Nitrogen Credits from Cowpea, Soybean, Groundnut and Mucuna to Maize in Rotation

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Abstract

Legumes constitute a major component of sustainable cropping systems due to their biological nitrogen fixing capacity. A field study was conducted in 1999 and 2000 at Ejura in the forest savanna transition zone of Ghana to quantify nitrogen credits to maize from early (65–105 days) and medium/late-maturing (80–120days) grain legumes (cowpea, soybean, and groundnut), and from *Mucuna* cover crop. The design was a split plot in randomized complete block with three nitrogen levels (0, 45, 90 kg N ha^{-1}) applied to maize following legumes as the main plots. There was in addition a basal application of 26 kg P ha^{-1} and 42 kg K ha^{-1}. Subplot treatments were 10 cropping systems: 6 grain legumes (an early and later-maturing variety each of soybean, cowpea, and groundnuts), *Mucuna pruriens* as a planted fallow, a natural fallow, and two maize varieties as reference crops, early (95 days) and medium (105 days). *Mucuna* had the highest nodule mass (20 kg ha^{-1}), cowpea (7.8 and 10.2 kg ha^{-1}) and soybean (10.1 and 17 kg ha^{-1}) were intermediate, with the least nodule mass on groundnut (5.2 and 5.4 kg ha^{-1}). Nitrogen credit to maize from *Mucuna* and medium-maturing cowpea variety "Soronko" was more than 90 kg N ha^{-1}, 22 N ha^{-1} from early-maturing cowpea "Asontem" and 16 kg N ha^{-1} from natural fallow. No appreciable N credits were measured from soybean and groundnut varieties. Early soybean variety TGX 1478-2E had negative N credit to maize. The species and maturity group of legumes are important determinants of their N contribution to crops in rotation.

Introduction

Soil fertility decline is a major constraint to crop production in Ghana and other developing African countries where slash and burn constitute major features of land preparation, with minimal application of fertilizers or none at all due to high cost (GGDP, 1992a, 1994; Bationo *et al.*, 1997). In a recent survey on maize production in the Ejura-Sekodumase district (a predominantly maize growing area), 70% of farmers had never used inorganic fertilizers, due to their high cost (GGDP, 1994).

The inclusion of legumes as an essential component of cropping systems is an inexpensive, feasible, and sustainable intervention to supplement inorganic fertilizers. Legumes may be used in crop rotations as cover crops (Asibuo and Osei Bonsu, 2000; Ennin and Clegg, 2001), in intercropping (Ennin *et al.*, 2001), as green manures (Sekhon and Bajwa, 1993), and in alley cropping (Tossah *et al.*, 1999). This will ensure increased crop production at high yields per unit area, while maintaining or improving on the soil fertility status. The benefit of legumes in cropping systems is through biological nitrogen fixation (BNF), which can be as much as 450 kg

N ha^{-1} (Wani *et al.,* 1995). Cowpea [*Vigna unguiculata* (L.) Walp] is reported to fix 30–125 kg N ha^{-1} (Ennin-Kwabiah and Osei-Bonsu, 1993) although as much as 201 kg N ha^{-1} per season has been reported (Singh and Rachie, 1985). Soybean (*Glycine max*) usually fixes between 60 and 240 kg N ha^{-1} with a high value of 300 kg N ha^{-1} also reported (Peoples and Herridge, 1990; Keyser and Li, 1992; Ennin and Clegg, 2001). Groundnut (*Arachis hypogaea*) fixes between 50 and 150 kg N ha^{-1} with values as high as 206 kg N ha^{-1} (Giller 2001) and 210 kg N ha^{-1} also being reported (Bell *et al.,* 1994). The amount of N contributed to the soil by a legume for the benefit of another crop grown either in association or in rotation depends on the total amount that is fixed, and the proportion of fixed N that is removed from the field in the harvested seed and straw (Peoples and Herridge, 1990; Giller, 2001).

In Ghana, legume varieties are developed and recommended based on maturity group and grain yield, with little consideration of their contribution of N to the environment and cropping systems. A major source of variation in nodulation, total crop N, and N fixation within a legume species is the crop duration. George *et al.* (1988) for example, reported increased nodule numbers with an increase in maturity group number of soybean without a corresponding increase in nodule weight. Bell *et al.* (1994) reported crop duration in groundnut varieties as the major determinant of total crop N accumulation and N fixed, with a positive correlation.

Grain legumes also serve as a source of inexpensive and affordable protein for both human consumption and animal feed. It is important to quantify the N and non-N contributions by the common grain legumes in tropical Africa (cowpea, groundnut, and soybean), and leguminous cover crops, such as *Mucuna* to the soil environment and to other crops in the cropping system, under conditions similar to farmers' production systems. This will enable the adjustment of N fertilizer recommendations when crops are grown after legumes.

The objectives of the study were to: (1) quantify the amount of N fertilizer savings when maize is grown in rotation with grain legume (soybean, cowpea, and groundnut) varieties which vary in maturity, and also after a leguminous cover crop (*Mucuna pruriens* var. *utilis* (velvet bean), and (2) assess grain yield increases of maize following the legumes.

Materials and methods

Field studies were conducted in July 1999 and 2000 at the Crops Research Experimental station at Ejura in the forest/savanna transition zone of Ghana (7°23' N, 1°21' W). The soils are described as Dystric Cambisol, also called Ejura series with 20–30 cm top layer of loamy soils (FAO, 1988; Asamoah, 1968). At the beginning of the study in 1999, average soil chemical properties in the 0–30 cm depth were as follows: 0.3 g kg soil^{-1} total N; 23.2 mg kg^{-1} Bray 1 P; 105.1 mg kg^{-1} available K; and 7.9 g kg^{-1} soil organic matter. Total annual rainfall in the past decade ranged from 1000 mm to 1650 mm. Ten cropping systems consisted of an early- and a medium- or late-maturing variety of the grain legumes, soybean, cowpea, and groundnut; a leguminous cover crop *Mucuna pruriens* as planted fallow; a natural fallow with *Rottboellia cochinchinensis* and *Panicum maximum* as the predominant weeds; and an early- and a medium-maturing maize variety as reference crops (Table 1). The crops were planted in July 1999 and followed by medium-maturing maize variety "Obatanpa" in April 2000. The experimental design was split plot in randomized complete block with three N levels (0, 45, 90 kg N ha^{-1}) applied to maize following legumes as the main plots. Subplot treatments were the 10 previous cropping systems. There were three replications. There was a basal appli-

TABLE 1
Agronomic characteristics of crop varieties.

Cropping system	Maturity period (days)	Growth habit	Target plant density(ha^{-1})
1. Early soybean variety ("TGX 1478-2E")	105	Erect	166 667
2. Medium soybean variety ("Anidaso")	115	Erect	166 667
3. Early cowpea variety ("Asontem")	65	Semi-erect	166 667
4. Medium cowpea variety ("Soronko")	80	Semi-erect	166 667
5. Early groundnut variety ("RLRS-11")	90	Semi-Erect	166 667
6. Late groundnut variety ("F-mix")	120	Semi-erect	166 667
7. Planted fallow (*Mucuna pruriens*)	140*	Spreading	62 500
8. Natural fallow	–	–	–
9. Early maize ("Dorke –SR")	95	165cm tall	62 500
10. Medium maize ("Obatanpa")	105	175 cm tall	62 500

* *Mucuna* was killed by 10 December with the onset of the dry season.

cation of 26 kg P ha^{-1} to all plots in the form of triple super phosphate and 42 kg K ha^{-1} muriate of potash fertilizers. The land was prepared by ploughing and harrowing, and grain legumes were planted in 60 cm rows, and *Mucuna* and maize in 80 cm rows for target plant population densities as indicated in Table 1. Uniform plot size of 4.8 m^2 was used for the subplots. Weeds were controlled manually when needed. Cowpea was protected against insect damage with two applications of Karate 2.5EC (lamdacyhalothrin) at 15 g a.i. ha^{-1} at pre-flowering and flowering stages and one application of Dimethoate 40EC (dimethoate) at 400 g a.i. ha^{-1} during podding. No *Bradyrhizobium* inoculum was applied to the legume crops. Soil samples up to 30 cm were taken for chemical analysis at the beginning of the growing season, on replication basis in 1999 and on plot basis in 2000. The soil chemical characteristics in the 0–30 cm depth at the beginning of the study using standard methods for soil analysis. Nodules were sampled at the peak of flowering from five randomly selected plants outside the two central rows of a plot. At physiological maturity, five randomly selected plants from each plot were cut above ground level, except for groundnut. These were uprooted; the roots were cut off, and oven dried at 80 °C for 48 hours for dry matter determination. Grain yield data were obtained from the two central rows. For cowpea, only pods are harvested; for soybean, the whole plant is uprooted when the leaves have dropped; for groundnut, the whole plants are uprooted with approximately 5% leaf drop. No plant part was harvested from the *Mucuna* plots. All plant residues not harvested were left on the field to decompose, and the vegetation on the fallowed plots was not disturbed. Data collected were subjected to statistical analysis of variance using SAS (SAS, 1988). Differences in means were declared significant at $P \leq 0.05$ using the standard error of the mean (Snedecor and Cochran, 1980). Quadratic regression models were fitted to the yield of maize following the two maize variety reference crops. The Nitrogen Fertilizer Replacement Value (NFRV), using continuous maize as reference, was used to determine N credits to maize. The NFRV is the N fertilizer application rate needed to produce a cereal–cereal yield equal to that obtained without applied N in a legume–cereal

TABLE 2
Nodulation and dry matter accumulation of legumes at Ejura, 1999.

Cropping system	Nodule number plant^{-1}	Nodule dry weight (g plant^{-1})	Achieved Plant density (%)	Nodule dry weight (kg ha^{-1})	Total dry matter (kg ha^{-1})
1. Early soybean variety ("TGX 1478-2E")	26	0.13	81.1	17.0	3 021
2. Medium soybean variety ("Anidaso")	20	0.10	63.2	10.1	3 208
3. Early cowpea variety ("Asontem")	17	0.06	80.4	7.8	4 515
4. Medium cowpea variety ("Soronko")	28	0.07	83.3	10.2	3 902
5. Early groundnut variety ("RLRS-11")	63	0.05	71.3	5.4	-
6. Late groundnut variety ("F-mix")	97	0.06	47.2	5.2	2 903
7. *Mucuna pruriens*	5	0.31	100	20.0	3 422
$SED_{(0.05)}$	4.8	0.025	3.02	1.26	455

rotation system (Bundy *et al.,* 1993). It is a measure of the contribution of legumes to a following crop.

Results and discussion

Soil chemical analyses

Some chemical characteristics of 0–30 cm depth were as follows: pH, 6.3; total N, 0.03 g kg^{-1} soil; Bray-1 P, 23.2 mg kg^{-1} soil; K, 105.1 mg kg^{-1} soil; and soil organic matter, 7.9 g kg^{-1} soil.

Nodulation, dry matter accumulation and grain legume yields

Mucuna produced fewer but bigger nodules than soybean, cowpea, and groundnut, with significantly ($P \leq 0.05$) higher nodule mass per plant, and area basis than the others (Table 2). Both early- and late- maturing groundnut varieties produced 300 to 400 % more nodules than the cowpea and soybean varieties. However, nodules were much smaller in size than those of soybean and *Mucuna.* The smaller nodule size coupled with the low plant population density resulted in a very low nodule mass (Table 2). Soybean and cowpea had intermediate nodule numbers and mass. Within a legume species, maturity period appeared to be important only in soybean, where the early-maturing variety had more nodule mass than the medium-maturing variety. The reduced nodulation of the medium-maturing soybean variety, "Anidaso" could be attributed to root knot nematode infestation of this variety, with an incidence score of 2 (21– 40% of plants) on a 5-point scale, resulting in fewer and smaller nodules and loss of plants. Soybean, cowpea, and groundnut could be susceptible to various root knot nematode (*Meloidogyne* sp.) infestations (Riekert and Henshaw, 1998), and it is therefore important for breeding programs to develop varieties that are resistant to nematodes.

Total dry matter was highest for the cowpea, intermediate for *Mucuna* and soybean, and least for groundnut (Table 2). Plant population density (Tables 1 and 2) was obviously a contributory factor to the observed trends. Nematode infestation contributed to the low plant population of the medium-maturing soybean and rodent attacks reduced the late-maturing groundnut varieties. The current population density of 62 500 being recommended in Ghana for *Mucuna* (Osei-Bonsu and Asibuo, 1997), may be too low for optimum dry matter accumulation by *Mucuna* for mid- and minor season plantings. It is suggested that densities similar to those of the grain legumes should be investigated.

TABLE 3
Grain yield and yield components of legumes, Ejura, 1999.

Cropping system	Grain yield (kg ha^{-1})	Number of plants (ha^{-1})	Number of pods (plant^{-1})	Number of seeds (pod^{-1})	100 seed weight (g)
1. Early soybean variety ("TGX 1478-2E")	1 698	135 185	59	2.0	13
2. Medium soybean variety ("Anidaso")	988	105 247	48	2.2	13
3. Early cowpea variety ("Asontem")	1 051	133 951	9	14.1	12
4. Medium cowpea variety ("Soronko")	757	138 889	12	15.1	11
5. Early groundnut variety ("RLRS-11")	453	118 742	10	2.0	24
6. Late groundnut variety ("F-mix")	379	78 703	10	1.7	29
$SED_{(0.05)}$	93.5	5 030	5.7	0.4	1.5

Among the legumes, the highest grain yield was achieved by early-maturing soybean, which also had the greatest number of pods, followed by medium-maturing soybean and early- maturing cowpea. Groundnut varieties had the lowest yields (Table 3). Early maturing varieties of soybean and cowpea in this study yielded significantly higher than their medium maturing varieties probably as a result of escape from the effect of intermittent drought during flowering and podding of later maturing varieties. Report from variety trials of early maturing soybean (99-103 days) and medium maturing soybean lines (102–108) in the forest-savannah transition zone of Ghana (CSIR-CRI, 2003) showed that, the mean soybean grain yield (2.1 t ha^{-1}) obtained from the early maturing soybean varieties were higher than from the medium maturing varieties (1.2 t ha^{-1}). Also in two cowpea variety trials, of early maturing (60–70 days) and medium maturing (70–80 days), the mean grain yields of lines across five locations in the forest-savannah transition and the forest zones of Ghana ranged from 1.3 t ha^{-1}to 1.6 t ha^{-1} for the early maturing lines and 1.0 t ha^{-1} to1.9 t ha^{-1} for the medium maturing lines. This indicates that the cowpea lines with the highest and the lowest mean grain yield across locations were within the medium maturing group (CSIR-CRI, 2003). Under semi-arid agro-ecology (Signets Foundation for Sustainable Agriculture. 2004), early maturing 65-70 day cowpea variety IT89KD-34 was reported to have higher yield than medium maturing 75-85 day variety IT89KD-245. There appears to be an interaction between maturity group and environment on legume grain yield that needs further investigation.

Grain yield of following maize

The previous crop and current N application rate main effects on maize yield were significant ($P \leq 0.05$). However, there was no significant interaction between the current N application rate and previous crop on the yield of maize (Table 3). Average maize yields were not significantly different at 90 kg N ha^{-1} and 45 kg N ha^{-1} , but significantly lower at 0 N than at the higher rates (Table 4). The similarity in yield of maize at 45 and 90 kg N ha^{-1} is expected as the N recommendation for the forest–savanna agro-ecology of Ghana on land cropped for a maximum of one year after fallow is 45–51 kg N ha^{-1} (GGDP, 1992b).

Among the previous crops, the average maize yield was highest after *Mucuna* (Table 4), medium cowpea variety "Soronko", and late groundnut variety "F mix". Least maize yields were obtained after early groundnut variety

TABLE 4
Maize grain yield as influenced by current N application rate and previous crops. Ejura, 2000.

Current N application rate and previous crops	Maize yield (kg ha^{-1})	*Average yield increase over maize (%)	*Yield increase over maize at O (kg N ha^{-1} %)
N rate (kg N ha^{-1})			
0	3 046	–	–
45	4630	–	–
90	4760	–	–
SED $_{(0.05)}$	212.7		
Previous crop			
1. Early soybean variety ("TGX 1478-2E")	3 885	10	–41
2. Medium soybean variety ("Anidaso")	4 112	16	6
3. Early cowpea variety ("Asontem")	4 078	15	39
4. Medium cowpea variety ('Soronko")	4 959	40	93
5. Early groundnut variety ("RLRS-11")	3 065	-14	-2
6. Late groundnut variety ("F-mix")	4 578	29	3
7. Planted fallow (*Mucuna pruriens)*	5 438	53	96
8. Natural fallow	4 252	20	30
9. Early maize ("Dorke –SR")	3 607	–	–
10. Medium maize ("Obatanpa")	3 482	–	–
SED $_{(0.05)}$	388	–	–

*Based on combined mean yield of early- and medium-maturing maize.

"RLRS-11", and medium ("Obatanpa") and early ("Dorke- SR") maize varieties. Osei-Bonsu and Asibuo (1997), reported 122% higher yield of maize following *Mucuna* compared with cowpea. However, the cowpea variety used in their study was "Asontem", the early variety and not a medium- or late-maturing variety, which we found to result in a similar maize yield increase to the yield increase following *Mucuna*. In general, reported yield increases of cereals in legume–cereal rotations are from 11% to 350% compared to continuous cereal production (Peoples and Herridge, 1990). In our study, the average increase in yields across N fertilizer application rates ranged from 10% to 53%. In early groundnut, however, there was an average of 14% decrease in the following maize yield probably as a result of greater soil N uptake by this early variety and the harvesting of all the plant biomass of groundnut from the field. Yield increase when no N fertilizer was applied to maize ranged from 3% to 96% with decrease in yield of 2% when maize followed early soybean and 41% when maize followed early groundnut (Table 4). This showed that under the farmers' circumstances of rain-fed agriculture, and where the majority does not apply fertilizer and most of the soybean and groundnut biomass is harvested from the field, the residual benefits from *Mucuna* and medium-maturing cowpea in rotation with maize were greater than when N fertilizer was applied. However, early groundnut and early soybean in rotation with maize were not beneficial.

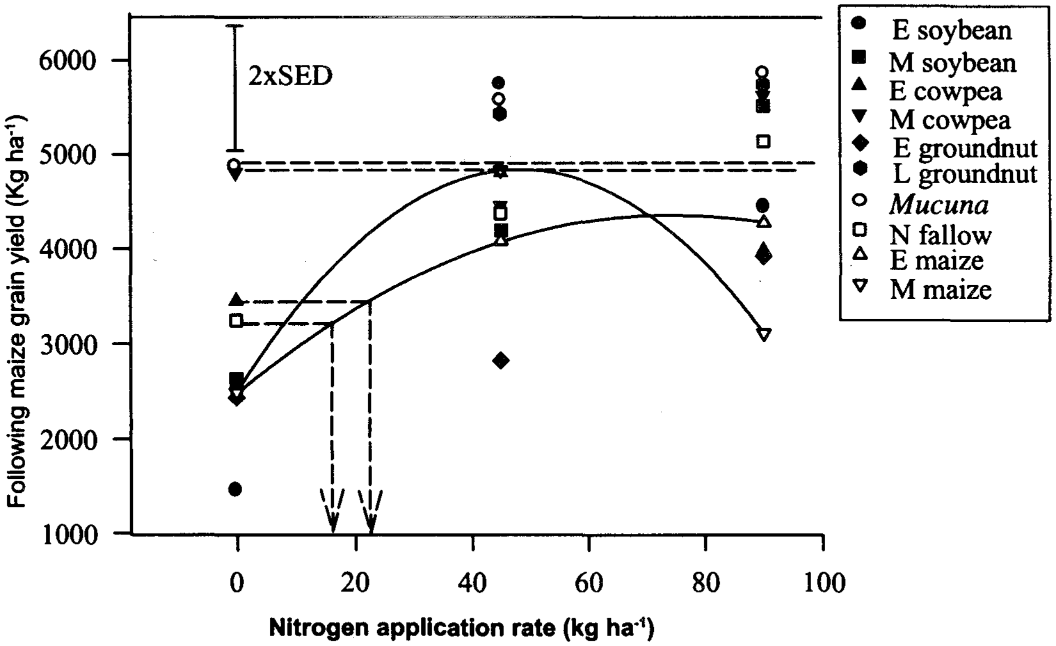

Figure 1. Maize yields and Nitrogen-credits from previous legumes, Ejura, 2000.

Nitrogen- credits

The yield advantage obtained when legumes are grown in rotation with non-legumes is often equated to equivalent amount of inorganic N fertilizer savings, termed nitrogen-credit (Lory *et al.*, 1995). Quadratic regression models fitted to the two maize variety reference crops were: Early maize ($Y = 2478 + 51.02X_1 - 0.35X_2^2$, $r^2 = 0.99$), and late maize ($Y = 2499 + 96.63 X_1 - 0.99 X_2^2$, $r^2 = 0.99$) (Fig. 1). Nitrogen credit to maize (Fig. 1) at Ejura using early maize as the reference crop was greater than 90 kg N ha^{-1} when maize followed Mucuna cover crop and "Soronko". "Asontem" cowpea gave N-credit values of 22 N ha^{-1}, and natural fallow gave 16 kg N ha^{-1}. No appreciable N-credits were measured from groundnut and soybean varieties. On the contrary, early soybean and early groundnut varieties appeared to have negative N-credits to maize. It is important to note that with the exception of the minimal (approximately 5%) leaf fall before harvest in groundnut, and leaf fall in soybean, all the aboveground dry matter produced is harvested from the field and may reduce the residual benefits from these legumes. Beck *et al.* (1991) reported negative N balances (total N fixed less N removed in harvested portion) up to 70 kg N ha^{-1} from field grown legumes when both seed and legume residues were removed from the field. However, harvesting only the grain resulted in a positive N balance up to 44 kg N ha^{-1}. Also, legumes can mine the soil of N when planted at very low plant population densities (Ennin and Clegg, 2001). This could contribute to the negative N credit recorded for the early groundnut variety, which had a low achieved plant population. Bell *et al.* (1994) similarly found that a high N harvest index of 0.62–0.73 in three out of four groundnut varieties studied resulted in negative apparent N balance. Contrary to our results for soybean, positive N-credits between 16–75 kg N ha^{-1} have been reported for soybean–cereal rotations (Mohammed and Clegg, 1993; Ennin and Clegg, 2001). In these studies, inoculants were applied, only seeds were harvested, and soybean aboveground residues were returned to the field. In cowpea-maize rotations, N- credits of 20–80 kg N ha^{-1} (Singh and Rachie, 1985), and 37 kg N ha^{-1} (Asafu-Agyei *et al.*, 1997), similar to our findings, have been reported. Within the same legume species, there was a trend for N-credits from the early-maturing variety to be lower than from the medium- or late-maturing variety. Reports from studies with soybean (George *et al.*, 1988) and groundnut (Bell *et al.*, 1994) indicate that early-maturing varieties of these legumes have lower nodulation, and N fixation and a high N harvest index. These attributes may have contributed to the lower N-credits from the early-maturing varieties.

In the USA, nitrogen recommendations for maize production are reduced by 22–45 kg N ha^{-1} when maize is grown after soybean in various locations (Kurtz *et al.*, 1984). It is important for N- credits to maize to be determined for the common legumes in the different agroecologies and soils for accurate fertilizer recommendations for maize when grown in rotation with legumes.

Soil fertility and moisture availability

Changes in soil chemical properties at the beginning of 2000 did not follow any consistent trend among the treatments. Overall, the study indicated a significant 67% increase in total N at planting of the following maize. There were decreases of 8.1% in pH, 74.3% in available P, and 83.6% in available K. Soil moisture availability appeared to be higher in the previous *Mucuna* plots (131 mg g^{-1} soil) than all other plots (111–125 mg g^{-1} soil) although this was not significant at $P \leq 0.05$. In recent times, it is becoming apparent that yield increases in non-legumes when grown in rotation with legumes may have a significant non-N rotation effect component, related to improved soil structure and moisture storage. Copeland *et al.*, (1993) reported that a contributory factor to the 30% yield increase of maize in a soybean–maize rotation compared to maize–maize continuous system was increased root surface resulting in increased soil water depletion of 16 mm and increased water use efficiency in the soybean–maize rotation. Increased precipitation use efficiency from 83.6 kg ha^{-1} cm^{-1} to 101.8 kg ha^{-1} cm^{-1} in soybean or clover–maize rotation over maize–maize was reported to contribute to increased maize yields and reduction in crop failures in soybean–maize rotation compared to continuous maize, under rain-fed agriculture (Varvel, 1994; Kurtz *et al.*, 1984; Copeland *et al.*, 1993; Ennin and Clegg, 2001). Another set of observations (Peoples and Herridge, 1990; Lory *et al.*, 1995; Ennin and Clegg, 2001) that point to the importance of non-N rotation benefits is that the potential N contribution by legumes, the net N balance, (N fixed less N removed by harvested seed) is often lower than the determined N credits when non-legumes are grown after legumes. Ennin and Clegg (2001) reported a maximum positive N balance of 17 kg N ha^{-1} from soybean while N-credits from the Nitrogen Fertilizer Replacement Value reached a maximum of 46 kg N ha^{-1}. They concluded that increased yields of maize in rotation with soybean compared to continuous maize may be due to an N-fixation, reduction in N immobilization, and non-N rotation effects such as increased water use efficiency.

Conclusions

It is apparent that maturity group, and the species of legumes are important factors that will determine the contribution of legumes to the yield of following crops. *Mucuna* and medium-maturing cowpea in rotation with maize resulted in significantly higher maize grain yields than continuous maize with or without applied N and had N-credits greater than 90 kg N ha^{-1}. Soybean and groundnut of both early- and later-maturity did not have yield benefits to maize in rotation when no N was applied. Maize planted after early-maturing soybean resulted in a significant decrease in maize grain yield (41%) at 0 N and negative N-credits to maize. With the current farmer practice for soybean and groundnut production in Ghana including no application of inoculant, their method of harvesting where most of the crop residues are removed from the field, and no fertilizer is applied in maize production, planting soybean and groundnut as rotational crops may not be beneficial in maize production. Maize may be grown in rotation with *Mucuna*, and early- and medium-maturing cowpea varieties with increased yield benefits.

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