Legumes in Sustainable Maize and Cassava Cropping Systems in Ghana

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Resumé

Ennin, Stella A. & Dapaah, H. K. *Les Légumineuses dans les systèmes durables de la culture du maïs et du manioc au Ghana.* Une étude de la rotation légumineuse maïs a montré une favorable arrière action en faveur du maïs dans la zone transitionnelle de la forêt savanne par rapport à la zone de la savanne côtière et quand le maïs a suivi *Mucuna pruriens* avec une grande production de la matière sèche (7,556 kg ha^{-1}) le rendement des graines de 4020 kg ha^{-1} à 4397 kg ha^{-1} et N valeurs de crédit de 14 kg N ha^{-1} à > 90 kg N ha^{-1} les analyses économiques pourtant ont indiqué que les systèmes rotationnelle niébé maïs à 45 - 60 - 60 kg ha^{-1} N - $P_2 0_5$ - K_2 O, particulièrement le système "Soronko" maïs était l' option plus préférée avec de bonne graine légumineuse (662 - 1804 kg h^{-1}) et deuxième au mucuna dans la production du maïs (3,405 et 4,235 kg ha^{-1}) et l'amélioration du sol avec maximum N valeur crédits de 13 kg N ha^{-1} à 20 kg N ha^{-1}. Le système maïs-niébé ('Soronko') possède la potentialité d' améliorer le régime avec un rapport rapide sur l'investissement des paysans et encore avec un profit élevé de $1,700 ha^{-1}. Il est donc recommandé de cultiver le niébé aux environs de 266,600 cultures ha^{-1} et le manioc à 6,600 cultures ha^{-1} dans l'inter-culture soĵà-manioc à cause de la plus grande moyenne de la ratio équivalente de terre (LER) de 1.5, avec une plus grande productivité de 54% que la culture unique.

Mots clés: Le manioc, l' inter-culture, les légumineuses, le maïs, la rotation.

Abstract

A legume-maize rotation study showed that greater residual benefits to maize were achieved in the forest-savanna transition zone than the coastal savanna zone, and when maize followed *Mucuna pruriens* with largest dry matter production (7,556 kg ha^{-1}), grain yields of 4020 kg ha^{-1} to 4397 kg ha^{-1} and N-credit values of 14 kg N ha^{-1} to > 90 kg N ha^{-1}. Economic analysis however, indicated that the cowpea-maize rotation systems at 45-60-60 kg ha^{-1} N-P_2O_5-K_2O, particularly medium maturing cowpea ('Soronko')-maize system, was the most attractive option with good legume grain (662-1804 kg ha^{-1}) and second to mucuna in maize (3,405 and 4,235 kg ha^{-1}) production, and soil improvement, with maximum N credit values of 13 kg N ha^{-1} to 20 kg N ha^{-1}. The medium maturing cowpea ('Soronko') - maize system has the potential for improving diets, with immediate returns on farmers' investment, and with high net benefit of ¢1,700 ha^{-1}. It is recommended to plant soybean at about 266,600 plants ha^{-1} and cassava at 6,600 plants ha^{-1} in soybean-cassava intercrop because of the largest mean Land equivalent Ratio (LER) of 1.5, with 54% greater productivity than sole cropping.

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Keywords: Cassava, intercropping, legumes, maize, rotation.

Introduction

Maize and cassava constitute the maĵor staple food crops in Ghana, grown in the forest, coastal savanna, forest-savanna transition, and Guinea savanna zones of the country. Maize and cassava are the main sources of carbohydrates, providing the calorific needs of humans and animals. The development of quality protein maize and its widespread production and consumption in the country and elsewhere in Africa (Nyirigira *et al*., 2005) has an added advantage of providing essential amino acids, lysine and tryptophane. Cassava, in recent times is also becoming an important industrial crop in Ghana, serving as a raw material for cassava starch processing.

Food crop production in Ghana is characterized by no fertilizer or very limited fertilizer application. A ton of yam tubers for example is reported to extract 3.8-4.0 kg N, 0.39-1.1 kg P_2O_5, and 4.2-5.9 kg K_2O from the soil (Le Buanec, 1972 and Ferguson and Haynes, 1970) , 1 ton of maize 15-18 kg N, 2.5-3.0 kg P and 3-4 kg K (ARC, 2003 and PANNAR SA, 2006), and 1 ton cassava 4.91 kg N, 1.08 kg P, 5.83 kg K, 1.83 kg Ca and 0.79 kg Mg (Suyanto, 1998). Farmers' average maize yield of 2 tons ha^{-1} with no fertilizer application translates into mining the soil of 30-5-6 kg ha^{-1} N-P-K and farmers' average cassava yield of 12 tons ha^{-1} translates into soil nutrient mining of 59-13-70 kg ha^{-1} N-P-K. In the past, farmers had resorted to long natural fallow periods of 10-20 years to restore lost fertility. However, due to population pressure on land, continuous cropping and insufficient fallow periods of less than 5 years have become the order of the day. Coupled with absence or minimal use of chemical and organic fertilizers by the maĵority of food crop farmers in the developing world, food crop production and productivity is far below the potential. Leguminous crops, have a unique opportunity due to their nitrogen fixing capacity to fix Nitrogen for their own use and contribute some residual N to other crops in the cropping system (Carsky *et al*., 1999). Organic matter residue from the legumes especially cover crops have also been reported to improve on soil organic matter content and other soil physical properties (Azontoude *et al.,* 1998). Legumes, thus need to play a key role in the development of affordable and sustainable cropping systems in Tropical Africa.

The benefits of crop rotations are increased yields and productivity, improved soil fertility and soil physical properties, reduction in weeds, disease and insect pest populations, increased yield stability and farmers' income (Yamoah *et al*., 1998).

Carsky *et al*. (2001a) reported that maize yields following five varieties of cowpea over a three year period to which no fertilizer was applied were greater than maize following natural fallow to which 30 kg N ha^{-1} was applied, but smaller than when 60 kg N ha^{-1} was applied.

In a study of dry matter partitioning in 6 soybean genotypes differing in maturity, Singh *et al*. (2002) reported no significant differences in grain yield of early (1357 kg N ha^{-1}) and late (1446 kg N ha^{-1}) maturing soybeans. On the contrary, significantly greater dry matter of nodules, roots, stover and leaves was produced by the medium and late maturing soybeans and it was postulated that medium and late maturing varieties may be able to sustain soil organic matter better when residue is recycled. Carsky *et al*. (1997) reported significantly greater mean yield increase of maize over 10 sites, in rotation with a late maturing soybean variety (TGXx1660-19F, 115-120 days) with FRV of 40 kg N ha^{-1} than when maize was in rotation with a medium maturing variety (TGX1456-2E, 100-105 days), following farmer practice of no inoculation of soybean and export of plant residue other than leaf litter fall before soybean harvest. Ali *et al*. (2002), reported that mean dry matter and grain yields of maize in rotation with soybean, mungbean, and blackgram were 14-70% greater than continuous maize. The yield benefits from legume-maize rotations over continuous maize disappeared at application of 50kg N ha^{-1} and above to maize.

There have been several studies on Mucuna (*Mucuna pruriens var. utilis*) cover crop in West Africa in recent times (Boateng, 1998; Osei Bonsu *et al*., 1998; Carsky *et al*., 2001b; Ennin *et al*., 2004). The primary benefit derived from mucuna in cropping systems, which has resulted in its adoption across agroecologies in West Africa and in Latin America is its weed suppression ability especially of noxious weeds such as *Rottboellia*, *Imperata cylindrica*, *and Chromolaena odorata* (Carsky *et al*., 2001). A secondary benefit is the increase in yield of crops, associated with high nitrogen credits following mucuna rotations. Medicinal properties of mucuna have also been reported (Poornachandra *et al*., 2005). Nitrogen credits to maize in rotation of 30-90 kg N ha^{-1} (Tarawali *et al*., 1999; Ennin *et al*., 2004) are common although extremes, 6-148 kg N ha^{-1} have been reported (Carsky *et al*., 2001b) and in most cases, with greater N credits when mucuna residue was incorporated than when left as mulch. These authors have attributed high N credits from mucuna to the high biomass production and high N content of the biomass. While cover crops including mucuna have been reported to increase yield of maize in rotation with mucuna by 50% - 100% compared to the continuous maize, cowpea and natural fallow controls (Osei Bonsu *et al.,* 1998; Boateng, 1998; Mugwe *et al*., 2005, Carsky *et al.*, 2001b), addition of chemical fertilizers to maize following mucuna and other cover crops often times resulted in further significant increases in maize grain yield compared to cover crops alone (Boateng, 1998 and Mugwe *et al.*, 2005).

Studies by Enin *et al* (2005a, b) showed that soybean-maize intercrop was more productive in the drier coastal savanna zone than the forest, with simultaneous planting of the two crops being most productive with a yield advantage of 51% over sole crops. They also reported that spatial arrangement of soybean between the rows of maize was not as important as relative time of planting in influencing productivity of the soybean-maize intercropping system.

The obĵectives of this study were to :1) Quantify the amount of nitrogen credit to maize grown after grain legumes (soybean, cowpea, groundnuts) and mucuna as a cover crop; 2) Assess grain yield increases of maize following the various grain legumes; 3) Verify the appropriate time of planting soybean and cassava and optimum soybean population density for maximum crop productivity and 4) Assess economic benefits of the different cropping systems.

Materials and methods

Description of sites

The studies were conducted at Eĵura (7^o $28^{'}$ N, 1^o 28' W) in the forest savanna transition and at Pokuase (5^o36' N, 00^o1' W) in the coastal savanna zones of Ghana from 2001 to 2004. The Eĵura soils are classified as Ferric Lixisol and Pokuase soils as Dystric Cambisol (FAO, 1988; Asamoah, 1968; Adu and Asiamah, 1992). Soil analysis from 0-30 cm depth at the onset of the study in 2001 showed that soils at both Eĵura (pH 4.8) and Pokuase (pH 5.2) were acidic, with low to moderate levels of nitrogen (0.05% N and 0.11% N) and organic matter (0.85 and 1.21 %), and moderate levels of phosphorous (11.08 and 8.02 mg kg^{-1} P) and potassium (79.64 and 188.96 mg kg^{-1} K) respectively. Rainfall is bimodal in both agro-ecologies with a maĵor and a minor season and mean annual rainfall from 2001 to 2004 of 1446.1 mm at Eĵura and 902.7 mm at Pokuase (Table 1).

Study 1

The experimental design was a split plot with three levels of nitrogen (0, 45 and 90 kg ha^{-1}) applied to following year maize as main plot. There was basal application of 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1} to all plots in the form of triple super phosphate and muriate of potash fertilizers respectively at planting of the main plot treatments. Sub-plots consisted of eight crops or systems of an early, medium or late variety of soybean and cowpea; *Mucuna pruriens* (velvet bean) cover crop or planted and natural fallows; an early and medium open pollinated maize variety. The maize varieties served as reference crops. The legumes together with the reference crops were planted in July 2001 and followed by two consecutive years of

Table 1. Mean monthly rainfall for Ejura and Pokuase (2001 - 2004).

Year	*Monthly rainfall (mm)*												*Total*
	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*annual*
						Ejura							
2001	0	0	97.1	248.1	123.1	142.5	88.3	18.3	282.7	105.2	7.6	0	1,112.9
2002	4.7	16.4	80.4	146.3	222.9	227.5	168.6	114.3	211.9	116.9	33.6	31.8	1,375.3
2003	4.3	80.9	108.8	154.3	108.0	265.6	35.8	27.0	239.6	147.2	155.7	7.5	1,334.7
2004	24.4	23.8	115.9	114.3	289.5	72.5	115.5	215.2	198.1	180.7	80.7	15.5	1,446.1
Mean 2001-2004	8.35	30.2	100.6	165.8	185.9	177.0	102.1	93.7	233.1	137.5	69.4	13.7	1,317.3
						Pokuase							
2001	0.0	47.7	73.5	109.5	137.4	232.5	39.7	18.4	85.5	53.2	92.0	0.0	889.4
2002	39.3	83.0	13.3	149.2	133.6	212.8	72.5	40.3	38.9	101.6	89.8	10.0	984.3
2003	22.4	26.4	32.8	173.6	123.2	105.0	86.3	32.0	89.6	126.4	76.7	18.2	912.6
2004	34.7	7.3	61.4	50.0	119.1	65.2	62.4	58.0	199.6	84.7	81.9	34.7	824.3
Mean 2001-2004	24.1	41.1	45.3	120.6	128.3	153.9	65.2	37.2	103.4	91.5	85.1	15.7	902.7

maize planted on all plots in April or May 2002 and 2003, and the cycle repeated with legumes and reference crops planted in 2003 followed by maize in 2004. Plot size was 4 m long, 4.8 m wide. Spacing was 60 cm rows, 20 cm within row, 2 plants per hill for grain legumes, and 80 cm rows, 40 cm within row, 2 plants per hill for the *Mucuna pruriens* and maize crops. Weeds were controlled manually and pre-flowering and post-flowering cowpea pests were controlled with Karate 2.5EC (lamda-cyhalothrin) at 15 g a. i. ha^{-1} and Dimethoate 40EC (dimethoate) at 400 g a. i. ha^{-1} respectively. Harvesting was done in 2 central rows, 3m long for all crops. As is the practice of Ghanaian farmers, plant parts harvested differed for the crops. Cowpea pods were harvested leaving all other plant parts in the field, soybean harvesting involved uprooting of the plant at maturity leaving leaves in the field, and dehusked maize cobs were harvested from the field. Plant residue after harvest was left in situ on the field.

Study 2

A cassava-soybean intercrop verification study was established in 2 farmers' fields in the Eĵura-Sekyedumase district in the forest savanna transition agroecology in 2001 and repeated in 6 farmers fields in Eĵura-Sekyedumase and Wenchi districts in April or May 2002. The experimental design was incomplete block. The treatments were soybean planted 2 weeks before cassava and 4 weeks after cassava combined with 3 soybean population densities (66,600; 133,300 and 266,600 plants ha^{-1}). It consisted of 2 rows of soybean intercropped between 2 rows of cassava. Between row spacing from crop to crop was 0.5 m. Within-row spacing for cassava in the intercrop was 1 m, while that for soybean was adĵusted (20 cm 1plant per hill, 20 cm 2 plants per hill and 10 cm 2 plants per hill to obtain the target plant populations 66,600, 133,300 and 266,600 plants ha^{-1} respectively. Sole crops were added for comparison. Intercropped cassava plant population density was 6,600 plants ha^{-1} and sole cassava was 10,000 plants ha^{-1}. Each farmer received five treatments, which included the three soybean population densities planted at either 2 or 4 weeks, the two sole crops and the farmers' practice. At each location or farmer's field in 2002, two separate adĵacent fields containing one of the relative times of planting with the plant populations were established. This was to allow for easy comparison of planting soybean 2 weeks before with planting soybean 4 weeks after cassava. Field demonstrations followed the verification studies at 7 locations in the Eĵura-Sekyedumase and Wenchi districts in 2003 and at 12 locations in Eĵura-Sekyedumase, Wenchi, and Nkoranza districts of the forest-savanna transition zone in 2006.The field size for the demonstrations was 50 m x 20 m. Based on the previous years verification trials, the most productive option demonstrated or promoted was planting soybean 4 weeks after cassava and at two rows of soybean between 1 row of cassava. Row spacing from crop to crop was 50 cm, while within-row spacing was 1 m (1 plant per hill) for cassava and 10 cm, 2 plants per hill for target soybean population of 266,600 plants ha^{-1}. The varieties used were 'Anidaso' soybean and 'Afisiafi' cassava. An essential component of the demonstrations was farmers' field days carried out to expose more farmers to the technology.

Results and Discussion

Study 1

Legume grain yields

Significant interactions ($p \leq 0.05$) were recorded between location and legume crop on grain yields in 2001. While similar yields of soybeans were realized at both Eĵura and Pokuase, cowpea yields were greater ($p \leq 0.05$) at Eĵura than Pokuase (Table 2). Among the grain legumes, cowpea yields were greater than soybeans at Eĵura, in both 2001 and 2003, but the reverse was the case at Pokuase. The low amount of rainfall at Pokuase during the month of August 2001 (Table 1) when cowpea was flowering might have contributed to the low cowpea yields in this location. No seeds were harvested from the *Mucuna pruriens*, with all plant material left in the field. Trends in grain yield could not be explained by trends in plant population density (Table 2). The results reflect different responses of yield of legume species to rainfall patterns in different locations.

Legume dry matter yield

Mucuna produced the largest total dry matter ($p \leq 0.05$) followed by soybean and cowpeas (Table 3). Osei Bonsu *et al.* (1998) reported greater dry matter production by mucuna than grain legumes. The large organic matter production by mucuna, 11 t ha^{-1} in 135 days has also been reported by Mahama *et al.* (2001). This trend in total dry matter production was similar to trends in partitioning into pod dry matter, and different from trends in dry matter partitioning to stalk, leaves and seeds. Mucuna was unable to flower, pod and set seed in the minor season of 2003, therefore was portioned only into stalk and leaves. It had the largest partitioning into stalk and leaves compared to cowpea and soybean. Early maturing soybean apparently had greater harvest index than the medium maturing soybean. The reverse was observed for cowpeas. The residual dry matter (Table 3) was least for soybeans (total-stalk-pod) due to harvest of whole plant with leaves dropped, intermediate for cowpeas (total-pod) and largest for mucuna (total) since no plant part was harvested from the mucuna plots. We are proposing that a technology such as mechanized harvesting and threshing of grain legumes in the field, or returning of all plant parts except seed to the field in manual harvests, would increase the residue left in the field by grain legumes which is currently low (Table 3) as a result of current farmer harvesting practices, and increase N-credits and yield of following maize from grain legume cultivation.

Table 2. Grain yield of legumes at Ejura and Pokuase (2001 and 2003).

	2001				2003	
	Grain yield		*Number of plants*		*Grain yield*	*Number of plants*
Preceding crop	*Ejura*	*Pokuase*	*Ejura*	*Pokuase*	*Ejura*	*Ejura*
	kg ha^{-1}		*ha^{-1}*		*kg ha^{-1}*	*ha^{-1}*
1. Early soybean variety (TGX 1830-20/TGX 1478-2E)	1 167	1 359	134 200	296 700	1 259	109 400
2. Late soybean variety (Anidaso)	1 012	976	107 400	251 700	1 511	108 100
3. Early cowpea variety (Asontem)	1 991	639	99 700	160 400	1 679	71 000
4.Late cowpea variety (Soronko)	1 804	662	101 700	159 500	1 531	83 500
5. *Mucuna pruriens*	-	-	-	-	-	-
SED $_{(0.05)}$	177.9		12 523.6		118	5 935.7

Following maize grain yields

There were no significant interactions on following maize grain yields in 2002 and 2004. Main effects of location, previous legume or cropping system and N application rate were different ($p \leq 0.05$). Mean maize grain yield (Table 4) was 62% greater at Eĵura (3.9 t ha^{-1}) than at Pokuase (2.4 t ha^{-1}). N application up to 90 kg ha^{-1} resulted in a linear response in 2002 (r^2=0.99, Y=2444.0939 + 15.7854x) and a quadratic response in 2004 (r^2=1, Y=2630.8692 + 73.1953x 0.5692x^2). In 2004, following maize grain yields were generally greater, and at Eĵura (5.3 t ha^{-1}), mean yield was again greater by 96% than at Pokuase (2.7 t ha^{-1}). Averaged over N application rates and locations (Table 4), maize following *Mucuna pruriens* produced greater (p <0.05) greater grain yields in 2002 and non-significantly largest yield in 2004. Maize grain yield following medium maturing cowpea 'Soronko' was the next largest across the two locations in both years, and was greater (p <0.05) than maize following continuous maize of the medium maturing group only in 2002. Maize following natural fallow was the next largest yielding but it was not significantly different from other legumes and early maize in both years. *Mucuna pruriens* cover crop as a preceding crop resulted in superior grain yields of following maize, especially in 2002. Medium maturing cowpea variety ('Soronko'), a grain legume appeared to be equally good, especially in 2004, where following maize grain yields were greater. The superiority of maize yields following *Mucuna pruriens* have often been reported (Osei Bonsu *et al*.,

Table 3. Dry matter yield and partitioning by legumes at Ejura (Minor season 2003).

Crop	*Dry matter Yield (kg ha^{-1})*						
	Total	*Stalk*	*Pod*	*Seed*	*Leaves*	*Residual*	**Harvest Index*
1. E. soybean (TGX 1478-2E)	3002	632	1691	1000	679	679	0.33
2. M. soybean (Anidaso)	3112	976	1488	817	647	648	0.27
3. Early cowpea (Asontem)	2473	592	1081	898	830	1392	0.36
4. M. cowpea (Soronko)	2207	798	935	899	473	1272	0.41
5. *Mucuna pruriens*	7556	4214	0	0	3094	7556	0
SED $_{(0.05)}$	423	280	166	116	172		

*Harvest index = (seed yield/total dry matter).

Table 4. Grain yield of following maize averaged over N application rates at Ejura and Pokuase (2002 and 2004).

	Year 2002			*Year 2004*		
	Ejura	*Pokuase*	*Mean*	*Ejura*	*Pokuase*	*Mean*
Preceding crop			*kg ha^{-1}*			
Early soybean	4 159	1 979	3 069	5 143	2 712	3 927
Medium soybean	3 938	2 266	3 102	5 163	2 601	3 882
Early cowpea	3 427	2 647	3 037	5 659	2 076	3 868
Medium cowpea	4 097	2 712	3 405	5 239	3 230	4 235
Mucuna	5 131	2 910	4 020	5 729	3 065	4 397
Fallow	4 286	2 296	3 291	5 263	2 799	4 031
Early maize	4 063	2 176	3 120	5 108	2 615	3 861
Medium maize	3 217	2 248	2 732	5 051	2 842	3 946
Mean	3 899	2 410	3 222	5 302	2 705	3 991
SED $_{(0.05)}$	ns		216.4	ns		239.1

1998; Okito *et al*., 2004). However, similar grain yields of maize were reported (Ennin *et al*., 2004) when maize followed the medium maturing cowpea variety "Soronko" and mucuna. Maize yields following soybean at both locations were similar to maize yield in continuous maize cropping system. This finding is in contrast to other findings, where soybean as a preceeding crop resulted in significant increases in maize yield as a result of increased water use and water use efficiency (Copeland *et al*., 1993) breaking of pest cycle (Noel and Edwards, 1996) and residual soil N when only soybean seed was exported from the field (Omay *et al*., 1998; Hood, 2004). In our study, and as is the practice of Ghanaian farmers where soybean plants are uprooted during harvesting leaving only the fallen leaves, and also where no *Rhizobium* innoculum is applied to boost N-fixation, it is apparent that soybean may not be contributing much to improving yields of maize in rotation. Recycling of soybean residue, has been reported to play a key role in sustaining soil organic matter and maize yields in rotation (Singh *et al*., 2002), and its absence may have contributed to the observed absence of maize yield increase in the soybean-maize rotation. It is apparent from the performance of medium maturing cowpea "Soronko" that some grain legumes may be as beneficial as cover crops in the development of sustainable cropping systems. Breeding and agronomic research efforts need to be directed to identify such grain legume varieties.

Second year maize grain yields

There was no interaction between the 10 previous legumes or cropping systems in 2001 and the second year maize grain yield in 2003. The main effects of previous legume crops or systems, which was better ($p \leq 0.05$) in first year maize was not significant on maize yields 2 years later (Table 5). There was however a trend for *Mucuna pruriens* as a preceding legume to result in greater yield of maize 2 years later. Porter *et al*. (1997) also reported no difference in 2nd year maize grain yield following soybean, compared to continuous maize**.** Vanotti and Bundy (1995) reported a decrease in yield equivalent to soil N-debit of 36 kg ha^{-1} in second year maize and oats in rotation with soybean. It is deduced that while maize following *Mucuna pruriens*, and medium cowpea consistently out-yielded maize following maize in the first year in the forest-savanna transition zone, yield increase in second year maize may be realized only when maize follows *Mucuna pruriens*. This may be due to the more positive N balance often reported (Okito *et al.*, 2004) from *Mucuna pruriens* and other cover crops due to the fact that no plant material is harvested and all fixed N is left in the field.

Table 5. Second year maize grain yield following legumes or cropping systems at Ejura (2003).

Preceding crop , 2001	*Second year maize grain yield kg ha^{-1}*
1. E. soybean (TGX 1478-2E)	2 704
2. M. soybean (Anidaso)	2 674
3. Early cowpea (Asontem)	2 955
4. M. cowpea (Soronko)	2 940
5. *Mucuna pruriens*	3 609
6. Natural fallow	2 866
7. E. maize (Dorke SR)	2 938
8. M. maize (Obatanpa)	2 755
SED	472.8

Nitrogen credits

The magnitude of N credits, determined by the N fertilizer replacement value or index (the amount of N needed in the continuous maize to achieve yield equal to that in rotation with no added N), were greater at Eĵura than Pokuase in both 2002 and 2004 (Figures 1 and 2). At Eĵura, grain yield of maize at zero N following *Mucuna pruriens* was very big, in both years, resulting in the largest N credit of over 90 kg ha^{-1} in 2002 and 24 kg ha^{-1} in 2004. At Pokuase, *Mucuna pruriens* gave largest N credit (14 kg ha^{1}) in 2002, with medium maturing cowpea 'Soronko' giving the largest N credit (13 kg ha^{-1}) in 2004. Within a location and year, N credits were small for the other legumes and natural fallow and ranged from 19 to 32 kg ha^{-1} (Eĵura) and 0 to 6 kg ha^{-1} (Pokuase) in 2002, and 4 to 9 kg ha^{-1} (Eĵura) and 0 to 5 kg ha^{-1} (Pokuase) in 2004. Maize yields at 0-N following early soybean 'TGX 1478-

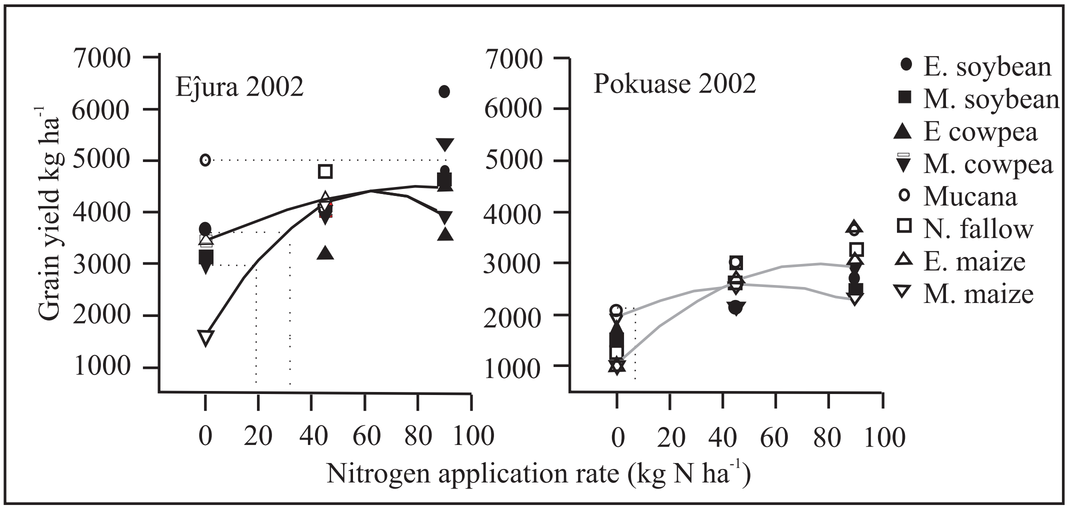

Figure 1. N credit to maize from legumes. Ejura and Pokuase, 2002.

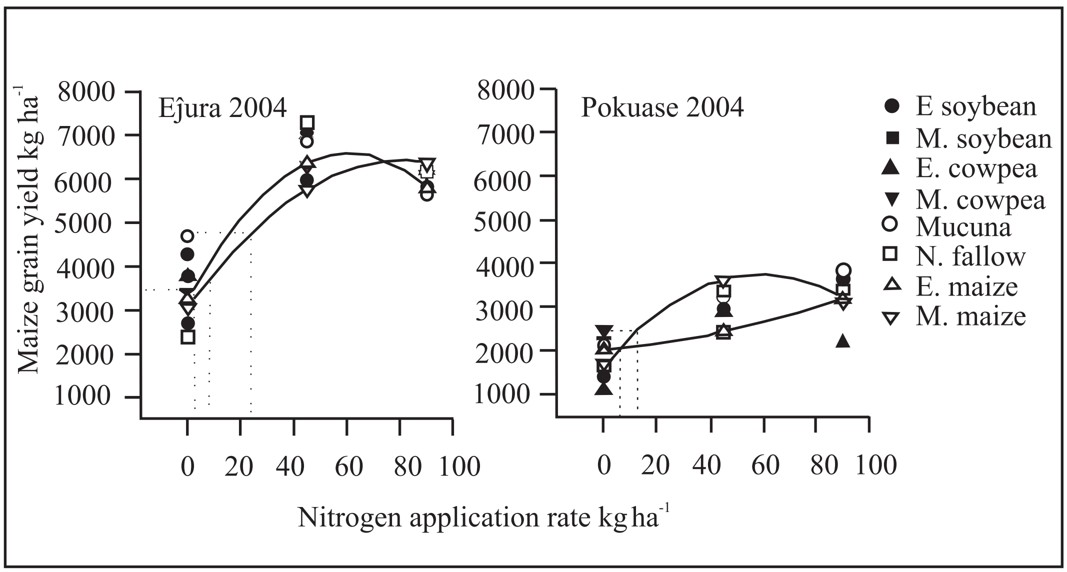

Figure 2. N credit to maize from legumes. Ejura and Pokuase, 2004.

2E', an experimental variety at both Eĵura and Pokuase in 2004, early cowpea at Pokuase in 2004 and natural fallow at Pokuase in 2004 were smaller than continuous maize yields, leading to negative N credits. Tian *et al*. (2000) studying 13 legume cover crops including *Mucuna pruriens* reported similar values of N credits (11 to 96 kg ha^{1}) in the derived savanna of West Africa. Killpack and Bucholz (1993) reported greater N credits of 100 - 140 kg ha^{-1} from good stands of alfalfa and sweet clover green manure than from inoculated grain legume, soybeans with 15 to 60 kg ha^{-1} N credits to maize, sorghum and wheat. They also reported that it is commonly recommended in Missouri, USA to reduce N fertilizer rates in corn following inoculated soybeans by the N credit value of 34 kg ha^{-1}. It appears that low rainfall regime and spells of intermittent drought during the growing seasons at Pokuase may have influenced nodulation, N fixation, % N derived from fixation of legumes and the growth (Evans, 1988) and yield of following maize resulting in lower N credits in this location. Kirkegaard *et al*. (2000) also reported that wheat yield in rotation was highly correlated to the amount of stored soil moisture at sowing, which in turn was a function of the amount of plant residue from the previous crop, regardless of the crop being a cereal or a legume. Carsky *et al*. (1999) studying cowpea and covercrop (Mucuna, Lablab, Crotolaria), maize rotations in the Guinea Savanna zone of Nigeria, reported mean N fertilizer replacement value of 6 kg N ha^{-1} at the drier site with 900mm annual rain and 14 kg N ha^{-1} at the wetter site with 13500mm rain, from the legume maize rotations. At zero and 30 kg N ha^{-1} to following maize, maize in cowpea-maize rotation was similar to maize following natural fallow and the cover crops. Similar to our study, Ennin *et al*. (2004) reported more than 90 kg N ha^{-1} to maize from *Mucuna pruriens* and medium maturing cowpea variety 'Soronko', with smaller contributions of 22 and 16 kg N ha^{-1} from early maturing cowpea variety 'Asontem' and natural fallow respectively from a study conducted at Eĵura from 1999 to 2000. No appreciable N credits were measured from soybean varieties. The early soybean variety 'TGX 1478-2E' was reported to have mined the soil, resulting in negative N credit to maize. Cowpea in rotation with maize gave FRV of 75 kg N ha^{-1} (Adetunĵi, 1996), within the range observed in this study. This study has shown that removal of soybean plant residue may be limiting the contribution of soybean to maize in rotation. Location, year, legume species and maturity appeared to be maĵor determinants of N credits from legumes, with mucuna and medium maturing cowpea contributing most to increased maize yield in rotation and greater maize yields and N credits obtained from wetter forest-savanna transition than drier coastal savanna agroecology.

Partial budget analysis

A partial budget analysis was done for

Eĵura and Pokuase using the mean grain legume yields in 2001 and 2003, maize grain yields following legumes in 2002 and 2004, and prices in 2004 (Table 6). At all rates of fertilizer application, all cropping systems were twice as profitable at Eĵura as at Pokuase, as a result of the greater grain yields at Eĵura (Table 6). At Eĵura, the early and medium cowpea+maize rotation systems were the most profitable, and the soybean+maize systems were also more profitable than the continuous maize systems. The trend was different at Pokuase, where continuous medium maturing maize was most profitable followed by medium maturing cowpea+maize rotation. The use of mucuna as a cover crop in maize production, although had high N credits and soil improvement, was less profitable than the grain legume (cowpea and soybean) - maize systems due to the absence of income from mucuna seeds. The high field price for cowpea (GH¢ 0.4 kg^{-1}) compared to soybean (GH¢ 0.25 kg^{-1}) makes up for the extra cost of insect control in cowpea contributing greatly to the greater profits in the cowpea+maize rotation. The natural fallow+maize system was the least profitable.

The marginal rate of return (MRR), which is the change in net benefits as a ratio of the change in costs, expressed as a percentage (CIMMYT, 1988) was positive when fertilizer rate of 45- 60-60 kg ha^{-1} N-P_2O_5-K_2O was applied rather than 0-60-60 kg ha^{-1} N-P-K indicating that it was economically viable to change from the 0-60-60 kg ha^{-1} N-P-K to the 45-60-60 kg ha^{-1} N-P-K application rate in all the cropping systems at both locations. Although, greater grain yields were achieved at 90-60-60 kg ha^{-1} N-P_2O_5-K_2O, the doubling of fertilizer costs and its attendant increase in variable costs resulted in the 90-60-60 kg ha^{-1} N-P_2O_5-K_2O being economically non-viable and dominated. Okito *et al*. (2004) also did economic analysis on legume+cereal cropping systems and reported that rotations such as the groundnut+maize rotation system, which although depleted the soil at 0-N was the most attractive system in the short term to the smallholder farmer due to the additional income from the groundnut kernels, compared to the *Mucuna pruriens*+ maize rotation with greater maize yields. It was similarly reported (Oyewole *et al*., 2006) that in on-farm studies in Nigeria, although yield of maize was greater following mucuna than cowpea, farmers choice was for the cowpea+maize rotation due to greater immediate economic returns to farmers. Carsky and Ellittä (2004) concluded from a review of mucuna work in West Africa that high soil fertility improvement alone by mucuna and other systems such as alley cropping does not drive adoption because a direct economic benefit is required by resource poor farmers for adoption. The combination of biological efficiency in the area of grain yields and nitrogen

Table 6. Mean net benefits and Marginal Rate of Returns (MRR) in 2004 of legume+maize rotation and fallow systems at different N fertilizer rates. Ejura and Pokuase.

Cropping system	*0-60-60 kg ha^{-1} N-P_2O_5-K_2O*		*45-60-60 kg ha^{-1} N-P_2O_5-K_2O*		*90-60-60 kg ha^{-1} N-P_2O_5-K_2O*	
	Ejura	*Pokuase*	*Ejura*	*Pokuase*	*Ejura*	*Pokuase*
	Total variable cost (GH¢ ha^{-1})					
E. soybean+maize	88	88	245	245	403	403
M. soybean+maize	88	88	245	245	403	403
E. cowpea+maize	118	118	275	275	433	433
M. cowpea+maize	128	128	285	285	443	443
Mucuna+maize	56	56	214	214	371	371
Natural fallow+maize	56	56	214	214	371	371
E. maize+maize	88	88	245	245	403	403
M. maize+maize	88	88	245	245	403	403
	Net benefit (GH¢ ha^{-1})					
E. soybean +maize	1,007	587	1,452	735	1,204	722
M. soybean+maize	1,091	606	1,314	677	1,219	539
E. cowpea+maize	1,529	492	1,735	675	1,520	546
M. cowpea+maize	1,338	699	1,658	694	1,652	776
Mucuna+maize	1,152	484	1,154	567	1,126	549
Natural fallow+maize	671	307	1,291	531	978	432
E. maize+maize	909	588	1,237	690	1,042	679
M. maize+maize	751	995	1,252	1,158	1,141	907
	MRR (%)					
E. soybean+maize			282.78	93.57	D	D
M. soybean+maize			141.90	45.48	D	D
E. cowpea+maize			131.03	115.87	D	D
M. cowpea+maize			203.10	-3.25	D	D
Mucuna+maize			1.43	52.30	D	D
Natural fallow+maize			393.81	142.14	D	D
E. maize+maize			208.17	64.84	D	D
M. maize+maize			317.94	103.17	D	D

*Exchange rate (24th January 2008): 1 USD ($) = GH¢ 0.974.
D = dominated.

credits, and economic considerations identified that cowpea+maize rotation systems at 45-60-60 kg ha^{-1} N-P_2O_5-K_2O, and especially the medium maturing cowpea+maize system to be the best system. Although application of more fertilizer resulted in increased maize grain yields, the high cost of fertilizers tend to make greater fertilizer rates uneconomical for staple food crop production in developing economies such as Ghana.

Study2

Plant population densities achieved for intercrop and sole crop soybean were 42-70 % and 78-98 % of targeted plant densities in 2001/02 and 2002/03 respectively (Table 7). In both seasons, yields of soybean planted either 2 weeks before or 4 weeks after cassava at 266,600 plants ha^{-1} were similar to the sole soybean yields (Table 8). Generally, soybean yield tended to increase with increased plant population in the intercrop. Generally soybean planted 2

Table 7. Soybean plant population densities on farmers' fields in Ejura-Sekyedumase district.

	Soybean population density					
	2001			*2002*		
Soybean planting time targeted	*Targeted (plants ha^{-1})*	*Achieved (plants ha^{-1})*	*% of targeted*	*Targeted (plants ha^{-1})*	*Achieved (plants ha^{-1})*	*% of*
2WBC*	66 600	46 600	70	66 600	62 700	94
	133 300	88 700	67	133 300	131 100	98
	266 600	170 800	64	266 600	215 000	81
Sole crop	400 000	170 000	43	400 000	342 200	86
4WAC	66 600	40 000	60	66 600	61 600	93
	133 300	74 500	56	133 300	117 700	88
	266 600	168 700	63	266 600	207 200	78
Sole crop	400 000	168 300	42	400 000	330 000	83
SED		20900	3.7		38 800	2.46

* 2WBC = Soybean planted 2 weeks before cassava.
4WAC = Soybean planted 4 weeks after cassava.

weeks before cassava did not yield far above that planted 4 weeks after cassava. This may be due to the slow growth of cassava, such that when soybean planting was delayed for 4 weeks, its growth was not substantially affected by the cassava. Cassava yields tended to decrease with increasing soybean plant population and with planting soybean before cassava (Table 8). Across 2001-2002 and 2002-2003, soybean at 266,600 plants ha^{-1} planted 4 weeks after cassava had the largest mean land equivalent ratio of 1.54. The yield of soybean in this system was similar to sole soybean yield with the cassava yield as bonus, resulting in a 54% increase in productivity over sole cropped cassava and soybean. The superiority of intercropping soybean 4 weeks after cassava in terms of income generation has been reported by Ennin *et al*. (2005b), with a 46% increase in productivity over sole crops.

Table 8. Mean soybean and cassava yield and LER of a cassava+soybean intercrop, on farmers' fields in Ejura-Sekyedumase district.

	2001 - 2002			*2002 - 2003*			
Soybean targeted plant population	*(Soybean grain yield (kg ha^{-1})*	*Cassava fresh yield (t ha^{-1})*	*LER*	*Soybean grain yield (kg ha^{-1})*	*Cassava fresh yield (t ha^{-1})*	*LER*	*Mean LER*
			2WBC*				
66 600	166.7	15.99	1.11	889	21.8	1.62	1.37
133 300	208.3	12.14	1.07	944	15.6	1.39	1.23
266 600	458.3	10.40	1.65	1111	11.4	1.33	1.49
Sole crop	375.0	23.97	-	1333	22.9	-	-
			4WAC				
66 600	208.3	23.95	1.39	667	24.5	1.51	1.45
133 300	250.0	18.21	1.28	611	16.8	1.19	1.24
266 600	500.0	12.05	1.65	944	13.9	1.42	1.54
Sole crop	416.7	26.84	-	1000	28.9	-	-
SED	45.75	2.24	0.104	81.59	2.11	-	-

* 2WBC = Soybean planted 2 weeks before cassava ; 4WAC = Soybean planted 4 weeks after cassava; LER = land equivalent ratio.

Conclusion

Location, year, legume species and maturity were found to be maĵor determinants of maize yields and N credits in rotation with legumes. Some grain legumes were as beneficial as cover crops, as shown by high N credits and high yield of maize following medium maturing cowpea variety 'Soronko'. Consideration of biological efficiency and economic benefits revealed the cowpea+maize rotation systems at 45-60-60 kg ha^{-1} N-P_2O_5-K_2O, and especially the medium maturing cowpea-maize system to be the best option for small to medium scale farmers. It has potential for soil improvement, with maximum N credit values of 13 kg ha^{-1} to 20 kg ha^{-1} (compared to N credit of 24 kg ha^{-1} to 90 kg ha^{-1} from Mucuna), potential to improve diets and increase farmer incomes with high net benefit of GH¢1,700 ha^{-1} year^{-1}. Greater benefits from the legume were derived in the forest-savanna transition where mean annual rainfall from 2001 to 2004 was 1,317.3 mm, than the drier environment of the coastal savanna with mean annual rainfall from 2001 to 2004 of 902.7 mm. Research efforts need to be directed to identify and further improve on the agronomic and genetic traits of such grain legume varieties with high and direct economic benefits in addition to their soil improvement attributes. It is also speculated that mechanized harvesting and threshing of grain legumes in the field, or returning of all plant parts except seed to the field in manual harvests, would increase the residue left in the field, reduce export of plant residue from the field and has the potential to increase N-credits and yield of following maize from grain legume cultivation.

Intercropping soybean and cassava at 266,600 plants ha^{-1} and 6,600 plants ha^{-1} respectively which resulted in largest mean productivity of 54% greater than sole cropping, is recommended.

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