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Screening legume green manures as nitrogen sources to succeeding non-legume crops

I. The fallow soil method

W. T. BOWEN[1], J. O. QUINTANA[1], J. PEREIRA[2], D. R. BOULDIN[1], W. S. REID[1], and D. J. LATHWELL[1]

[1]*Department of Agronomy, Cornell University, Ithaca, NY 14850, USA.* [2]*EMBRAPA/CPAC, C. P. 70.0023, 73.300 Planaltina, DF, Brazil*

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Abstract

Legumes managed as green manures provide a good alternative to the use of commercial N-fertilizer for non-legume crop production. An accurate method for predicting the N supplying potential of legumes must be available in order to select the most promising legumes. A field procedure based on the periodic measurement of inorganic nitrogen accumulated in bare fallow soil after the incorporation of legumes was tested on three field experiments carried out from 1983 to 1986 on Oxisols of the Cerrado Region of Central Brazil. The response of maize (*Zea mays* L.) to incorporated legumes was estimated from companion cropped plots. The amount of inorganic nitrogen accumulated in fallow soil was highly correlated to both nitrogen content in the aboveground dry matter of maize and nitrogen content in the aboveground dry matter plus the residual inorganic nitrogen in the cropped plots in all three experiments. The results showed that the nitrogen supplying potential of legumes for a succeeding non-legume crop may be estimated by the accumulation of inorganic nitrogen in bare fallow soil after the incorporation of the legumes.

Introduction

High energy inputs required for production and transportation of fertilizers, and concerns over their environmental effects have led to a renewed interest in the use of legume green manures to provide N for succeeding non-legume crops (Baldock and Musgrave, 1980). Other effects of legumes that contribute to increased yields beyond the simple N effect include; i) improved availability of other nutrients for crop production (Wade and Sanchez, 1983), ii) improved soil aggregate stability (Burns and Davies, 1986), iii) amelioration of compacted soils (Hulugalle et al., 1986; Jordan et al., 1956), iv) reduced nematode infestations (Reddy et al., 1986; Resck et al., 1982). In spite of these other effects, the N supplied by a legume is usually taken as the basis for determining its worth to an agricultural system (Westermann and Crothers, 1980).

Because of the large number of species of legume that merit evaluation (Bouldin et al., 1979), a procedure for identifying those with the highest N supplying potential is needed. Crop response studies in the field offer the most valid test (Scarsbrook, 1965), but they are expensive and time consuming. Other field methods involving less time, space, and expense than crop response studies have been used to follow the mineralization pattern of leguminous materials incorporated into the soil. Schofield (1945) incorporated four tropical legume green manures and found that the amount of accumulated nitrate N in the soil profile (0.0–0.6 m) increased as the quantity of incorporated legume N increased. In the work reported here the objective was to assess the value of a fallow soil method as a means of screening different legume green manures as sources of N for a succeeding maize crop.

Materials and methods

Experiments were conducted on three different sites within the Cerrado Research Center (CPAC/EMBRAPA; 15°36′S and 47°42′W, alt 1000 m) near Brasilia, Brazil. The average annual precipitation is about 1500 mm (95% falls during the October–April wet season) and average monthly temperatures are 22 °C during the wet season and 20 °C during the dry season (EMBRAPA/CPAC, 1976).

Experiments 1 and 3 were carried out during the 1984 and 1986 dry seasons under controlled sprinkler irrigation so that leaching of accumulated inorganic N would be minimal. Experiment 2 was carried out during the 1984–85 wet season when high rainfall occurs and leaching losses are certain. Experiments 1 and 2 were on a Red Yellow Latosol while Experiment 3 was on a Dark Red Latosol, both of the suborder Ustox (Goedert, 1983; Macedo and Bryant, 1987). All sites had been cleared of savanna vegetation and cropped several years prior to these experiments.

In each experiment a common experimental design was to have for each treatment shown in Ta 1 a companion fallow and cropped (maize) pl For the dry season experiments, legumes wa grown on site during the previous wet season. legumes except soybean were harvested near flo ering stage, weighed, coarsely chopped, and even distributed over the same plot (top + roots tre ment) or transported to another plot (tops on treatment) leaving the roots (roots only treatmen Soybean was harvested at maturity for grain an the residue either returned to the same plot removed.

Table 1. Treatments (4 replicates) and average dry matter and total N in aboveground plant materials incorporated before maize

Plant material incorporated[a]	Dry matter (mg ha^{-1})	Total N (kg ha^{-1})
Expt. 1, 1984, dry season, irrigated		
None		
Mucuna tops 1	4.3	128
Mucuna tops 2	8.5	252
Mucuna roots		
Mucuna top + roots	8.8	260
Soybean roots		
Soybean residue	7.4	108
Expt. 2, 1984–85, wet season		
None (after fallow)		
Mucuna tops	5.6	182
None (after maize)		
Maize stover	5.0	29
Maize + mucuna	18.5	353
Expt. 3, 1986, dry season, irrigated		
None		
Zornia top + root	2.5	58
Mucuna top + root	4.9	117
Canavalia top + root	5.0	156
Crotalaria top + root	10.3	170

[a] Mucuna (*Mucuna aterrima*), soybean (*Glycine max*), Maize (*Zea mays* L.), Zornia (*Zornia latifolia*), Canavalia (*Canavalia ensiformis*), Crotalaria (*Crotalaria paulina*).

Except for mucuna tops which were obtaine from a nearby field, plant materials used for the we season experiment were grown on site during th previous wet season. Where no plant material wa incorporated, the plot either remained bare durin the previous wet season or was cropped to maize The maize + mucuna intercrop resulted in high dr matter production because the maize acted as trellis for mucuna resulting in increased biomass production. Previous wet season maize was harvested for grain and the stover either removed or returned and, in the case of the intercrop, returned with mucuna.

Subsamples of green manure legumes were taken for dry matter and total N determinations. All plant materials were then incorporated with a rototiller to a depth of 0.2 m. Within two weeks after incorporation hybrid maize "Cargill 111" was planted in each of the experiments. Prior to incorporation, broadcast rates of lime, P, K, and micronutrients were applied to each experiment as required.

Following legume incorporation, fallow soils were sampled periodically at about two week intervals until 160 days after incorporation. From every plot at each sampling time, 3 subsamples were taken from each 0.15 m depth interval to 0.6 m and from each 0.3 m in the following 0.6 m. Immediately following sampling, about 5 g of field-moist soil was removed from each of the subsamples for each depth interval and added to a 100-ml glass flask containing 50 ml of 1 *M* KCl. The flacks were shaken by hand and allowed to settle before analysis. Total inorganic N (NH_4^+-N + NO_3^--N + NO_2^--N) was determined on the extract using the MgO-Devarda alloy-steam distillation method (Bremner, 1965; Keeney and Nelson, 1982). The results were corrected for moisture content and soil

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bulk density and are reported as kg ha^{-1}. To facilitate comparisons among the three experiments and for ease of presentation, the different sampling dates have been averaged and are presented for successive 40-day periods until 160 days after incorporation.

At the end of each experiment, maize was harvested for grain and stover to determine grain yields and N content of total above ground dry matter. During the wet season experiment sequential harvests of whole plants were made in the mucuna tops treatment to follow the time course of N accumulation in aboveground maize.

Linear correlation coefficients between inorganic nitrogen accumulation in fallow and cropped soil, and legume or maize parameters were determined using the CORR program of SAS (SAS, 1982).

Results

Initial inorganic N levels differed according to cropping history prior to planting legumes; highest levels were found after bare fallow and lowest levels were found after an unfertilized maize crop (Table 2). The addition of legume green manures resulted in substantial accumulations of inorganic N by 40 days after incorporation. Only the lower N containing soybean (1.46% N) and maize (0.58% N) residues showed slight decrease in inorganic N, indicating net immobilization. Likewise, crotalaria (1.65% N) in Experiment 3, likely as a consequence of a wider C/N ratio, initially released less inorganic N than canavalia (3.12% N) although both green manures had similar total N contents (Bartholomew, 1965).

Inorganic N which accumulated throughout the season during the two irrigated dry season Experiments (1 and 3) was found mainly in the top 0.6 m of the profile. Leaching losses were therefore minimal during these two experiments. During the wet season Experiment (2) some inorganic N accumulated in the top 0.6 m, but by 80 days after incorporation, most of the inorganic N had leached due to heavy rainfall and was located between 0.6 and 1.2 m. The amount of inorganic N that leached below 1.2 m was not known.

The relationship between inorganic N accumulated in fallow soil and N uptake by maize varied among the different experiments depending on

Table 2. Inorganic-N accumulated in fallow soil by successive 40-day periods after incorporation and N uptake by maize in adjacent cropped soil

Plant material incorporated	Inorganic N accumulated to 1.2 m (kg ha^{-1})					N uptake by maize (kg ha^{-1})
	0	40	80	120	160	
Experiment 1						
None	247	254	258	264	274	120
Mucuna tops 1	247	272	291	307	350	149
Mucuna tops 2	247	307	332	359	439	168
Mucuna roots	151	160	172	190	213	125
Mucuna top + root	151	222	235	266	333	168
Soybean roots	124	122	116	137	150	84
Soybean residue	124	119	135	170	201	116
Experiment 2						
None (after fallow)	181	159	157	148	148	111
Mucuna tops	181	224	246	232	235	145
None (after maize)	86	86	92	124	114	55
Maize stover	86	79	89	96	93	46
Maize + mucuna	86	121	151	186	171	107
Experiment 3						
None	33	76	86	104	115	69
Zornia top + root	59	125	147	176	195	116
Mucuna top + root	77	186	192	223	236	159
Canavalia top + root	45	206	196	239	257	170
Crotalaria top + root	45	144	163	209	237	149

Table 3. Correlation coefficients for the relation between inorganic N accumulated in fallow soil by successive 40-day periods and maize N uptake at harvest

Depth (m) of accumulation	Days after incorporation			
	40	80	120	160
Experiment 1				
0–0.6	0.88**	0.94***	0.93**	0.92**
0–1.2	0.76*	0.81*	0.85*	0.91*
Experiment 2				
0–0.6	NS	NS	NS	NS
0–1.2	0.95*	0.96**	0.94*	0.94*
Experiment 3				
0–0.6	0.95*	0.99**	0.99***	0.99***
0–1.2	0.96**	0.98**	0.99***	0.99***

*, **, *** = Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
NS = not significant at 0.05 probability level.

depth to which inorganic N accumulated (Table 3). As leaching was minimized during the irrigated dry season experiments, sampling to 0.6 m was sufficient to demonstrate significant correlations on all sampling dates. When accumulation to 1.2 m was included in Experiment 1, the correlation coefficients decreased, probably due to high initial levels of inorganic N in the 0.6- to 1.2-m layer (80 to 185 kg ha^{-1}). Conversely, the coefficients in Experiment 3 did not decrease because inorganic N levels in the 0.6 to 1.2 m layer remained low (20 to 35 kg ha^{-1}). For the wet season experiment, significant correlations were obtained only by increasing the sampling depth to 1.2 m, thus recovering more of the mineralized N.

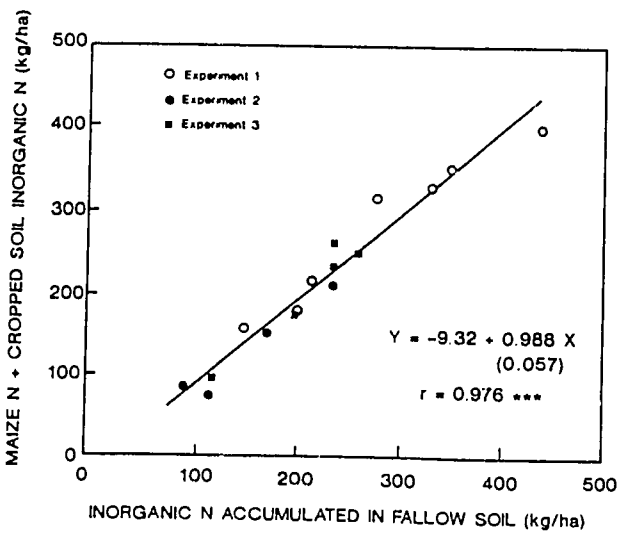

Fig. 1. Relationship between inorganic N accumulated in fallow soil (0–1.2 m) and the sum of N in aboveground maize plus residual soil inorganic N (0–1.2 m) at harvest.

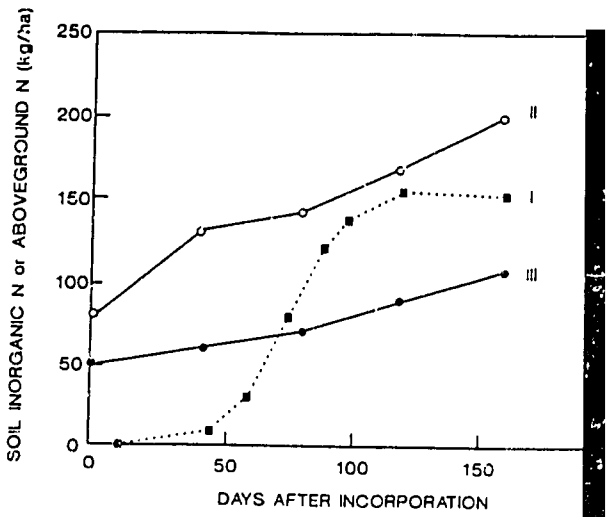

Fig. 2. Net mineralization patterns as measured by inorganic N accumulated in fallow soil to a 0.6 m depth and N uptake by maize (I-N uptake by maize, kg ha^{-1}; II-Net mineralization > 145 kg ha^{-1}; III-Net mineralization < 145 kg ha^{-1})

When inorganic N remaining in cropped soil at harvest was added to maize aboveground N and the sum plotted against inorganic N accumulated in fallow soil at the end of the season, the points from all three experiments fell along a common regression line (Figure 1). The slope of the line, b = 0.99, indicated cropped soil and fallow soil estimates of N availability were about equal.

The N demand curve of maize (Figure 2) was determined by sequential harvesting following the incorporation of mucuna tops in Experiment 2. Total aboveground N at harvest was 145 kg ha^{-1}. Average inorganic N accumulated (net mineralization) in fallow soil to 0.6 m during Experiments 1 and 3 could be separated into two groups: 1) those treatments where net mineralization was greater than 145 kg ha^{-1} N uptake, and 2) those where net minerlaization was less than 145 kg ha^{-1} N uptake (Table 2). In these experiments, N uptake by maize for treatments comprising the upper mineralization pattern averaged 161 kg ha^{-1} but only 105 kg ha^{-1} for treatments comprising the lower mineralization pattern.

Maize grain yields were directly proportional to N uptake in all experiments. The dry matter yields ranged from 4.3 (soybean roots) to 6.3 (mucuna top + roots) t ha^{-1} for Experiment 1, 1.3 (maize

stover) to 6.8 (mucuna tops) t ha^{-1} for Experiment 2, and 3.7 (none) to 6.3 (mucuna top + roots) t ha^{-1} for Experiment 3. These yields are similar to those reported by Grove et al. (1980) using fertilizer N on these same soils.

Discussion

The treatments established in these experiments provided a sufficiently wide range in available N to test the assumption that inorganic N accumulated in fallow soil is proportional to N uptake by maize. A significant correlation between these two estimates of N available clearly demonstrated the fallow soil method to be an appropriate field screening procedure when testing the N supplying potential of different legumes.

Certain conditions that prevailed in these experiments, however, deserve more emphasis. Net mineralization patterns and total inorganic N accumulation were most accurately estimated during the two dry season experiments because leaching was minimized by controlled irrigation. When participation was excessive as in the wet season experiment deep sampling was needed to recover part of the mineralized N. Deep sampling was possible in these experiments because the soil had excellent structure, a low bulk density, and no hard pans or stones. Where deep sampling is not feasible and precipitation is excessive, adoption of this procedure would require some means to limit or correct for leaching.

The fallow soil method has certain advantages over crop response studies in that the N supplying potential is estimated without interference by environmental factors such as diseases and pests that can affect crop uptake. Fallow plots can be smaller than cropped plots, thus making it possible to screen more options. Periodic measurements of accumulated inorganic N allow for the determination of net mineralization patterns that can then be compared to known plant N demand curves. Once the more promising legumes are identified, further evaluation should be carried out using appropriately designed crop response studies.

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