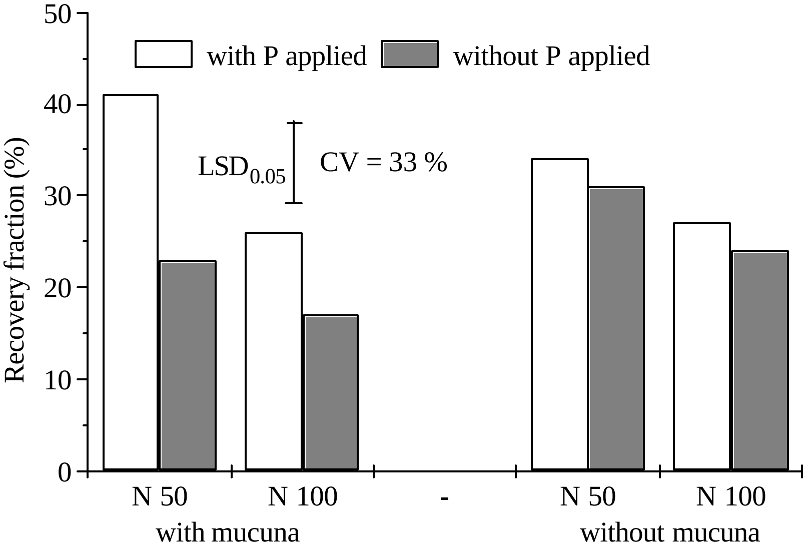

***Figure 4*. Apparent N recovery fraction (%) in total export (grain and stover) as affected by NP fertilizer application and mucuna short fallows (1999-2000).**

Addition of P fertilizer influenced positively NRF after MSF but not without MSF. Analysis of variance combined over both years showed that trial year, P and N ($P \leq 0.001$) fertilizer were significant factors. Though MSF effect on NRF was not significant, there was however MSF x P interaction ($P \leq 0.05$), confirming the MSF effect on NRF when P is applied. After MSF, NRF mean values were apparently lower with no P applied as compared to values without MSF, though the differences were not significant. Addition of P fertilizer resulted, however, at 50 kg N ha^{-1} rate in the highest NRF increases. Indeed, P application after MSF significantly increased NRF by 78 % at 50 kg N ha^{-1} and by 53 % at 100 kg N ha^{-1} rate as compared to no P applied. Without a previous MSF, P application did not increase NRF.

Phosphorus

P uptake by maize was increased by P fertilizer application in both years. But increase was highest in the presence of N (Table 2). The low P rate appears enough for the maximum P uptake, at least in the first year. Even in the absence of P, fertilizer N increased P uptake more than fertilizer P did. Application of both N and P produced further increases in P uptake, leading to a significant N x P interaction in the second year (P = 0.01).

Table 2. **Total P uptake by maize as affected by NP fertilizer and mucuna short fallows (1999 and 2000).**

				Year 1999			
P rate (kg ha^{-1})		P 0		P 20		P 40	
Amendment		-M	+M	-M	+M	-M	+M
N rates (kg ha^{-1})							
N 0		3.2	4.0	5.5	4.4	3.6	4.2
N 50		8.1	9.0	10.5	12.7	10.0	13.5
N 100		9.5	9.9	14.2	14.7	11.9	13.8
$^{a)}$ LSD$_{0.05}$	4.5						
CV (%)	35.0						
				Year 2000			
N 0		8.6	14.7	10.5	14.6	11.6	13.2
N 50		10.9	14.3	18.4	15.3	13.6	20.6
N 100		13.9	14.2	19.0	16.9	22.0	17.8
$^{a)}$LSD$_{0.05}$	3.0						
CV (%)	14.0						

-M with mucuna, +M with mucuna, $^{a)}$ mucuna x nitrogen x phosphorus interaction

MSF improved P uptake in both years in most cases, with significant effect being obtained only in the second. With no P and N applied, MSF induced an averaged P uptake of 0.8 kg ha^{-1} (25 % increase) in 1999 and 6.1 kg ha^{-1} (71 % increase) in 2000. Additionally, a combined application of the maximum P rate (40 kg ha^{-1}) and 50 kg N ha^{-1} after MSF led in the second year to the highest P uptake increase (7 kg P ha^{-1}), resulting in a significant MSF x N x P interaction (P = 0.001).

Discussion

Grain yield increase with no MSF at 50 kg N ha^{-1} was 1.2 t ha^{-1} in 1999 and 0.9 t ha^{-1} in 2000, with N being a significant factor in both years ($P \leq 0.001$). Indeed, N was clearly a key element for yield increase as shown by the response of maize to N application (Figure 2 and 3). Maximum grain yield never exceeded 3 t ha^{-1}, suggesting crop growth limitations – as grain yields of up to 5 t ha^{-1} were obtained in some areas of the region during the 1999-2000 cropping seasons, with the same field management and under similar growing conditions (ITRA and IFDC-Africa 2000).

A possible limitation to maize yield is availability of water. Precipitation from sowing to harvest in 1999 (596 mm) and 2000 (403 mm) were far below the average water demand for high yields. The total dry matter accumulated was on average 3258 kg ha^{-1} and 4780 kg ha^{-1} in 1999 and 2000, respectively (*data not shown*). Accepting that the water use efficiency of maize in mulched plots is 5.5 kg mm^{-1} (Verplancke et al. 1988) rainfall was not sufficient to support yields higher than 3 t ha^{-1}.

The response of maize grain yield to the second increment of fertilizer N was relatively low as compared to the first. This may have been caused by both a supply of N by fertilization and MSF, in excess of the demand for N by maize crop under growing conditions with water shortage. Moreover, water may have been limited for appreciable yield increase up to 100 kg N ha^{-1} rate as rain in 2000 was lower than in the first and not evenly distributed. A period of one month with less than 30 mm rainfall during grain filling (only 26 mm rainfall in July 2000) may result in water deficit at this location, impairing efficient use of nutrients (e.g. N, Figure 5) and resulting in grain yield reduction of up to 40 % (Ehlers 1996). Competition between maize and mucuna for water may not be responsible for the low maize response to higher N rate. Indeed, authors observed a strong competition between maize and mucuna when they are planted the same day, but planting mucuna 45 days after maize appears to be the best period for the maize-mucuna relay cropping in the bimodal rainfall regime of Benin and Ghana (Osei-Bonsu and Buckles 1993).

NAE by maize obtained in this study was low, indicating that another factor than N has limited crop growth. Recent research in northern Nigeria with maize and legume rotation has demonstrated similar trends (Carsky et al. 1999). NAE decreased with increasing fertilizer N rate, reflecting the grain yield limitation observed with the second increment of applied N.

In this study, we could not detect a notable yield improvement with increasing P application, indicating that P was not limiting maize yield. P fertilization increased NRF after MSF but not without MSF. Our results provide evidence of appreciable effect of P fertilization on fertilizer NRF by maize following mucuna. Phosphorus has been found to be a key element for legume production (Giller and Wilson 1991) and particularly for mucuna biomass accumulation (Becker and Johnson 1998), suggesting an indirect positive effect of P fertilization by mucuna on NRF of the subsequent maize. With no fertilizer P applied NRF was lower with MSF than without MSF, though the differences were not significant. This indicates an increased P requirement after MSF. According to Blair and Boland (1978), materials with P content lower than 2.5 g kg^{-1} immobilized P. This confirms our assumption as P content in the biomass of MSF was about 2.0 g kg^{-1}. In this case, only a small fraction of soil organic P deriving from decomposed mucuna is labile in the short term, the rest of soil organic P occurs in stabilized soil organic matter and is not rapidly mineralized. Materials showing net N mineralization (for instance mucuna) can result in net P immobilization and vice versa (Palm et al. 1998). Further study is needed to know to which extent the soil organic P from decomposed mucuna can be available for the subsequent maize.

MSF alone did not show any notable effect on N and P uptake. Furthermore, N uptake did not always reflect the grain yield observed as for instance grain yields attained in control plots were after MSF higher than without MSF (Fig. 3) though the corresponding N uptakes were not. This suggests that yield improvement after MSF was not chiefly related to increased nutrient uptake alone, indicating some indirect effects of MSF. Indeed, N content in the harvested maize across all fertilizer N and P treatments in 2000 (MSF was a significant factor) was 0.38 % with and 0.54 % without MSF in stover, and 1.45 % with and 1.66 % without MSF in grain. This suggests that MSF led to N dilution, resulting in an improved N use efficiency. The most likely explanation for this better N use is that MSF provides other non-N benefits. These non-N benefits from cover crops have been ascribed to improvement of soil structure through physical soil protection (MacRae and Mehuys 1985), suppression of diseases (Osunlaja 1990), and release of growth-promoting substances (Badlock et al. 1981), resulting in a better conservation and use of N and water (Palm et al. 1998; Tian et al. 2000).

These explanations could also apply to the relationship between grain yield and N uptake (across years, N and P treatments) in Figure 5. The grain yield - N uptake relationship is shifted by MSF with the grain yield increase per unit of N uptake being higher with than without MSF at the higher yield part of the curves. For example, with 30 kg N ha^{-1} uptake, grain yield was 2845 kg ha^{-1} after MSF and 2480 kg ha^{-1} without MSF. In other words, fertilizer N use efficiency was 95 kg kg^{-1} with MSF and 83 kg kg^{-1} without MSF. When estimated for each year, the relationships between grain yield – N uptake showed that the regression lines of the treatments without MSF are always below of those with MSF. In addition, the coefficients of the two regression lines (with and without MSF) in 1999 were homogeneous while those in 2000 were significantly different (Gomez and Gomez 1984).

Given the fact that grain yield was highly correlated to N uptake, it can be assumed that the grain yield increase per unit of N uptake observed after MSF expresses the positive “mucuna-induced” indirect effect. The indirect “cover crop-induced” benefits are often inconsistent and difficult to quantify or even substantiate (Smith et al. 1987). Verification of “mucuna-induced” effects and a means of quantifying such benefits would facilitate more definitive evaluation of the agronomic and economic feasibility of mucuna based technologies.

Thus, the higher grain yields obtained in 2000 (compared with 1999) can be attributed to the cumulative “mucuna-induced” effect, including improvement of soil structure, better N and water conservation and use, as the number of MSF increases from one year to the next. Mucuna-biomass in 1999 was estimated at about 6 t ha^{-1} dry matter which is likely to have influenced maize grain yield building in 2000. On the contrary mucuna-biomass in 1998 was much lower (Tamelokpo, personal communication 2000) than in 1999 as the rainfall during the maize growth at this location in 1998 (300 mm) was substantially lower than in 1999 (596 mm). This supports a hypothesis of cumulative “mucuna-induced” positive effect on grain yield in 2000.

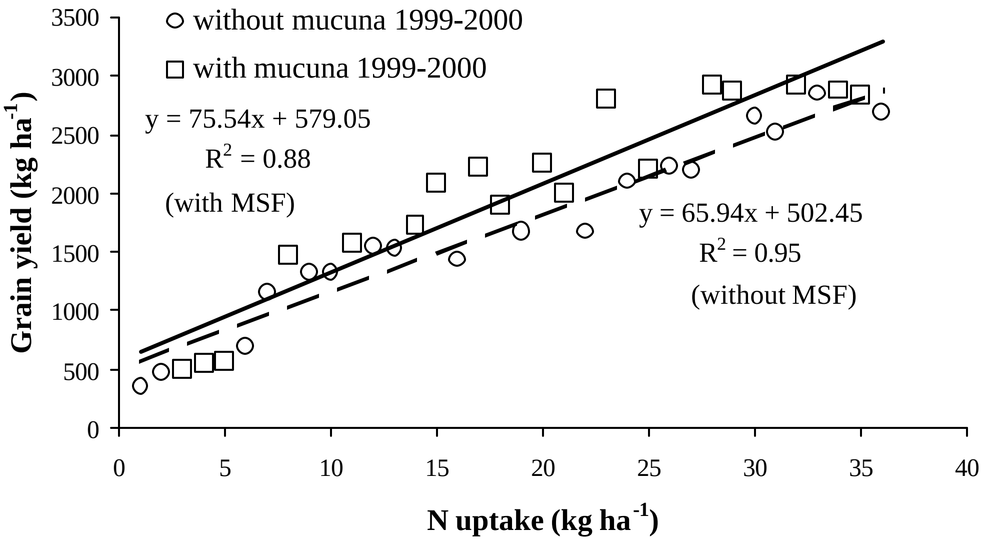

Figure 5. **Effect of mucuna short fallow on N uptake - yield relationship by maize (1999-2000), MSF mucuna short fallow.**

The mucuna biomass was not recorded by the national extension service in 1998 as prior to our experiments (in 1997 and 1998) the plots were used mainly for dissemination/demonstration of technologies.

When compared to the first year, maize grain yields in the second were significantly higher even in the control plots without MSF. Thus it seems likely that other factors not related to MSF positively influenced maize grain yield in the second year. This could be attributed to the 2 years cumulative effects of incorporation of crop residues. Earlier studies also reported increased maize dry matter and grain yield with application of plant residues (Tian et al. 1993).

The practical application of this result would be more advantageous to farmers who have started to adopt the MSF system like those in the coastal savanna of Togo and Benin where soils are very depleted. Such farmers may apply phosphorus and expect to take greater advantage of the “mucuna-induced” benefits. It is important to note, however, that some farmers are reluctant to adopt mucuna technology because the land needed to feed the family is occupied by mucuna without providing a direct return to their investment of land, labor and seed. Mucuna technologies would however be beneficial in the long term and biologically sustainable (Fischer and Wortmann 1997). It is our aim to prevent severe soil degradation in the first place but where this has not been possible, mucuna technology may have an important role in rehabilitating otherwise unproductive land.

Conclusion

The present study shows that continuous maize leads to lower grain yield than maize after MSF. MSF and P fertilization together contributed, especially at 50 kg N ha^{-1} rate, to an increase of apparent nitrogen recovery fraction. Combining MSF and P fertilization should therefore lead to improved N use efficiency, making the application of lower N rates ($\leq$ 50 kg N ha^{-1}) more attractive to small-scale farmers. Fertilizer N was undoubtedly the key element for maize yield building. Although N uptake accounts for much of the yield response, there is evidence that mucuna may also elicit yield responses via mechanisms other than N fertility, as N uptake alone did not reflect on its own the yield obtained. Given the crucial importance of P fertilization of mucuna in improving N uptake by the subsequent maize crop, and accepting the need for further socioeconomic evaluation, a mucuna based technology package, consisting of (i) mucuna as cover crop and recycling of crop residues (organic soil amendments), (ii) a high yielding variety of maize such as Ikenne 81-49-SR (90-day cycle) and (iii) mineral fertilizers, should be proposed to farmers for testing before recommendation/dissemination. Experimental trials will therefore be implemented in many villages in order to identify suitable areas for scaling up. In view of the agronomic implications, long-term effects of mucuna on nutrient use efficiency should be foreseen. Research that helps to identify those soil properties and conditions under which “mucuna-induced” non-nutritional benefits are maximized deserves high priority.

Acknowledgments

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