Restoration of "terre de barre" fertility using pigeonpea grown in rotation or intercropping with maize in the derived savanna of Benin

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Abstract

The following nine main cropping systems were evaluated: maize/maize in rotation without N-fertilizer (control); maize/cowpea in rotation where maize received N-fertilizer; maize/pigeonpea intercropping without N-fertilizer; maize/cowpea/pigeonpea in rotation where maize received N-fertilizer; maize/maize in rotation with N-fertilizer; maize/pigeonpea fallow in rotation where maize received N-fertilizer; maize/pigeonpea intercropping where maize received N-fertilizer; pigeonpea/maize/cowpea in rotation where maize received N-fertilizer; pigeonpea/maize/maize where maize received N-fertilizer. The rate of N-fertilizer applied was 74 kg N as urea (28 kg N/ha 2 weeks after planting maize and 46 kg N/ha 6 weeks after planting maize). Compared to the control, the increase in maize grain yield ranged from –1.55 to 215 % for all cropping systems receiving N-fertilizer and intercropping without N-fertilizer, maize grain yield in intercropping without N-fertilizer increased by 9 % in first year and decreased by 1.55 % in second year compared to the control. The maize stover yield with N-fertilizer application increased by -24 up to 203 %. Pigeonpea grain yield (in intercropping) without N-fertilizer was 56 % higher than with N-fertilizer. Pigeonpea as fallow produced 73-97 % more fresh wood than intercropped pigeonpea without fertilization and 91-118 % more fresh wood than intercropped pigeonpea with N-fertilizer. The intercropped *Cajanus cajan* with N-fertilizer produced 11 % less fresh wood than intercropped without N-fertilizer. The total N amount in the maize grain yield increased by 5-245 % for the first season of year 1 compared to the control and increased by 241-260 % for the second season of year 1 compared to the control. The total N amount in the maize grain of the intercropped pigeonpea/maize with N-fertilizer was 190 % higher than the intercropped pigeonpea/maize without N-fertilizer. The total amount of P follows the same trend as N-fertilizer in intercropped systems. The yield efficiency was low in year 1 compared to year 2. The Land Equivalent Ratio (LER) was higher in cropping system without N-fertilizer than with N-fertilizer.

Key words: N-fertilization, P, yield efficiency, LER, Benin.

Restauration de la fertilité des terres de barre par la culture du pois d'angole en rotation ou en association avec le maïs dans la savane dérivée au Bénin

Résumé

Les 9 principaux systèmes de culture suivants ont été évalués : rotation maïs/maïs sans apport d'azote (témoin) ; rotation maïs/niébé avec fertilisant (apport d'azote sur maïs) ; maïs/pois d'angole en culture intercalaire sans fertilisant ; rotation maïs/niébé/pois d'angole avec fertilisant ; rotation maïs/maïs avec fertilisant ; rotation maïs/jachère de pois d'angole avec fertilisant ; maïs/pois d'angole en culture intercalaire avec fertilisant ; rotation pois d'angole/maïs/niébé avec fertilisant ; rotation pois d'angole/maïs/maïs avec fertilisant sur le maïs. L'azote a été appliqué à la dose de 74 kg sous forme d'urée aux doses de 28 kg d'azote/ha et 46 kg d'azote/ha respectivement à 2 et 6 semaines après le semis du maïs. Comparé au témoin, l'accroissement du rendement en maïs grain a varié de –1,55 à 215 % pour tous les systèmes de culture avec fertilisant et les cultures intercalaires sans fertilisant. Le rendement en maïs grain en culture intercalaire sans fertilisant a augmenté de 9 % durant l'année 1 et a diminué de 1,55 % pendant l'an 2 comparé au témoin. Le rendement en paille de maïs avec fertilisant a augmenté de -24 à 203 %. Le rendement en grains de pois d'angole (culture intercalaire) sans fertilisant a été supérieur de 56 % à celui avec fertilisant. La jachère de pois d'angole a produit plus de bois frais (73-97 %) que la culture intercalaire sans fertilisant de pois d'angole et (91-118 %) qu'en culture intercalaire

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de pois d'angole avec fertilisant. La culture intercalaire de *Cajanus cajan* avec fertilisant a produit 11 % en moins de bois frais que celle sans fertilisant. Comparé au témoin, la quantité totale d'azote dans les rendements de maïs grain a augmenté respectivement en 1ère et 2ème saison de l'année 1 de 5-245 % et de 241-260 %. La quantité totale d'azote dans les rendements de maïs grain en culture intercalaire de pois d'angole/maïs avec fertilisant est supérieure de 190 % à celle dans ceux sans fertilisant. La quantité totale de P suit la même tendance dans les systèmes de culture intercalaire avec fertilisant. L'amélioration du rendement a été plus faible en année 1 que celui en année 2. Le Rapport en Équivalent de Terre (LER) a été plus élevé en système de culture sans fertilisant que celui avec fertilisant.

Key words: N, P, rendement efficient, LER, Benin.

Introduction

In the Mono Province of Benin, reduced fallow periods as a result of increasing demographic pressure (200-250 persons/km^2) have led to a decline in soil fertility and, hence, to reduced agricultural productivity. In this Province, N was evaluated at 68 % of the total cost of chemical fertilizer required to restore soil fertility in a degraded soil (Honlonkou *et al.,* 1999). Farmers' perception of crop importance in improving or depleting soil fertility were investigated in a recent survey conducted in the derived savanna (DS) in southern Benin to get first-hand indications of technologies that could enhance soil nutrients' stocks (Houngnandan *et al*., 2000; Aihou *et al*., 2006a; Aihou *et al.,* 2006b). Giller and Wilson (1991) reported that various approaches could be used to solve the problem of soil fertility. The most obvious solution is to import nutrients in the form of chemical fertilizers but for a variety of social, economic, and other reasons, this is generally difficult. The alternative is to increase the biological input of nutrients and it is here that the biological fixation of atmospheric N has a crucial role to play in increasing the sustainability of yields with minimal external inputs.

Farming systems based on the direct drilling with cover plants on Ferralsols showed advantages in the dynamics of certain nutritive elements (Balbino *et al.*, 2007). Thus, concerning P, the direct drilling with cover plants also contribute to a better valorization while exploiting the organic share of this element in the system. Several low input practices offering a potential for improving soil fertility management in the study area were introduced. They include alley cropping and its variants which consist of the simultaneous planting trees and food crops (*Acacia auriculiformis*, *Leucaena leucocephala* and *Gliricidia sepium* are the most commonly used trees), *Mucuna sp* fallow or *Mucuna sp* in relay maize (*Zea mays*) cropping systems, and the pigeonpea (*Cajanus cajan*) as a resource management technology because of its dense biomass. All these introduced technologies at different scales face low adoption rates because of many technical, social, cultural and economic reasons: mismanagement, the socio-economic aspect, land tenure systems, suitable germplasms, nutrient deficiencies, diseases, etc. Cereals, particularly maize and sorghum, were regarded as depleting soil nutrients while legumes (*Mucuna* sp., *Cajanus cajan* and cowpea (*Vigna unguiculata*) in that order) are regarded as non-depleting. *Cajanus cajan* is a relatively new crop for smallholders of most African countries. But in recent times its cultivation in the moist savanna agro-ecological zone has gained popularity as a consequence of the increasing need for food and fodder. It is also important as a cash crop. Increasing attention goes also to the N_2-fixation capacity of *Cajanus cajan* and its contribution to the subsequent crop in an attempt to develop sustainable cropping systems. Cereal/legume rotation effects on cereal yields have been frequently reported for semi-arid regions of West Africa (Bagayoko *et al*., 2000). Many authors have reported that a generally proposed cause for such effects is an increased N availability for the cereal crop from symbiotic N_2-fixation by the preceding legume, which can lead to significant increases in the available soil N pool.

Intercropping is an age-old practice in the tropics, and it has received the attention of researchers. Several studies indicate that this practice offers a considerable yield advantage over a sole cropping system, because of its efficient utilization of plant growth resources. In terms of land use, growing crops in mixed stands is regarded as more productive than growing them separately (Ofori and Stern, 1987). This may be due to some of the established and speculated advantages for intercropping systems such as higher grain yields, greater land use efficiency per unit land area, and improvement of soil fertility through the addition of N by fixation and excretion from the legume. Legumes are often credited with supplying large amounts of N to the succeeding non-leguminous crops grown in rotation (Hesterman *et al*., 1987). Kumar Rao *et al.* (1987) estimated that the amount of N_2-fixed by *Cajanus cajan* genotypes of different maturity groups ranged between 6 and 60 kg N/ha. Adu-Gyamfi *et al*. (1997) found that *Cajanus cajan* fixed between 120-170 kg.ha^{-1} of atmospheric N throughout the cropping season. *Cajanus cajan* is unique in that, being a shrubby grain legume, it combines food production with ease of establishment, fast growing, high biomass productivity, and local acceptance. Azam *et al.* (1985) found with a pot experiment that fertilizer-N uptake by corn was reduced when *Sesbania aculeta* residues were added to the soil, although only 5 % of the legume's residue-N was absorbed. There are few published data on the relative availability of fertilizer-soil N and *Cajanus cajan* residue-N to crops in West Africa and particularly in the derived savanna. It was hypothesized that *Cajanus cajan* could intensify cropping in the derived savanna zone by restoring and maintaining the soil fertility status and by sustaining crop yields in improving the soil nutrient status for the companion crop in the intercrop or subsequent crop in rotation. As a result of the above-mentioned problems, the objectives of this study were (i) to evaluate the agronomic potential of maize and *Cajanus cajan* in rotation and as intercrop; (ii) to examine the factors influencing the performance of *Cajanus cajan* and maize in both systems.

Material and methods

Site description

The study was carried out at an experimental field belonging to the “Centre de Recherches Agricoles Sud-Bénin Sekou II˝ (6.625°N, 2.245′E) with an altitude of 100 m above sea level in the DS benchmark area, southern Benin. The zone is characterized by a bimodal rainfall distribution: between March and July and from September to November with an annual rainfall ranging from 947 to 1,060 m. A pronounced irregular rainfall pattern is observed during the cropping period. The trial was established on a site referred to as “terre de barre” soils, a common local name for the various red soils developed on the continental terminal formation as found in the coastal zone of Benin, Togo and south-western Nigeria. The soil of the site was deep; dark reddish brown with a textural B-horizon developed on Continental Terminal material and is classified as Ferrali-Haplic Acrisols (FAO, 1991). The selected soil chemical properties of the soil profile before the trial implementation at Sekou II are given in Table 1.

Table 1. Selected soil profile physical and chemical characteristics at Sékou II (Derived Savanna, Benin)

	Depth				
Soil characteristics	**0-8 cm**	**8-22 cm**	**22-44 cm**	**44-94 cm**	**94-140 cm**
Sand ($g.kg^{-1}$)	770	750	620	460	400
Silt ($g.kg^{-1}$)	60	40	40	20	10
Clay ($g.kg^{-1}$)	170	210	340	520	590
Total C (%)	0.85	0.65	0.37	0.32	0.25
Total N (%)	0.073	0.056	0.042	0.048	0.037
C/N	11.7	11.6	8.6	6.7	6.9
Bray P ($mg.kg^{-1}$)	2.20	0.70	0.90	1.40	0.20
CEC (cmol. kg^{-1})	4.2	3.7	3.4	4.0	5.7
pH(H_2O)	5.7	5.7	5.6	5.8	5.8
PH(KCl)	4.9	4.7	4.6	4.8	5.0

Experimental details

The experiment started in site, where three years old fallow vegetation dominated by *Chromolaena odorata* was removed from the trial area. The experiment was a randomized complete block design with four replications and the following treatments (cropping systems) in rotation or in intercropping (Table 2). An amount of 28 kg N, 46 kg P_2O_5, and 28 kg K_2O/ha was applied 2 weeks after planting and an additional 46 kg N/ha was applied 6 weeks after planting on the maize. For this trial, simple fertilizers were used such as urea (46 %N), triple superphosphate (46 % P_2O_5) and KCl (60 % K_2O). The plot area for each treatment was 6.4 m x 6.4 m. In monoculture or in intercropping, maize was planted at 0.80 m x 0.40 m with 2 plants per hill. Cowpea was planted at 0.60 m x 0.20 m with 1 plant per hill. *Cajanus cajan* was planted at 0.80 m x 1.60 m with 1 plant per hill in monoculture as well as in intercropping.

Soil sampling

Before the trial implementation in year 1, the field soil were sampled taken at the top soil (0-30 cm) and the following soil chemical characteristics were determined: total C (0.62 %), total N (1.07 %), total phosphorus (13.82 %), pH (H_2O) (5.40), pH ($CaCl_2$) (6.68).

Table 2. Repartition in time and space of the cropping system

Cropping system	Identification	Year 1		Year 2	
		Season 1	Season 2	Season 1	Season 2
Maize (*Zea mays*) non fertilized in monoculture	MZNFm (T1)	Sole Maize non fertilized in monoculture	Sole Maize non fertilized in monoculture	Sole Maize non fertilized in monoculture	Sole Maize non fertilized in monoculture
Maize (*Zea mays*) fertilized in rotation with Cowpea (*Vigna unguiculata*)	MZF/Co (T2)	Sole Maize fertilized	Sole Cowpea without fertilization	Sole Maize fertilized	Sole Cowpea without fertilization
Maize (*Zea mays*) non fertilized intercropped with Pigeonpea (*Cajanus cajan*)	MZNFICc (T3)	Sole Maize non fertilized intercropped with Pigeonpea	Sole Pigeonpea after harvesting Maize	Sole Maize non fertilized intercropped with Pigeonpea	Sole Pigeonpea after harvesting Maize
Maize (*Zea mays*) fertilized in rotation with Cowpea (*Vigna unguiculata*) and Pigeonpea (*Cajanus cajan*)	MZF/Co/Cc (T4)	Sole Maize fertilized	Sole Cowpea without fertilization	Sole Pigeonpea	Sole Pigeonpea
Maize (*Zea mays*) fertilized in monoculture	MZFm (T5)	Sole Maize fertilized in monoculture	Sole Maize fertilized in monoculture	Sole Maize fertilized in monoculture	Sole Maize fertilized in monoculture
Maize (*Zea mays*) fertilized in rotation with Pigeonpea (*Cajanus cajan*)	MZF/Cc (T6)	Sole Maize fertilized	Sole Maize fertilized	Sole Pigeonpea	Sole Pigeonpea
Maize (*Zea mays*) fertilized intercropped with Pigeonpea (*Cajanus cajan*)	MZFICc (T7)	Sole Maize fertilized intercropped with Pigeonpea	Sole Pigeonpea after harvesting Maize	Sole Maize fertilized intercropped with Pigeonpea	Sole Pigeonpea after harvesting Maize
Pigeonpea (*Cajanus cajan*) in rotation with Maize (*Zea mays*) fertilized and Cowpea (*Vigna unguiculata*)	Cc/MZF/Co (T8)	Sole Pigeonpea	Sole Pigeonpea	Sole Maize fertilized	Sole Cowpea without fertilization
Pigeonpea (*Cajanus cajan*) in rotation with Maize (*Zea mays*) fertilized	Cc/MZF/MZF (T9)	Sole Pigeonpea	Sole Pigeonpea	Sole Maize fertilized	Sole Maize fertilized

(Ti): Treatment i

Plant sampling

At harvest, maize grain and stover; cowpea grain and haulms; *Cajanus cajan* grain, biomass and fresh wood were recorded. For maize, cowpea and *Cajanus cajan*, four plants were randomly selected in each plot and at harvesting time recorded for dry matter (DM) yield after drying the samples at 65 °C for 72 hours. All samples of the maize parts were analyzed for N and P following the method described by Anderson and Ingram (1993).

Calculation of yield efficiency

Fertilizer N use by maize from urea-N was evaluated as follows:

$$\text{Yield efficiency (kg maize grain DM kg}^{-1}\text{ N)} = \frac{\text{Actual maize DM yield} - \text{Absolute control DM yield}}{\text{Amount of fertilizer applied}}$$

Land Equivalent Ratio

The Land Equivalent Ratio (LER) was used to evaluate intercrop efficiencies in yield and N uptake by the plants with respect to simple crops (Willey, 1979). The LER defines yield as a function of area:

$$\mathbf{LER = IC_a / MC_a + IC_b / MC_b}$$, where:

IC and MC refer to intercrop and monocrop yields or N uptake, respectively, and the subscripts a and b indicate the crop yields of the two plants in the mixture.

Statistical analysis

All data from maize, cowpea, and *Cajanus cajan* were submitted to analysis of variance with the GLM procedure of the SAS system (SAS, 1992). The LSMEANS statement was used to calculate the means.

Results

Crop yields

In year 1 and year 2, both the sole and intercropped maize showed significant responses to N applied at the rate of 74 kg N/ha^{-1}. The increase in maize grain yield ranged from –1.55 to 215 % compared to the control. Maize grain yield of the intercrop treatment without N-fertilizer in year 1 increased by 9 % compared to the control, while in year 2, it decreased by 2 % compared to the control (1,809 kg.ha^{-1}). In year 1 and year 2, maize stover yield increased between -24 and 203 % compared to the control. Maize stover yield in the intercrop treatment without N-fertilizer decreased by 24 % in year 2 compared to the control (3,194 kg.ha^{-1}) (Tables 3 and 4).

In the second season of both years, the mean cowpea grain was higher in treatment 2 than the treatment 4. The same trend was observed with cowpea haulms in the second season of year 1. In the second season year 2, cowpea grain and haulms were lower compared to year 1 (Table 5).

Cajanus cajan grain yield (in intercrop) without N-fertilizer (298 kg.ha^{-1}) was 56 % higher than with N-fertilizer (132 kg.ha^{-1}). *Cajanus cajan* fallow produced 16 % less grain than intercropped *Cajanus cajan*. In the present study, only data of *Cajanus cajan* in year 1 were evaluated. *Cajanus cajan* in pure stand as fallow and at the same density as intercropped produced 43 to 62 % more leaf dry matter than intercropped leaf dry matter without N-fertilizer (1,248 kg.ha^{-1}) and 31 to 48 % more leaf dry matter than intercropped *Cajanus cajan* leaf dry matter with N-fertilizer. Without fertilization *Cajanus cajan* in pure stand as fallow produced 73 to 97 % more fresh wood than intercropped and 91 to 118 % with N-fertilizer. Intercropped *Cajanus cajan* with N-fertilizer produced 11 % less fresh wood than intercropped without N-fertilizer (Table 6).

A significant correlation was found between the leaf dry matter and the fresh wood of *Cajanus cajan* (r=0.72). The *Cajanus cajan* grain yield was significantly inversely related to the maize grain yield (r=-0.51). A significant correlation was found between the maize grain yield and the maize stover (r=0.69) (Table 7).

Table 3. Mean of maize grain and stover dry matter yield (kg.ha^{-1}) and percentage increase over the cropping system maize non fertilized in monoculture (MZNFm) (T1) in the first season in year 1 and year 2.

Cropping system	Year 1						Year 2					
	grain (kg.ha^{-1})	SD	% increase	stover (kg.ha^{-1})	SD	% increase	grain (kg.ha^{-1})	SD	% increase	stover (kg.ha^{-1})	SD	% increase
MZNFm (T1)	582	153	-	1,474	278	-	1,809	553	-	3,194	1,728	-
MZF/Co (T2)	1,737	411	198	2,747	968	86	4,052	940	124	6,076	1,509	190
MZICcNF (T3)	634	305	9	1,914	687	30	1,781	1,243	-155	2,426	1,148	-24
MZF/Co/Cc (T4)	1,836	575	215	2,820	812	91	-	-	-	-	-	-
MZFm (T5)	1,483	217	155	2,800	984	90	3,565	390	97	5,566	584	74
MZF/Cc (T6)	1,780	202	206	2,569	210	74	-	-	-	-	-	-
MZFICc (T7)	1,813	361	212	2,869	474	95	3,991	1,177	121	6,260	2,494	96
Cc/MZF/Co (T8)	-	-	-	-	-	-	3,982	620	120	5,004	1,380	57
Cc/MZF/MZF (T9)	-	-	-	-	-	-	4,324	811	139	4,700	1,107	47

SD: Standard Deviation

Table 4. Mean of maize grain and stover dry matter yield (kg.ha^{-1}) and percentage increase over the cropping system maize non fertilized in monoculture (MZNFm) (T1) in the second season in year 1 and year 2

Cropping system	Year 1						Year 2					
	grain (kg.ha^{-1})	SD	% increase	stover (kg.ha^{-1})	SD	% increase	grain (kg.ha^{-1})	SD	% increase	stover (kg.ha^{-1})	SD	% increase
MZNFm (T1)	719	172	-	865	1,789	-	349	108	-	1,178	270	-
MZFm (T5)	2,344	235	226	2,289	462	165	2,101	515	502	2,218	295	88
MZF/Cc (T6)	2,276	252	217	2,617	1,619	203	-	-	-	-	-	-
Cc/MZF/MZF (T9)	-	-	-	-	-	-	2,352	314	574	2,881	349	145

SD: Standard Deviation

Table 5. Mean of cowpea grain and haulms dry matter (kg.ha^{-1}) in the second season in Year 1 and Year 2

Cropping system	Year 1				Year 2			
	grain (kg.ha^{-1})	SD	haulms (kg.ha^{-1})	SD	grain (kg.ha^{-1})	SD	haulms (kg.ha^{-1})	SD
MZF/Co (T2)	519	134	3,811	622	181	4	1,887	287
MZF/Co/Cc (T4)	438	105	3,538	755	-	-	-	-
Cc/MZF/Co (T8)	-	-	-	-	83	1	2,468	472

SD: Standard Deviation

Table 6. Grain, leaves and fresh wood dry matter of *Cajanus cajan* (kg.ha^{-1}) in year 1

Cropping systems	grain (kg.ha^{-1})	SD	leaves dry matter (kg.ha^{-1})	SD	Fresh wood (kg.ha^{-1})	SD
MZNFICc (T3)	298	131	1,249	625	5,857	1,633
MZFICc (T7)	132	35	1,361	246	5,300	2,633
Cc/MZF/Co (T8)	249	76	2,022	485	10,136	1,239
Cc/MZF/MZF (T9)	249	49	1,784	771	11,543	1,402

SD: Standard Deviation

Table 7. Correlation coefficient between pigeonpea grain, pigeonpea dry matter leaves, pigeonpea fresh wood and maize grain and stover

parameters	pigeonpea grain	pigeonpea dry matter leaves	pigeonpea fresh wood	maize grain	maize stover
pigeonpea grain	-	ns	Ns	-0.51	ns
pigeonpea dry matter leaves	ns	-	0.72	ns	ns
pigeonpea fresh wood	ns	0.72	-	ns	ns
maize grain	-0.51	ns	Ns	-	0.69
maize stover	ns	ns	Ns	0.69	-

*** significant at p<0.05; ** significant at p<0.01; ns: not significant**

Total nitrogen content in the maize plants

The total N content in the maize grain increased by 5 to 245 % compared to the control (7.65 kg N/ha). It was 190 % higher than without N-fertilizer (8.02 kg N/ha). A similar trend was observed in the N content of maize stover and the total N content of the maize cobs. In the second season of year 1, treatments without intercropping and receiving N fertilizer had a total N content in the maize grain that varied between 9 and 30.67 kg N/ha. For the stover, it varied between 4.37 and 16.24 kg N/ha, and for the cobs, it ranged between 0.85 and 2.61 kg N/ha (Tables 8, 9 and 10).

Total phosphorus content in the maize plants

In the first season of year 1, the total phosphorus content in the maize grain increased between 21 and 366 % compared to the control (1.49 kg P/ha). While the total phosphorus content in the grain of the intercrop *Cajanus cajan* with N-fertilization was 13 times more than of the intercrop without N-fertilizer. In the stover, it increased by 4.41 to 84.56 % compared to the control (1.36 kg P/ha). The total phosphorus content in the cobs increased by 106 to 176 % compared to the control. But with the intercrop, without fertilizer, it decreased by 11.76 % compared to the control. In the second season of year 1, the treatments without intercropping and receiving N-fertilizer had a total phosphorus content in the maize grain which varied between 2.12 and 5.73 kg P/ha, for stover it varied between 0.43 to 1.29 kg P/ha, and for the cobs, it ranged between 0.08 and 0.28 kg P/ha. However, a significant increase was not observed between the total phosphorus content in the stover when intercropped with N-fertilizer or without N-fertilizer (Tables 8, 9 and 10).

Yield efficiency

In year 1, the yield efficiency ranged between 12.18 and 21.95 %.While in year 2, it varied between 23.67 and 33.98 %. It was observed that the efficiency was low in all cropping systems in year 1 (Table 11). The water is one of the main factors, which affect the yield efficiency. When the rainfall pattern was favourable in year 2, the yield efficiency was higher in all-cropping systems receiving N-fertilizer than those in year 1.

Land Equivalent Ratio

Cajanus cajan/maize intercropping gave a higher LER of 2.41 in grain production than the monoculture cropping but it was the monoculture cropping and intercrop without N-fertilizer that gave the highest LER (Table 12).

Table 8. % total N and % total P in maize grain and stover, and cob in first season year 1

Cropping systems	% total N						% total P					
	Grain	Standard Deviation	Stover	Standard Deviation	Cob	Standard Deviation	Grain	Standard Deviation	Stover	Standard Deviation	Cob	Standard Deviation
MZNFM (T1)	1.32	0.11	0.68	0.22	0.53	0.09	0.25	0.06	0.10	0.05	0.11	0.02
MZF/Co (T2)	1.32	0.16	0.62	0.12	0.51	0.24	0.25	0.03	0.05	0.01	0.09	0.04
MZNFICc (T3)	1.29	0.12	0.69	0.14	0.51	0.16	0.27	0.07	0.12	0.03	0.10	0.04
MZF/Co/Cc (T4)	1.41	0.15	0.63	0.12	0.47	0.09	0.36	0.09	0.06	0.02	0.08	0.01
MZFm (T5)	1.18	0.09	0.78	0.25	0.61	0.11	0.28	0.07	0.08	0.03	0.11	0.03
MZF/Cc (T6)	1.20	0.15	0.73	0.10	0.60	0.09	0.27	0.08	0.07	0.02	0.11	0.03
MZFICc (T7)	1.27	0.12	0.77	0.15	0.60	0.10	0.31	0.05	0.09	0.03	0.10	0.03

Table 9. Total N and P ($kg.ha^{-1}$) in the different parts of maize and percentage increase over the control (MZNFm) in the first season 1999

Cropping systems	Total N						Total P					
	Grain ($kg.ha^{-1}$)	% increase	Stover ($kg.ha^{-1}$)	% increase	Cob ($kg.ha^{-1}$)	% increase	Grain ($kg.ha^{-1}$)	% increase	Stover ($kg.ha^{-1}$)	% increase	Cob ($kg.ha^{-1}$)	% increase
MZNFm (T1)	7.65	-	9.81	-	0.79	-	1.49	-	1.36	-	0.17	-
MZF/Co (T2)	22.50	195	16.15	65	2.09	165	4.21	183	1.42	4	0.38	124
MZNFICc (T3)	8.02	4.84	13.40	37	0.74	-6	1.80	21	2.18	60	0.15	-12
MZF/Co/Cc (T4)	26.41	245	18.07	84	2.74	171	6.94	366	1.70	25	0.35	106
MZFm (T5)	17.67	131	20.81	112	2.31	192	4.18	181	1.90	46	0.43	153
MZF/Cc (T6)	21.30	178	18.76	91	2.65	235	4.22	183	1.74	28	0.48	182
MZFICc (T7)	23.27	204	21.50	120	2.61	230	5.61	277	2.51	85	0.47	176

Table 10. Total N and P (kg.ha-1) in the different parts of maize and percentage increase over the control (MZNFm) in the second season year 1

Cropping systems	Total N						Total P					
	Grain (kg.ha-1)	% increase	Stover (kg.ha-1)	% increase	Cob (kg.ha-1)	% increase	Grain (kg.ha-1)	% increase	Stover (kg.ha-1)	% increase	Cob (kg.ha-1)	% increase
MZNFm (T1)	9.00	-	4.37	-	0.85	-	2.12	-	0.43	-	0.08	-
MZFm (T5)	32.40	260	12.91	195	2.25	165	6.05	185	1.11	158	0.22	175
MZF/Cc (T6)	30.67	241	16.24	272	2.61	207	5.73	133	1.29	200	0.28	250

Table 11. Maize grain yield efficiency in the first and second season of year 1 and Year 2

Cropping systems	Year 1				Year 2			
	Season 1		Season 2		Season 1		Season 2	
	Grain yield (kg)	Yield Efficiency	Grain yield (kg)	Yield Efficiency	Grain yield (kg)	Yield Efficiency	Grain yield (kg)	Yield Efficiency
MZNFm (T1)	582	-	719	-	1,809	-	349	-
(MZF/Co (T2)	1,737	15.60	-	-	4,052	30.31	-	-
MZNFICc (T3)	634	-	-	-	1,781	-	-	-
MZF/Co/Cc (T4)	1,836	16.95	-	-	-		-	-
MZFm (T5)	1,483	12.18	2,344	21.95	3,565	23.72	2,101	23.67
MZF/Cc (T6)	1,780	16.19	2,276	21	-	-	-	-
MZFICc (T7)	1,813	16.64 (15.93)	-	-	3,991	29.48 (29.86)	-	-
Cc/MF/Co (T8)	-	-	-	-	3,982	29.36	-	-
Cc/MZF/MZF (T9)	-	-	-	-	4,324	33.98	2,352	27.07

Values between brackets are yield efficiency of maize in intercropping

Table 12. Land Equivalent Ratio (LER) in first season of Year 1

Intercropping system	Maize grain yield in intercropping ($kg.ha^{-1}$)	Maize in monoculture cropping system	Maize grain yield in monoculture ($kg.ha^{-1}$)	*Cajanus cajan* in monoculture	*Cajanus cajan* grain yield in monoculture ($kg.ha^{-1}$)	Cajanus *cajan* in intercropping	*Cajanus cajan* grain yield in intercropping ($kg.ha^{-1}$)	LER
MZNFICc (T3)	634	MZNFm (T1)	582	Cc/MZF/Co (T8)	249	MZNFICc (T3)	298	2.41
MZFICc (T7)	1,813	MZF/Co/Cc (T4)	1,836	Cc/MZF/Co (T8)	249	MZFICc (T7)	132	1.52
MZFICc (T7)	1,813	MZFm (T5)	1,483	Cc/MZF/Co (T8)	249	MZFICc (T7)	132	1.75
MZFICc (T7)	1,813	MZF/Cc (T6)	1,780	Cc/MZF/Co (T8)	249	MZFICc (T7)	132	1.55

Discussion

Many authors have raised that the lack of N and P most often limit crop yields and microbial activity. Some cover plants as *Cajanus cajan* contribute to improve its biodisponibility (Balbino *et al.*, 2007). The fodder plant better recycle part of the ions NO^{3-}, K^{+}, $Ca^{2+\,E}$, Mg^{2+} which would be if not lixiviated (Balbino *et al.*, 2007). Consequently in this study, application of N enhanced grain yield as has been found in many studies. The most striking observation made in this study was that grain yields decreased in the intercropped, maize/pigeonpea without N-fertilizer, while it was increased with N fertilizer. Despite pigeonpea and maize generally grown under inter- or mixed cropping system, studies on fertilizer use efficiency (FUE) have mainly focused on sole cropping systems than in mixture.

The response to N-fertilization was remarkable in both years. Intercrop maize with N-fertilization produced the highest yield as compared to the other treatments with N. But intercrop maize without N-fertilization produced the lowest yield and no significant increase was observed as compared to the control. Rao *et al.* (1987) reported that any beneficial effect from legumes should have been evident when 0 $N.ha^{-1}$ is applied to the cereal. In fact, the legume reduces the cereal yield at 0 $N.ha^{-1}$. He pointed out that these results suggest that the cereal under most field conditions does not derive any beneficial effect from the legume during the current season, particularly when it is grown at full population and without N–fertilization. Therefore, to obtain good yields, fertilizers should be applied in both the inter and sole cropping. Application of N fertilizer to legumes decreases its dependency of the N_2 fixation. Therefore most farmers assume that N application to intercropping system may be antagonistic instead of synergetic (Adu-Gyamfi *et al.*, 1997). N requirements of sorghum when grown as sole crop are reported to be higher than when grown as intercrop (Adu-Gyamfi *et al.*, 1997). However, they pointed out higher nutrient uptake by pigeonpea/maize, pigeonpea/sorghum as compared to sole-cropped pigeonpea. It was reported also in a pigeonpea intercrop treatment that 80 kg $N.ha^{-1}$ was optimal, where as Adu-Gyamfy *et al.* (1996) recommended a moderate rate dose of 25-30 kg $N.ha^{-1}$.

The response of maize to N in any studied cropping system is mainly dependent on the seasonal rainfall. In a normal season, it is economical when rainfall is high and well distributed. In this study, in year 1, grain yields decreased with decreasing rainfall compared to the results of year 2. Despite the decreasing rainfall and grain yields in this study, a significant grain yield increase occurred due to N application and current soil fertility status. Sakala *et al.* (2000) reported that when crops are grown in association, the residues of the different crops become mixed so that residues of different quality decompose simultaneously within the same soil volume. Interaction between decomposing residues can be complex and result in N mineralization patterns which are not readily predicted from N mineralization of the separate component of the mixture. Maize yield in the rotation maize/cowpea or rotation *Cajanus cajan* fallow/maize, with N-fertilization, produced a good yield as intercrop. Giller (2001) argued that for grain legumes, to play an important role in maintaining soil fertility for other crops in rotation, they must obviously leave behind more N from N_2-fixation than the amount of soil N that is removed in the crop.

The amount of total N and P in the different plant parts of maize was high in all treatments receiving fertilizers but it was low with intercropping and no fertilizer. A probable explanation is that N-fertilization promotes the mineralization of soil N and consequently enhances N uptake and yield efficiency. Rao et al. (1987) reported that the efficiency of N utilization was less in intercropping, probably because of competition from legumes and their sharing of some N. They pointed out that the difference between a sole and intercropped cereal was less when the associated legume was pigeonpea or groundnut. It was reported that fertilizer N recovery (FNR) by sole-cropped pigeonpea (14 %) was higher than intercropped pigeonpea (2-4 %). The low FNR by intercropped *Cajanus cajan* is attributed to the fact that no N fertilizer was applied to intercropped pigeonpea (Adu-Gyamfi *et al.*, 1996). These authors suggested that N application to pigeonpea during the pod filling stage (where the N_2 fixing ability is low and N requirement is high) could help to increase the grown yield and the overall productivity of the system (Adu-Gyamfi *et al.*, 1997).

The Land Equivalent Ratio was higher in the treatment without N-fertilizers and less in the treatments with N-fertilizers. Willey (1979) reported that this trend apparently supports the hypothesis that intercropping is more relevant for poor environments; but the monetary advantage which remained little affected by N does not suggest that intercropping has to be replaced by sole cropping with N-fertilizer. Dalal (1974) reported that intercropping maize with either beans or cowpeas had more adverse effects on the grain yield of the maize than pigeonpea. He attributed this to the fact that high rates of nutrient absorption by the two legumes coincided with uptake by the maize crop, whereas with pigeonpea the greatest nutrient demand occurred after the maize crop had been harvested. N-beneficial effects of the legumes on the associated crop could arise from improved mineralization of soil N by the priming effect of the legume, excretion of nitrogenous compounds from nodulated root systems, N-conserving effects, the greater competitive ability of the companion crop for soil N compared to the legume which generally holds true when legumes are intercropped with cereals, the decay of sloughed-off nodules and roots, leaching of soluble N from leaves, and the decay of fallen leaves (Senaratne *et al.*, 1995). Danso *et al.* (1987) reported that the well known contribution of a grain legume in an intercrop is that of its ability to fix atmospheric N_2 which therefore presumably reduces the competition for soil N with the associated non-N-fixing crop. This was reported, despite some reports of N transfer from a grain legume to an associated non-legume. Several others have shown that this does not occur, or is of little importance.

Several researchers have reported N transfer from grain legumes to the associated crop i.e. from groundnut, cowpea and mungbean to sorghum, to wheat, from soybean to sorghum and from cowpea to maize. On the other hand, some researchers could not observe any N transfer from legumes to the associated crop, i.e. from fababean to barley. Nitrogen transfer from legumes may depend on the N_2 fixation, the genotype, the interspecies distance, the legume/cereal ratio, the fertility level, the mycorrhizal colonization, etc. (Senaratne *et al.*, 1995). They suggested that further studies on the above mentioned aspects would prove useful in elucidating and promoting N transfer, and in assessing its significance in sustaining the productivity of low-input legume-based intercropping systems. We do not know when intercropping began nor why civilization fostered its use, whether by design or accident. Intercropping dominated early agriculture and it is still practiced in many areas of the worlds (Anders *et al.*, 1996). With regard to that, it is known that legume/cereal intercropping would minimize the application of N–fertilizers in the tropics. In this study, there was no direct evidence that intercropped maize gained N from associated pigeonpea. For further research, it is necessary to draw more attention on plant species (germplasm and cycles), spatial arrangement, date of sowing (to minimize competition), tillage, balanced plant nutrient management and integrate diseases and insect control for optimum performance of maize/pigeonpea intercropping, pigeonpea fallow/maize rotation.

Conclusion

The increase in maize grain yield ranged from –1.55 to 275 % in all cropping systems (rotation or intercropping with pigeonpea), with or without N-fertilizer application compared to the control (maize/maize in rotation without N-fertilizer). The maize grain yield in intercropping without N-fertilizer increased by 9 %. Pigeonpea grain yield (in intercropping) without N-fertilizer was 56 % higher than this with N-fertilizer. Pigeonpea as fallow produced 73 to 97 % more fresh wood than intercropped pigeonpea without fertilization and 91 to 118 % more fresh wood than intercropped pigeonpea with N-fertilizer. The intercropped pigeonpea with N-fertilizer produced 11 % less fresh wood than intercropped without N-fertilizer. The total N amount in the maize grain increased by 5 to 245 % in all cropping system (rotation and intercropping with *Cajanus cajan*, with or without N-fertilizers compared to the control. The N yield was low in intercropping without N-fertilizer. The total P followed the same trend as total N. The Land Equivalent Ratio (LER) was higher in cropping systems without N-fertilizer than in those fertilized.

The ultimate result of a cropping system that does not replace the nutrients removed by the crops is impoverishing of soil and poor crop yields. The maize/pigeonpea intercropping without N-fertilizer produced the lowest grain yield and the lowest N yield compared to the cropping systems receiving N-fertilizers. To make more sustainable and efficient maize/pigeonpea intercropping or maize/pigeonpea rotation, a minimun amount of N-fertilizer as well as other biological treatments (e.g. % AMF) are required according to the soil fertility and water use management.

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