Nitrogen supplied to corn by legumes in a Central Amazon Oxisol

T.J. Smyth*

Department of Soil Science, North Carolina State University, Raleigh, NC 27695–7619, USA

M.S. Cravo

EMBRAPA/Centro de Pesquisa Agroflorestal da Amazônia, C.P. 455, 69.000 Manaus, AM, Brazil

and

R.J. Melgar

Instituto Nacional de Tecnología Agropecuaria, CC No 57, 3400 Corrientes, Argentina

Received February 1990; revised August 1990

Two field studies with legume crop residues were conducted during three consecutive years in a Central Amazon Oxisol to determine their fertilizer-N substitution value and the influence of legume residue management on succeeding corn crops. In the first experiment, incorporated legume residues from two legume cover crops, mucuna (*Mucuna aterrima* (Piper & Tracy) Merr.) and indigofera (*Indigofera tinctoria* L.), and from cowpea (*Vigna unguiculata* (L.) Walp.) were compared each year with five different urea-N rates (0–160 kg N ha^{-1}) with regard to their effect on yield and N accumulation by a succeeding corn crop. In the second experiment, legume residue management treatments, evaluated only with mucuna, were (1) incorporation; or (2) mulch of aboveground biomass produced *in situ*; (3) removal of aboveground biomass; and (4) incorporation of imported aboveground biomass to a bare plot. Mean fertilizer-N substitution value, during three consecutive years, was 74 kg ha^{-1} for mucuna and 26 kg ha^{-1} for indigofera and cowpea. Corn yields with incorporation of aboveground mucuna biomass exceeded the yields of the mulch treatment in only one of the three years.

Keywords: *Mucuna aterrima*; *Indigofera tinctoria*; *Vigna unguiculata*; *Zea mays*; Fertilizer-N substitution value; Humid tropics; Oxisol; Central Amazon

Continuous cropping of corn and rice requires N fertilizer inputs on Oxisols and Ultisols of the Amazon Basin (Valverde and Bandy, 1982; Oliveira *et al.*, 1986). Accessibility and use of fertilizers are often limited by poor infrastructure and high costs. Under such conditions, the supply of biologically fixed N_2 by legumes to succeeding non-legume crops is an important management alternative (Yost *et al.*, 1985).

Field studies in South Brazil have shown that several tropical legume cover-crops supplied large amounts of N to succeeding corn (*Zea mays* L.) crops when grown as green manures (Miyasaka *et al.*, 1983; Suhet *et al.*, 1985). In a Cerrado Oxisol, the fertilizer-N substitution value of four legumes to a succeeding corn crop ranged 50–170 kg ha^{-1} (Bouldin *et al.*, 1989). Further investigations are needed to evaluate the performance of such legumes under humid tropical conditions.

A major constraint to green manuring practices by small farmers is the energy expended in incorporating the legume materials (Wilson and Lal, 1986). Although surface mulch from legume ground covers is an alternative, there is a potential for increased N loss by volatilization (Smith *et al.*, 1987; Terman, 1979; Lathwell *et al.*, 1989). However, N losses must be balanced against positive effects on weed suppression (Wade and Sanchez, 1983) and soil physical properties (Lal, 1975) which are associated with mulching practices in the tropics.

The main objective of this study was to determine the fertilizer-N substitution value of legume residues to succeeding corn crops in an Oxisol in the Central Amazon. The influence of legume management, as a green manure or as a mulch, on succeeding corn yields was evaluated in a second experiment with only one legume cover crop.

Materials and methods

Two experiments were conducted at the EMBRAPA Experiment Station located 30 km north of Manaus, Amazonas (3° 8′ S, 59° 52′ W, 50 m elevation) during 1984–1986. Average annual rainfall is 2420 mm with a maximum of 295 mm month^{-1} in March and April and a minimum of 105 mm during August and September. Mean monthly maximum and minimum temperatures are 32 and 22°C, respectively (EMBRAPA, 1984). The soil at both sites is a clayey, kaolinitic, isohyperthermic Xanthic Hapludox (EMBRAPA, 1979). Initial chemical soil properties for the surface soil layer (0–15 cm) of each experimental site are shown in Table 1.

Fertilizer-N substitution experiment

Treatments for three successive corn crops consisted

* Author for correspondence

0041-3216/91/040366-07
© 1991 Trop. Agric. (Trinidad)

Table 1 Initial chemical properties of the surface soil layer (0–0.15 m) for both experimental sites, Amazonas, Brazil

Experiment	pH	$cmol_c\ l^{-1}$ Ca+Mg	K	Al	Al saturation (%)	Mehlich 1 P ($mg\ l^{-1}$)	Organic C ($g\ kg^{-1}$)
Fertilizer N substitution	4.2	0.90	0.27	1.27	52	4.7	27.6
Legume residue management	4.3	1.20	0.10	1.17	47	4.3	26.7

Table 2 Dates for planting and incorporating legumes in each experiment, Amazonas, Brazil

Experiment	Year	Legume	Planting	Incorporation
Fertilizer N substitution	1984	Cowpea	20 June	29 September
		Cover crops	15 June	29 September
	1985	Cowpea	20 August	28 November
		Cover crops	1 August	28 November
	1986	Cowpea	25 September	29 December
		Cover crops	13 September	29 December
Legume residue management	1984	Mucuna	10 June	26 September
	1985	Mucuna	2 September	9 December
	1986	Mucuna	12 September	6 January

of five rates of urea-N and three legumes, arranged in a randomized complete block design with four replications. Plots destined for urea treatments were kept weed-free during growth of the legumes which preceded each corn crop. For the two initial corn crops N rates were none, 20, 40, 60 and 120 kg ha^{-1}. Each rate was applied in three equal increments as a broadcast application at planting, and as side-dressings at 25 and 55 days after planting. Side-dressed applications were immediately incorporated with a hoe to minimize N volatilization losses. For the third corn crop, N rates were changed to none, 40, 80, 120 and 160 kg ha^{-1} and the N was broadcast and incorporated at planting. The three legumes evaluated in each corn crop were cowpea (*Vigna unguiculata* (L.) Walp. cv. IPEAN V-69) residues after pod harvest, and two cover-crops: (1) mucuna (*Mucuna aterrima* (Piper & Tracey) Merr.), and (2) indigofera (*Indigofera tinctoria* L.). Legume row spacing was 0.5 m. Planting density was approximately 200 000 plants ha^{-1} for cowpea and indigofera and 120 000 plants ha^{-1} for mucuna. Plot dimensions were 5 × 8 m.

Aboveground biomass for mucuna and indigofera were cut and incorporated when they reached flowering stage. Preliminary investigations showed that mucuna and indigofera flowered at approximately 100 days when planted during the dry season in this region. Since the growth cycle for cowpea was 65 days, planting dates for this legume were delayed by 1–3 weeks, relative to mucuna and indigofera (Table 2). One day prior to incorporation, the standing aboveground biomass for the entire plot was cut, weighed, and subsamples taken for moisture and nutrient determinations. Legume biomass was distributed uniformly across the entire plot and incorporated. Time between legume incorporation and corn planting never exceeded two days.

Corn (cv. BR 5102) was planted at approximately 55 000 plants ha^{-1} with a spacing of 1 m between rows. After the first corn crop, upland rice (*Oryza sativa* L., cv. CNAX-791048) was seeded with a planting stick at six seeds $hole^{-1}$ on a spacing of 0.3 × 0.3 m. No fertilizers were added to the rice crop. Harvest measurements were taken from 6.0 m sections of the central three rows of corn or five rows of rice. Crop residues in the harvest area were weighed and subsamples were taken for N and moisture determinations. Rice straw was removed with the grain for mechanical threshing. Grain yields adjusted to 130 g moisture kg^{-1} wet weight.

Two months prior to planting legumes in 1984, lime and fertilizers were broadcast and incorporated at the following rates to all treatments: 2.0 t ha^{-1} of calcitic lime ($CaCO_3$-equivalency basis), 88 kg P ha^{-1} as triple superphosphate, 50 kg K ha^{-1} as KCl and 1 kg Cu ha^{-1} as $CuSO_4$. Additional fertilizers were broadcast and incorporated prior to planting each corn crop. For the first corn crop K, B (as borax) and Zn (as $ZnSO_4.7H_2O$) rates were 33, 1 and 5 kg ha^{-1}, respectively. Phosphorus, K, B, and Cu were applied to the second corn crop at the rates of 44, 50, 1 and 1 kg ha^{-1}, respectively. Only P and K were applied to the third corn crop at the same rates as for the preceding crop. The same fertilizer carriers were used in all crops.

During the third corn crop, total inorganic N was measured in soil samples at depths of 0–0.15 and 0.15–0.30 m in each plot at six sampling dates (0, 23, 42, 56, 71 and 105 days after planting). The surface-soil samples were a composite of 20 subsamples as opposed to three subsamples for the 0.15–0.30 m depth increment. Samples at day zero were taken prior to fertilizer-N application. Changes in inorganic soil N resulting from urea and legume N, at each sampling date, were estimated by the difference in inorganic N levels for treatments with and without applied N in the 0–0.30 m depth. These values are referred to as delta inorganic N.

Legume residue management experiment

Mucuna was the only legume evaluated in this experiment. Treatments consisted of two urea-N rates and four legume management alternatives, arranged in a randomized complete block design with four replications. Nitrogen rates were none and 80 kg N ha^{-1} for the two initial corn crops and none and 120 kg N ha^{-1} for the third corn crop. Legume treatments were: (1) incorporation of aboveground biomass; (2) mulch of aboveground biomass; (3) removal of aboveground biomass; and (4) incorporation of biomass from treatment (3) to a bare

Table 3 Analysis of variance summary (*F* values) of grain yields and N accumulation for three corn crops in the fertilizer-N substitution experiment, Amazonas, Brazil

Source of variation	df	Corn crop 1984	1985	1986
Grain yield				
Replication	3	0.69	0.44	0.50
Treatment	7	3.80*	5.28*	7.91*
Urea-N	3	0.67	5.06**	4.24*
Control *vs.* urea	1	21.63**	16.93**	30.32**
Legume *vs.* urea	1	2.60	0.01	1.66
Indigofera *vs.* cowpea	1	0.20	0.22	0.04
Mucuna *vs.* ind. + cowpea.	1	0.15	4.65*	10.61**
N accumulation				
Replication	3	0.74	1.41	1.79
Treatment	7	3.53*	5.87*	6.81*
Urea-N	3	2.09	6.43**	5.79**
Control *vs.* urea	1	17.09**	18.63**	33.83**
Legume *vs.* urea	1	0.91	0.02	3.38
Indigofera *vs.* cowpea	1	0.29	0.11	0.01
Mucuna *vs.* ind. + cowpea	1	0.12	3.03	8.16**

*,**, Significant at $P \leq 0.05$ and 0.01, respectively

plot. Legume treatments, henceforth, will be identified in numerical order as whole-plant, mulch, root and top, respectively.

At the time of legume incorporation, aboveground biomass in the mulch treatment was cut, removed and returned to the plots after tillage operations to avoid confounding tillage and mulch effects. The sequence of rice and corn crops, lime and fertilizer additions, and management details were identical to the previous experiment. The sole exception was an additional 40 kg K ha^{-1}, applied to the root treatment, at the planting of the second and third corn crops, to compensate for K exported in the aboveground legume biomass.

Soil samples (0–0.15 m), comprising 10 random subsamples from the harvest area, were taken from each plot at the silking stage in the initial and final corn crops and at the rice flowering stage. A fourth sample was taken six months after harvesting the final corn crop.

Soil and plant analyses

Soil inorganic N in 1M KCl extracts was determined by semi-micro Kjeldahl procedures (Keeney and Nelson, 1982). Soil pH was determined in a 1:2.5 soil:H_2O suspension. Soil samples were extracted with 1M KCl for Ca, Mg and acidity, and with the Mehlich-1 solution for K and P. Exchangeable acidity was measured by titration with NaOH to the phenolphthalein endpoint.

After wet-ashing with H_2SO_4 and H_2O_2, legume tissue samples were analyzed for N, P, K, Ca and Mg, whereas corn and rice samples were analyzed only for N. Nitrogen was determined by semi-micro Kjeldahl procedures (Keeney and Nelson, *ibid.*). In both soil and plant extracts, Ca and Mg were determined by atomic absorption spectrophotometry, K by flame photometry and P by a colorimetric procedure (Murphy and Riley, 1962).

Statistical analyses

Data were analyzed by analysis of variance and regression procedures in the Statistical Analysis System (SAS Institute, 1985). Planned single-degree-of-freedom contrasts were used to partition treatment sum of squares for yield data in the fertilizer-N substitution experiment. Fertilizer-N response curves for each corn crop were developed by regression procedures. Linear, quadratic, log and square-root functions were evaluated. A log function gave the best description of data for the first corn crop as opposed to a square-root model for the two subsequent crops.

The fertilizer-N substitution value of each legume residue was defined as the amount of urea-N required by corn in the absence of legumes to obtain grain yields equivalent to those obtained where corn followed legume incorporation (Hesterman, 1988). These fertilizer-N substitution values were determined by solving the regression equations describing the yield response curves to urea-N for the corn yield measured in each legume residue treatment.

Results and discussion

Fertilizer-N substitution value of legumes

For the initial corn crop, yield and N accumulated in the aboveground biomass were not increased by fertilizer N rates ranging 20–120 kg ha^{-1} (Table 3). In subsequent corn crops, yield and N accumulation both increased with N fertilization. There was no difference in corn yields and N accumulation between the indigofera and cowpea treatments in all years, but yields with mucuna were superior to indigofera and cowpea in the second and third corn crops, and mucuna increased N accumulation in the third year. Yield and N accumulation for rice, following the initial corn crop, were similar among all residual N rates and legume treatments (data not shown). Mean values for rice grain yield and N accumulation were 2.0 t ha^{-1} and 45 kg ha^{-1}, respectively.

Yield response to urea-N for the three corn crops are shown in Figure 1. Maximum corn yields of 2.8–3.4 t ha^{-1} are within the range of yields reported by previous investigators for similar humid tropical environments (Sanchez *et al.*, 1983; Valverde and Bandy, *ibid.*). Yield response to urea-N increased with time of cultivation and was associ-

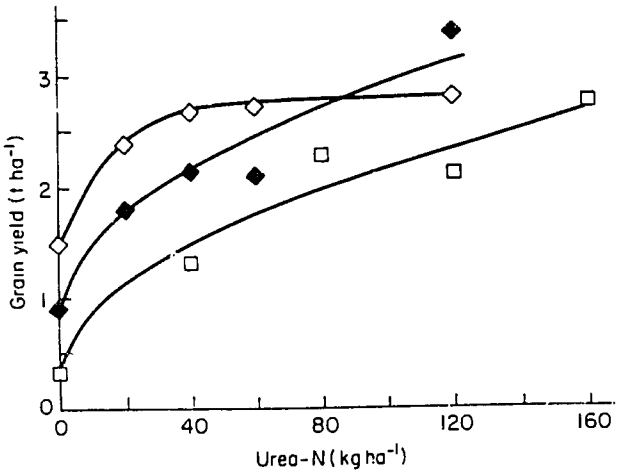

Figure 1 Corn yield as a function of urea-N rates during three consecutive years, Amazonas, Brazil. ◇, crop 1; ◆, crop 2; □, crop 3. For crop 1, $Y=2.77-1.35e^{-0.067x}$ (R^2, 0.99); for crop 2, $Y=0.81+0.21X^{0.5}$ (R^2, 0.94); for crop 3, $Y=0.30+0.19X^{0.5}$ (R^2, 0.95)

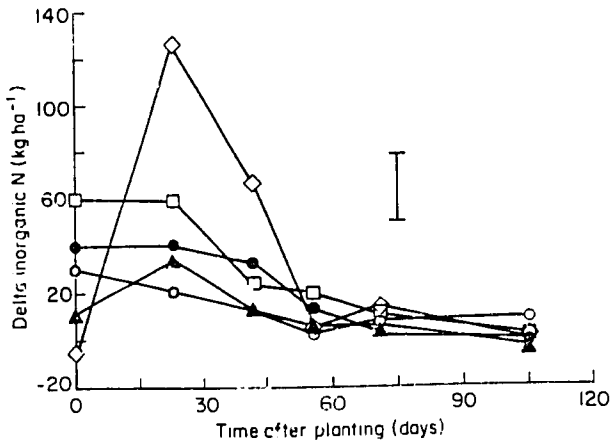

Figure 2 Delta inorganic N distribution in the surface 0.30 m layer of the Oxisol for legume and fertilizer N treatments during the third corn crop, Amazonas, Brazil. ◇, urea 120; □, mucuna; ●, indigofera; ▲, urea 40; ○, cowpea. Bar shows LSD ($P=0.05$)

Table 4 Legume biomass, N accumulation, and fertilizer-N substitution value for subsequent corn yields in three consecutive crops, Amazonas, Brazil

Legume	Year	Aboveground biomass: Dry weight (t ha⁻¹)	Aboveground biomass: N (kg ha⁻¹)	Corn yield (t ha⁻¹)	Fertilizer-N substitution value (kg ha⁻¹)
Mucuna	1984	7.1b[a]	168b	2.6	39[b]
	1985	7.0b	254a	2.6	73
	1986	10.7a	232a	2.2	109
Mean		8.2	218	2.5	74
Indigofera	1984	6.2a	152a	2.8	39
	1985	3.2b	91b	1.9	22
	1986	4.6b	77b	1.1	18
Mean		4.7	107	1.9	26
Cowpea	1984	1.4a	32a	2.6	39
	1985	0.3b	7b	1.7	22
	1986	1.3a	24a	1.1	18
Mean		1.0	21	1.8	26

[a] Entries in columns within the same legume followed by the same letter are not significantly different at $P \leq 0.05$
[b] Derived by solving equation in Figure 1 for N corresponding to corn yields obtained with legumes. The mean corn yields for the legumes were used whenever yields were not significantly different (Table 3)

ated with a progressive decline in yields for the treatment without N (Figure 1). Yields for the zero-N treatment decreased from 1.5 to 0.3 t ha^{-1} between the first and third corn crops. A total of 79 kg N ha^{-1} was exported from the zero-N treatment in crops (including rice) before planting the third corn crop. Changes in the placement of urea-N from three split applications in the two initial crops to a single broadcast application at planting of the third crop also influenced yield response patterns. In a separate experiment in this Oxisol, corn yields and apparent N recovery were reduced significantly when fertilizer N was applied at planting as opposed to 25 days after planting (Melgar, 1989).

The effect of incorporated legumes on grain yields and on the fertilizer-N substitution value are shown in Table 4 for each corn crop. Since yields with the three legume treatments were not significantly different in the first corn crop (Table 3), the fertilizer-N substitution value (Table 4) was based on their mean yield. A similar approach was used for estimating the fertilizer-N substitution value of indigofera and cowpea in the last two corn crops. With each succeeding crop, yields and fertilizer-N substitution values for indigofera and cowpea declined, whereas corn yields with mucuna remained relatively stable and the fertilizer-N substitution value increased. With the third corn crop the fertilizer-N substitution value of mucuna exceeded that of indigofera and of cowpea by a factor of six. Fertilizer-N substitution values for the three legumes are within the range, 15–203 kg N ha^{-1}, reported for winter cover-crops preceding corn in temperate regions (Frye *et al.*, 1988). Corn yield following mucuna incorporation to an Oxisol from the Brazilian Cerrado region equalled the yield obtained with 200 kg N ha^{-1} applied 42 days after emergence (Suhet *et al.*, *ibid.*).

Among the legumes the largest amounts of dry matter and N were added in the mucuna biomass (Table 4). Since fertilizer-N substitution values for legumes are derived from yield response functions to urea-N, increases in mucuna fertilizer-N substitution value with time may be partially attributed to

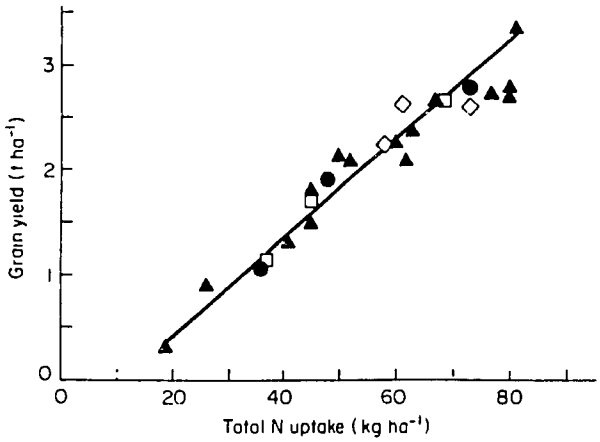

Figure 3 Relationship between grain yield and N accumulation in aboveground corn dry matter among variable N sources during three consecutive crops, Amazonas, Brazil. ▲, urea; ◇, mucuna; ●, indigofera; □, cowpea. $Y=0.52+0.05X$ ($r=0.99$)

the observed increased response to N with continuous cropping (Figure 1). Increases in mucuna fertilizer N value to corn may also have resulted from a build-up of residual N from preceding legume incorporation. Studies in temperate regions suggest that only 10–30% of the legume N is absorbed by the succeeding crop, with the remainder residing in soil N pools or lost by denitrification and leaching (Hesterman, *ibid.*). During two consecutive corn crops in an Oxisol, Reid *et al.* (1987) compared the residual effect from the initial incorporation of 260 kg N ha^{-1} as mucuna against a treatment where 180 kg N ha^{-1} as mucuna was applied only to the second corn crop. Corn yields, in the second crop, were identical for both treatments and exceeded the control (zero N) treatment by 2.2 t ha^{-1}. Nitrogen accumulation in corn for the residual mucuna treatment was 149 kg ha^{-1} as opposed to 111 kg ha^{-1} in the control treatment.

Progressive reductions in corn yield with indigofera are consistent with the declining quantities of N in its aboveground biomass (Table 4). With the cowpea treatment, however, yield reductions in corn were not consistent with the variations in N added by the legume crop residues. After grain harvest, cowpea residues remained in the field for approximately one month before they were cut and incorporated (Table 2). During this time most of the leaves had fallen and may have contributed additional N to the soil which was not measured in the standing crop residues. Furthermore, corn yield reductions with indigofera and cowpea suggest that there is little build-up of soil N by previous legume incorporations.

Changes in delta inorganic soil N for the three legumes are compared in Figure 2 with the 40 and 120 kg N ha^{-1} urea treatments as a function of time after planting the third corn crop. Treatment, time and treatment × time effects on delta inorganic N were all significant. Differences between treatments were limited to sampling dates between planting and the corn silking stage (56 days after planting). Maximum delta inorganic N values for urea treatments were detected at 23 days after planting and deviated by less than 15% from the actual quantities of applied N. In contrast, delta inorganic N values for the legume treatments were highest at planting and remained relatively constant up to the second sampling date. Previous investigations on C and N mineralization from legume cover crops in a Ustochrept showed that 40% of C was released in the first two weeks and that maximum NH_4-N release occurred between seven and 15 days after incubation (Beri *et al.*, 1989). Initial quantities of legume-derived soil N corresponded with their ranking as to N incorporated in aboveground biomass (Table 4), but suggested different levels of N mineralization. Delta inorganic N values at planting were equal to 26, 52 and 126% of the N added in mucuna, indigofera and cowpea residues, respectively.

The relationship between grain yield and N accumulation by corn at harvest in all crops was linear, regardless of N source (Figure 3). These results suggest that at equal corn yield levels, apparent N recovery would increase with decreasing N applied. Consequently, crop N recovery among the legumes was in the order of cowpea > indigofera > mucuna. Although the highest corn yields were not obtained with the cowpea residue treatment, it should be noted that this legume provided an additional return of 1.8 t ha^{-1} in grain during the three years of the experiment.

Legume residue management

Aboveground dry matter and nutrient accumulation for mucuna in the root, whole plant and mulch treatments, during three consecutive years, are shown in Table 5. Mucuna biomass and nutrient accumulation were reduced in 1985 by a 20-day drought following plant emergence. With the exception of K, legume dry matter and nutrient accumulation were not altered over time by the imposed management treatments. Transferal of aboveground mucuna biomass from the roots treatment in 1984 exported 91 kg K ha^{-1}. In 1985, after additional K removal in corn and rice grain and rice straw, mucuna in the root treatment had visual symptoms of K deficiency and a significant reduction in K accumulation relative to the other treatments. Supplementary K additions to the root treatment in subsequent corn crops alleviated this K constraint.

Grain yields and N accumulation for the three corn crops are shown in Table 6. Residual effects of treatments on yield and N accumulation of rice, following the initial corn crop, were not significantly different (data not shown). Mean values for rice grain yield and N accumulation were 2.8 t ha^{-1} and 58 kg ha^{-1}, respectively. Grain yields for successive corn crops in the zero-N treatment suggested a progressive decline in native soil N supply. Total N export (including rice) before planting the final corn crop in this treatment was 108 kg ha^{-1}. Yield reductions for legume treatments in the second corn crop coincided with the lower N accumulated by mucuna in 1985 (Table 5). In 1986, incorporation of aboveground mucuna biomass, after cutting and weighing, was delayed by 15 days because of intense rainfall. Consequently, corn yields for the top, whole-plant and mulch treatments were probably reduced because of legume N losses by leaching, volatilization, and/or immobilization. These results suggest that the time between cutting the legume ground-cover and establishing the succeeding non-leguminous crop is an important management factor for N supply by legume residues under these humid tropical conditions.

Table 5 Mucuna dry matter and nutrient accumulation during three consecutive years in the legume residue management experiment, Amazonas, Brazil

Mucuna treatment	Year	Aboveground dry weight (t ha^{-1})	N	P	K	Ca	Mg
			(kg ha^{-1})				
Root	1984	7.2	254	17	91	78	13
	1985	4.2	112	6	25	41	30
	1986	9.6	253	20	90	74	14
	Mean	7.0	206	14	69	64	19
Whole-plant	1984	8.1	298	18	110	87	18
	1985	5.3	198	13	71	37	32
	1986	10.6	276	24	97	76	17
	Mean	8.0	257	19	92	67	22
Mulch	1984	8.7	257	17	113	87	19
	1985	6.2	246	18	75	48	37
	1986	8.9	250	20	74	60	13
	Mean	7.9	251	18	87	65	23
Year means	1984	8.0	269	16	105	84	16
	1985	5.2	185	12	57	42	33
	1986	9.7	259	21	87	70	15
LSD (P=0.05)							
Treatment		NS	NS	NS	NS	NS	NS
Time		1.4	49	NS	31	15	5
Treatment × Time		NS	NS	NS	26	NS	NS

NS, not significant

Table 6 Grain yield and N accumulation for three consecutive corn crops in the legume residue management experiment, Amazonas, Brazil

Treatment	Grain yield (t ha^{-1})				N accumulation (kg ha^{-1})			
	1984	1985	1986	Mean	1984	1985	1986	Mean
Control[a]	2.3	1.1	0.4	1.3	56	44	20	40
Urea-N[b]	2.5	1.8	1.8	2.0	69	50	66	62
Root	1.9	0.7	0.4	1.0	53	35	22	36
Top	2.8	1.2	1.2	1.7	85	44	29	53
Whole-plant	3.2	2.2	1.7	2.4	82	65	73	73
Mulch	2.9	1.4	1.3	1.9	70	47	55	57
Mean	2.6	1.4	1.1		69	47	44	
LSD (P=0.05)								
Treatment		0.6				13		
Year		0.2				7		
Treatment × Year		0.5				17		

[a] No fertilizer N applied; [b] fertilizer N rates were 80 kg ha^{-1} for the first two crops and 120 kg ha^{-1} for the final crop

Comparison of corn yields in legume root and top treatments with the control treatment suggested that most of the N supplied to corn by mucuna was derived from the aboveground biomass (Table 6). The lower yields and N accumulation by corn in the root treatment, relative to the control, may be attributed to a reduction in native soil N supply to corn through the export of N in aboveground mucuna biomass from the root to the top treatment. Corn yields for the mucuna root treatment, in this environment, differ from those obtained by Reid *et al.* (*ibid.*) in an Oxisol of Central Brazil where mucuna roots increased the corn yield by 0.8 t ha^{-1} relative to a zero-N treatment.

Although N accumulation by corn was higher when mucuna was incorporated (whole-plant) than when left as a surface mulch, treatment means for grain yield showed no advantage from legume incorporation. Within the three years of this experiment the corn yields for the whole-plant treatment exceeded the mulch treatment only in 1985. Although weed control was not a variable in this study, weed populations were visibly lower in the mulch treatment in all years. Management of a legume ground-cover as a mulch is more compatible with manual tillage that dominates crop production in the Central Amazon region.

Aboveground mucuna biomass contained appreciable quantities of P, K, Ca, and Mg (Table 5). Soil analysis data showed no effect of green manure treatments on acidity, Ca, Mg or available P levels. Variations in soil K levels among treatments, during the course of the experiment, suggested that mucuna improved K cycling (Table 7). Although equal amounts of fertilizer K were applied to the control, urea-N, whole-plant and mulch treatments exchangeable K levels were consistently higher in the two latter treatments. Consequently, an additional benefit to the inclusion of mucuna in annual crop rotations during fallow periods would be to diminish fertilizer K requirements for continuous cropping in this soil.

Table 7 Soil exchangeable K ($cmol_c\ l^{-1}$) in the different treatments for the legume residue management experiment at five sampling dates, Amazonas, Brazil

Treatment	Time (months) 3	6	27	38	Mean
Control	0.09	0.10	0.12	0.11	0.10
Urea-N	0.07	0.10	0.08	0.16	0.10
Root	0.09	0.06	0.07	0.08	0.07
Top	0.13	0.16	0.21	0.18	0.17
Whole-plant	0.14	0.13	0.13	0.13	0.13
Mulch	0.17	0.14	0.16	0.13	0.15
Time means	0.11	0.11	0.13	0.13	
LSD (P=0.05)					
Treatment			0.03		
Time			NS		
Treatment × Time			0.03		

Sampling dates correspond to flowering stage in the first corn crop, the rice crop, the third corn crop, and after harvesting the third corn crop, respectively; NS, not significant

Acknowledgements

Financial and other support was provided by EMBRAPA, the US Agency for International Development, and INTA. This Paper is a joint contribution of the North Carolina Agricultural Research Service Journal Series no. 12562, and EMBRAPA.

References

Ben, V., Meelu, O.P. and Khind, C.S. (1989) Biomass production, N accumulation, symbiotic effectiveness and mineralization of green manures in relation to yield of wetland rice, *Trop. Agric. (Trinidad)* **66** 11–16

Bouldin, D.R., Quintana, J. and Suhet, A. (1989) Evaluation of mineralization potential of legume residues, in: (Caudle, N. ed) *TropSoils Technical Report, 1986–1987*, North Carolina State University, Raleigh, NC, pp. 304–305

EMBRAPA (1979) *Guia de excursao XVII Congresso Brasileiro de Ciencia do Solo, Manaus*, Empresa Brasileira de Pesquisa Agropecuaria, Servico Nacional de Levantamento e Conservacao de Solos, Rio de Janeiro, Brazil, 72 pp.

EMBRAPA (1984) *Boletim agrometeorologico*, Number **6**, Empresa Brasileira de Pesquisa Agropecuaria, UEPAE de Manaus, Manaus, Brazil, 25 pp.

Frye, W.W., Blevins, R.L., Smith, M.S. and Corak, J.S. (1988) Role of annual legume cover crops in efficient use of water and nitrogen, in: (Hargrove, W.L. ed) *Cropping Strategies for Efficient Use of Water and Nitrogen*, ASA Spec. Publ. **51**, American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI, pp. 129–154

Hesterman, O.B. (1988) Exploiting forage legumes for nitrogen contribution in cropping systems, in: (Hargrove, W.L. ed) *Cropping Strategies for Efficient Use of Water and Nitrogen*, ASA Spec. Publ. **51**, American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI, pp. 155–166

Keeney, D.R. and Nelson, D.W. (1982) Nitrogen – inorganic forms, in: (Page *et al.* eds) *Methods of Soil Analysis, Part 2*, 2nd ed., *Agronomy* **9** 643–698

Lal, R. (1975) *Role of mulching techniques in tropical soil and water management*, IITA Tech. Bull. **1**, Ibadan, Nigeria, 38 pp.

Lathwell, D.J., Bouldin, D.R., Bowen, W.T. and Costa, F. (1989) Soil- and crop-management systems in acid savanna soils using green manures and crop residues as N sources, in: (Caudle, N. ed) *TropSoils Technical Report, 1986–1987*, North Carolina State University, Raleigh, NC, pp. 308–309

Melgar, R.J. (1989) Nitrogen utilization by annual crops in the Central Amazon, *PhD dissertation*, North Carolina State University, Raleigh, 239 pp.

Miyasaka, S., de Camargo, O.A., Cavalen, P.A., de Godoy, I.J., Werner, J.C. and Curi, S.M. (1983) *Adubacao organica, adubacao verde e rotacao de culturas no Estado de Sao Paulo*, Campinas, Brazil, Fudacao Cargill, 138 pp.

Murphy, J. and Riley, J.R. (1962) A modified single solution method for the determination of phosphate in natural waters, *Anal. Chim. Acta* **27** 31–36

Oliveira, R.F., Singh, R., Couto, W.S., Cruz, E.S. and Dutra, S. (1986) Adubacao nitrogenada na regiao norte, in: (*Santana, M.B.M. ed) Simposio sobre adubacao nitrogenada no Brasil*, Comissao Executiva de Producao e Lavoura do Cacau, Ilheus, Brazil, pp. 125–151

Reid, S.W., Bowen, W.T., Carsky, R.J. and Suhet, A.R. (1987) Nitrogen availability from legume crop residues and green manures to succeeding nonlegume crops, in: (eds Caudle, N. and McCants, C.B.) *TropSoils Technical Report, 1985–1986*, North Carolina State University, Raleigh, NC, pp. 192–194

Sanchez, P.A., Villachica, J.H. and Bandy, D.E. (1983) Soil fertility dynamics after clearing a tropical rainforest in Peru, *Soil Sci. Soc. Amer. J.* **47** 1171–1178

SAS Institute (1985) *SAS User's Guide: Statistics*, SAS Institute, Inc., Cary, NC

Smith, M.S., Frye, W.W. and Varco, J.J. (1987) Legume winter cover crops, *Adv. Soil Sci.* **7** 95–139

Suhet, A.R., Peres, J.R. and Vargas, M.A. (1985) Nitrogenio, in: (Goedert, W.J. ed) *Solos dos Cerrados: tecnologias e estrategias de manejo*, Sao Paulo, Brazil, Livraria Nobel, pp. 167–202

Terman, G.L. (1979) Volatilization losses of nitrogen as ammonia from surface-applied fertilizers, organic amendments, and crop residues, *Adv. Agron.* **31** 189–223

Valverde, C. and Bandy, D.E. (1982) Production of annual food crops in the Amazon, in: (Hecht, S.B. ed) *Amazonia: agriculture and land use research*, Centro Internacional de Agricultura Tropical, Cali, Colombia, pp. 243–280

Wade, M.K. and Sanchez, P.A. (1983) Mulching and green manure applications for continuous crop production in the Amazon Basin, *Agron. J.* **75** 39–45

Wilson, G.F. and Lal, R (1986) New concepts for post-clearing land management in the tropics, in: (eds, Lal, R., Sanchez, P.A. and Cummings, Jr, R.W.) *Land Clearing and Development in the Tropics*, Accord, MA, A.A. Balkema, pp. 371–381

Yost, R.S., Evans, D.O. and Saidy, N.A. (1985) Tropical legumes for N production: growth and N content in relation to soil pH, *Trop. Agric. (Trinidad)* **62** 20–24