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Effect of legume-based cropping systems on nitrogen mineralization potential of Vertisol*

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Abstract

The quantity and patterns of net mineralization of soil nitrogen (N) were studied in Vertisols under different cropping systems in the semi-arid tropical areas. Eight cropping systems were selected; three contained pigeonpea (PP), one contained PP and cowpea (COP), and two contained chickpea (CP) as legume component crops, one included sequence cropping with nonlegumes during the rainy and postrainy seasons, and one system was kept fallow (F) during the rainy season and sown to sorghum (S) during the postrainy season. Cropping systems with PP as a component crop increased mineralizable $N(N_o)$ content two-fold in the soil compared with fallow + sorghum (F+S)- F+S system. The N mineralization rate constant (k) was not significantly affected by previous cropping history of the soil; however, a numerically higher rate constant was observed in the COP/PP intercrop, followed by sequential S+safflower (SF) system as compared to the other soils. Mineral N accumulation curves for six soils were more accurately described by the exponential model than the linear model. The active N fraction (N_o/N_{tot} %) varied between 8 and 16% for different systems and a direct relationship was observed between N_o/N_{tot} and total N for the soils under diverse cropping systems.

Introduction

Legumes are grown as intercrops or in rotation with cereals in the semi-arid tropics (SAT) and are important components of sustainable farming systems (Willey et al., 1989). Legumes often increase the yield of a subsequent cereal crop grown on the same soil as compared to the yield of a cereal grown after a nonlegume crop (Kumar Rao et al., 1983; Wani et al., 1991). Although cereal crops benefit from biological N fixation (BNF) and the soil N-conserving effect of the preceding legume-*Rhizobium* symbiosis, several reports suggest non-N "rotational effects" on soil properties and successive crops (Cook, 1988; Fyson and Oaks, 1990; Wani et al., 1991). The relation between cropping systems and the quantity and quality of soil organic matter has been inferred from studies of chemical and biological soil parameters (Birch and Dougall, 1967; Campbell et al., 1991; Wani et al., 1994a). Recently, measurements of microbial biomass (McGill et al., 1986; Wani et al., 1994b), potentially mineralizable $N(N_o)$ and mineralizable C (Stanford and Smith, 1972; Wani et al., 1994a) have been used to monitor biologically meaningful changes in the quantity and quality of soil organic matter. Some increases in soil organic matter content and N mineralization potential of Gray Luvisols have been attributed to perennial forages and legumes grown in rotations with cereals (Campbell et al., 1991; Poyser et al., 1957; Wani et al., 1994a). Similarly, some increase in total N content of Vertisol cropped with pigeonpea (PP) or cowpea (COP) in rotation with nonlegumes for 8 years were observed in India. No such increase in total nitrogen content of the soil was observed for chickpea (CP) (Rego and Burford, 1992). However, Janzen (1987) observed no difference in organic matter content and N mineralization potential of a Dark Brown Chernozemic soil following either alfalfa and

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crested wheat grass in rotation with wheat or continuous wheat cropping when neither system was fertilized. In contrast, potentially mineralizable N and total soil N were significantly lower in rotations containing a fallow period. The total quantity of organic matter changes more slowly than do the most active components. Potentially mineralizable N, i.e. the initial pool of mineralizable N at time zero (N_o) may represent a part of the "active fraction". McGill (1983) hypothesized that until the active fraction reached a steady state, a direct relationship would exist between total soil organic N and N_o/N_{tot}; thereafter the trend would reverse. McGill et al. (1988) showed an inverse relation between N_o/N_{tot} using the published data of Campbell and Souster (1982) for virgin prairie soils. There remains a need to determine the changes in N-supplying capacity and total soil N among cropping systems in the SAT as a prelude to determining the influence of legume-based cropping systems on the growth of successive crops in rotation. Long-term crop rotations at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) at Patancheru, India provide a suitable site to examine this issue, that mineralizable N provides an index of potential N supply for crop growth and also an estimate of the "active N" fraction. The objectives of this study were: i) to test the hypothesis that the quantity of active soil N varies with the cropping system; and ii) to determine the most appropriate model to describe net N mineralization amounts and rates.

Materials and methods

Site description and cropping systems

The soils used in this study were from the long-term rotation experiment on a Vertisol at ICRISAT Asia Center Patancheru, near Hyderabad, India (17°36′N, 78°16′E, 545 m altitude). Major characteristics of the Kasireddipalli soil series, a typic pellustert, have been described in detail by El-Swaify et al. (1985). The experiment was started in the rainy season of 1983. Eight cropping systems with 2-year rotations were selected: i) two rows of S intercropped with one row of PP every year (S/PP-S/PP); ii) two rows of COP intercropped with one row of PP followed by S in the rainy season and SF in the postrainy season (COP/PP-S+SF); iii) S/PP-in the first year followed by S in the next rainy season and then CP in the postrainy season (S+CP); iv) S/PP-S+SF; v) S+CP-S+CP; vi) S+CP-S+SF; vii) S+SF-S+SF; viii) fallow (F) in the rainy season followed by S in the postrainy season (F+S)-F+S.

All the crops were grown rainfed, and no mineral N was applied to any plot for the duration of the study. All the crops received 20 kg P ha^{-1} per season as single super phosphate prior to sowing by placement method. The plots were tilled with a bullock-drawn cultivator and harrow after harvest. All the crops were grown on raised broadbeds of 1.5 m width. The rainy season crops were dry seeded manually, 7-10 days before onset of the monsoon. After germination, all the crops were thinned to the desired population levels (Table 1). At harvest, above-ground plant material, except fallen leaves, was removed from all of the plots. After the harvest of the ninth year crops, soil samples were collected from 0-20 cm depth in early May 1992. Four replicated soil samples from each plot were obtained and combined to form one sample per plot. From the eight treatments and three replications in the field, a total of 24 surface soil samples were collected and used in this study. Soils were characterised by measurements of pH, total C and N, and extractable mineral N.

Potentially mineralizable N

Mineralizable N was determined in triplicate from each treatment using a leaching incubation procedure (Stanford and Smith, 1972). Nonseived soil (50 g) and acid-washed sand (50 g) were mixed and placed in a Buchnner funnel (7.5 cm dia) on top of a fine layer of glass wool on a fibre glass filter paper. The soil surface was covered with a glass wool layer to avoid disturbance to the soil surface during extractions. The soils were leached with 150 mL 0.01 *M* $CaCl_2$ with 25 mL increments followed with 50 mL N-free nutrient solution containing 0.002 *M* $CaSO_4.2H_2O$, 0.002 *M* $MgSO_4.7H_2O$, 0.005 *M* $Ca(HPO_4)_2.2H_2O$, and 0.0025 *M* K_2SO_4 (Stanford and Smith, 1972) at 0, 1, 2, 3, 4, 6, 8, 10, 13, 16, and 20 weeks. The soils were incubated at 30°C in the dark with the moisture content maintained at 70% water holding capacity.

Chemical analysis

Soil pH was measured by mixing 20 g soil with 40 mL distilled water and stirred frequently for 30 min. Organic C content was estimated by dispersing 2 g sieved soil in 10 mL of 1 *N* $K_2Cr_2O_7$ and 20 mL conc. H_2SO_4 containing 1.5% silver sulphate was added. After 30 min, 200 mL distilled water was added and using O-

Table 1. Details of the cropping systems used in this study

Cropping system	Year 1 Rainy season Crop	Plant pop × ha^{-1}	Year 1 Postrainy season Crop	Plant pop × ha^{-1}	Year 2 Rainy season Crop	Plant pop × ha^{-1}	Year 2 Postrainy season Crop	Plant pop × ha^{-1}
S/PP-S/PP	S	120,000	-[b]	-	S	120,000	-	-
	PP	40,000	-	-	PP	40,000	-	-
COP/PP S+SF	COP	180,000	-	-	S	120,000	SF	60,000
	PP	40,000	-	-				
S/PP-S+CP	S	120,000	-	-	S	120,000	CP	240,000
	PP	40,000	-	-				
S+PP-S+SF	S	120,000	-	-	S	120,000	SF	60,000
	PP	40,000	-	-				
S+CP-S+CP	S	120,000	CP	240,000	S	120,000	CP	240,000
S+CP-S+SF	S	120,000	CP	240,000	S	120,000	SF	60,000
S+SF-S+SF	S	120,000	SF	60,000	S	120,000	SF	60,000
F+S-F+S	-	-	S	60,000	-	-	S	60,000

[a] S/PP-S/PP = two rows of S intercropped with one row of P every year; COP/PP-S+SF = two rows of COP intercropped with one row of PP in the first year followed by S in the next rainy season and SF in the postrainy season; S/PP-S+CP = S/PP in the first year followed by S in the next rainy season and then CP in the postrainy season; S/PP-S+SF = S/PP in the first year followed by S in the next rainy season and then SF in the postrainy season; S+SF-S+SF = S in the rainy season followed by SF in the postrainy season each year; S+CP-S+SF = S in the rainy season followed by CP in the postrainy season and followed by S in the next rainy season and SF in the postrainy season; S+CP-S+CP = S in the rainy season followed by CP in the postrainy season each year; F+S-F+S = fallow in the rainy season followed by S in the postrainy season each year.

[b] No crop was grown in postrainy season as pigeonpea sown in rainy season continued to grow upto December end or soil was kept fallow in rainy season as per the treatment.

Phenathroline indicator the samples were titrated with 0.5 *N* $FeSO_4$ solution (Nelson and Sommers 1982). Total N content in soil was estimated by adding 5 mL of 20% $Na_2S_2O_3$ solution and then digesting with 15 g Na_2SO_4, 1.5 g $CuSO_4.5H_2O$ and 30 mL Con.H_2SO_4. The digest was diluted with water, distilled with 40% NaOH and titrated with 0.025 *N* H_2SO_4 (Dalal et al., 1984). Mineral N (NH_4+NO_3-N) content in soil was estimated by extracting soil with 2 *N* KCl (1:5 w/v) after shaking for an hour. The soil extracts were filtered through Whatman No. 1 filter paper and aliquots of KCl extracts and $CaCl_2$ leachates were analyzed for NO_3^- and NH_4^+ -N by distilling the aliquot in a microKjeldahl apparatus using MgO and Devarda's alloy (Jackson, 1973).

Mathematical and statistical analyses

The data were subjected to an analysis of variance and treatments were compared using the 'F' test of significance and least square difference (Panse and Sukhatme, 1957). A non-linear least squares fitting procedure was used for the exponential and hyperbolic models; a linear regression package was used for the linear model (SAS, 1987). Three models were used.

The first was linear:

$$N_t = \chi \times t \tag{1}$$

where N_t is the net quantity of N mineralized (mg kg^{-1}), χ is the zero order rate constant (mg kg^{-1} wk^{-1}) and t is time (wk). The second was an exponential model describing net accumulation of mineral N during first order decomposition of N from a potentially mineralizable N source:

$$N_t = N_o[1 - exp(-k \times t)] \tag{2}$$

where N_t is the cumulative net N mineralized (mg kg^{-1}) over time t (wk), k is the first order rate constant (wk^{-1}) and N_o is the potentially mineralizable N at t = 0. The hyperbolic equation comprised the third model:

$$N_t = N_o \times t/(T_c + t) \tag{3}$$

where N_o, N_t, and t are as defined above; T_c is the time (wk) required for mineralization of half the potentially mineralizable $N(N_o)$. The more complex models were compared to simpler models using the "F" statistic (Robinson, 1985) to determine if the reduction in the residual sum of squares (RSS) justified the increased model complexity. The "F" statistic was the quotient of the difference between the RSS of the two models divided by the residual mean square (RMS) of the more complex model. The result was compared to an "F" value at $p<0.05$ with 1 and n - p degrees of freedom, where n = number of data points and p = the number of estimated parameters in the model. The linear models were compared as paired treatments, with homogeneity of slope as the null hypothesis using an F-test of covariance.

Results

Mineral N, total N and organic C contents of the surface soil samples collected prior to the beginning of tenth season varied with cropping history (Table 2). Soil pH after 20 wk incubation was generally slightly lowered in all the soils, but the changes were not significant (results not shown).

Mineral N accumulation

Mineral N leached from the soils under different cropping systems ranged from 1.9 to 13.6 mg kg^{-1} dry soil wk^{-1} at week one and similar results were observed

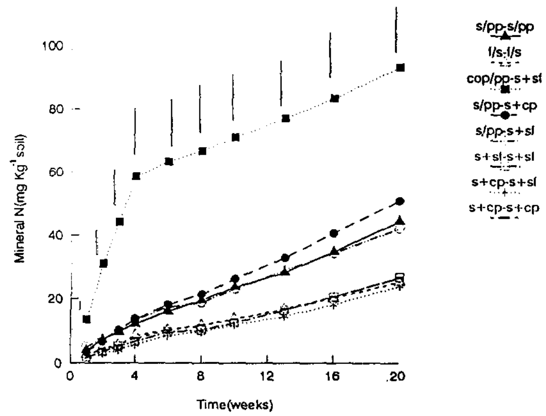

Fig. 1. Cumulative mineral N (mg kg^{-1} soil) during 20 weeks incubation of a Vertisol under different cropping systems. The bars represent SE to compare the treatments at a particular incubation period.

up to the fourth week; however, these values were not significantly different between treatments. From week six onwards mineral N extracted per week from different soils varied significantly ($p<0.05$) and these differences persisted until week 20 (data not shown). Cumulative mineral N accumulation during incubation of 20 weeks varied significantly ($p<0.05$) with the cropping history of the soil (Fig. 1). The rate of net N mineralization from all the soils was initially high and declined during later stages of incubation but remained greater than zero in all the soils throughout the incubation period.

Mathematical analysis of mineral N accumulation

The first order exponential model yielded N_o, values ranging from 40 to 100 mg kg^{-1} dry soil for six different cropping systems plots (Table 3). For the remaining two treatments (S+SF-S+SF and S+CP-S+SF), N_o values were not estimated as the exponential model was not found to be superior to the linear model. Estimated N_o values were highest for S/PP-S+CP followed by S/PP-S/PP, COP/PP-S+SF >> S/PP-S+SF, S+CP-S+CP > F+S-F+S. The first order rate constant of N mineralization (k) varied from 0.021 to 0.223 wk^{-1}, and was highest in the COP/PP-S+SF cropping system (Table 3). N_o values estimated using the hyperbolic model varied from 45.1 to 109.4 mg kg^{-1} soil in different cropping systems. Generally, N_o values estimated using the hyperbolic model were higher than the values obtained from the exponential model, except in three cropping systems. However, T_c values for all the

Table 2. Properties of soil samples collected from long-term plots under different cropping systems

Treatment[a]	pH	Organic C (g kg^{-1} dry soil)	Total N (g kg^{-1} dry soil)	Mineral N (NH_4+NO_3-N)[b] (mg kg^{-1} soil)
S/PP-S/PP 2:1	8.12	4.7	0.632	11.2
COP/PP-S+SF 2:1	8.00	4.6	0.625	9.7
S/PP-S+CP 2:1	8.04	4.9	0.616	12.2
S/PP-S+SF 2:1	8.02	4.5	0.597	4.01
S+CP-S+CP	7.97	4.1	0.529	8.00
S+CP-S+SF	7.90	3.8	0.534	7.1
S+SF-S+SF	8.06	4.2	0.547	7.06
F+S-F+S	8.17	3.8	0.489	4.8
SE±	0.035	0.162	0.011	1.36

[a]Numbers represent the ratio of number of rows of a crop in a particular intercropping system, details same as mentioned in the footnote of Table 1.
[b]Extracted with 2 *M* KCl.

cropping systems were similar, ranging from 19.99 to 20.02 wk (data not shown). The "active N fraction", the quotient of N_o and N_{tot} (N_{tot}=total N) expressed as a percentage, varied between 8 and 16% as estimated from the exponential model N_o values, and between 9 and 17% using the hyperbolic models (Table 3). Active N fraction values based on N_o values from exponential and hyperbolic models were similar for a particular soil.

Comparison of models to describe mineral N accumulation

The RSS values obtained with the hyperbolic model were higher than with the linear and exponential models (data not shown). Consequently the hyperbolic model was not pursued further. The RSS values were lower in the exponential than in the linear model. The "F" - ratios for the exponential model were significantly higher than those for the linear model in six out of eight soils, indicating that mineral N accumulation curves are described more closely by the exponential model than the linear model. For two soils from S+SF-S+SF and S+CP-S+SF, mineral N accumulation curves were described better by the linear than by the exponential model as evident from the nonsignificant 'F' values (1-1.3) for the exponential model over the linear model (Table 4). Cropping systems were ranked based on the time required to mineralize a fixed quantity (25 and 50 mg N kg^{-1} soil) of N from the soil, as calculated from the linear and exponential models. Time required to mineralize 25 mg N kg^{-1} soil varied from 1.5 to 19.6 wk using the exponential model (Table 5). Although the two models gave different values for this, the rankings of the cropping systems remained almost the same irrespective of which model was used (Table 5). For both models, cropping systems which contained PP required less time to mineralize a

Table 3. Nitrogen mineralization potentials (N_o), rate constants (k) as estimated by exponential model and active N fraction of the soils under different cropping systems

Treatment	N_o (mg kg^{-1} soil)	SE	k (wk^{-1})	SE	Active N fraction (%) Exponential	Hyperbolic
S/PP-S/PP	94.6^{ab}	15.98	0.030	0.006	15	13
COP/PP-S+SF	86.1^{ab}	19.90	0.223	0.148	14	17
S/PP-S+CP	100.0^{a}	10.04	0.021	0.005	16	16
S/PP-S+SF	67.3^{bc}	13.46	0.0461	0.013	11	13
S+CP-S+CP	56.1^{bc}	20.98	0.030	0.014	11	9
S+CP-S+SF	-^{z}	-	-	-	-	9
S+SF-S+SF	-	-	-	-	-	9
F+S-F+S	40.5^{c}	8.06	0.045	0.012	8	9

Values with different letters varied significantly ($p \leq 0.05$) from each other according to a 't' test.

^{z}-=Not calculated, as the exponential model was not found superior to the linear model.

fixed quantity of N than did CP-based systems or that contained no legume or were left fallow for one season (Table 5). Instantaneous rates of N mineralization for soils were calculated using linear and exponential models. Exponential model rates were initially higher than linear model rates, but reverse was true in the later stages of incubation. For the COP/PP-S+SF treatment the instantaneous rate of N mineralization was far higher than in other treatments up to the eighth week but decreased drastically at weeks 16 and 20 (Table 6). The zero order rate of N mineralization using the linear model for soil samples varied from 1.33 to 5.95 mg kg^{-1} soil wk^{-1}, with a maximum rate of N mineralization from samples in the order COP/PP-S+SF >> S/PP-S+CP, S/PP-S/PP, S/PP-S+SF > S+CP-S+CP, F+S-F+S, S+SF-S+SF > S+CP-S+SF (Table 6).

Discussion

Legumes can improve soil fertility or increase yield of the following crop, these benefits largely depend upon the total plant biomass produced, amount of N_2 fixed, amount of N added to the soil through roots, nodules and the leaf fall (Wani et al., 1994c). The benefits in terms of increased N_o values in case of PP-based systems were observed when all the above-ground plant parts, except fallen leaves, were removed. Average above-ground total plant biomass over the previous nine years for PP varied from 3.0 to 4.1 t ha^{-1} y^{-1} in different cropping systems; for CP it was around 1.7 t ha^{-1} y^{-1} and for COP it was 2 t ha^{-1} y^{-1}. Pigeonpea produces higher (20% of total plant biomass) root mass (Kumar Rao and Dart, 1977) and considerable amount of leaf fall than CP and other crops. Pigeonpea on an average added 700 kg root dry matter containing 7-10 kg N ha^{-1} (1-1.5% total N) and 2,500 to 3,000 kg dry leaf matter containing 37-45 kg N ha^{-1} (1.5% N) to the soil. On the contrary, in CP-based systems only 170 kg ha^{-1} root dry matter containing 1.7 kg N ha^{-1} (with 1% N) and 500 kg leaf dry matter containing 8 kg N ha^{-1} (1.6% N) was added to soil each year. In PP-based systems, 42-55 kg of plant N ha^{-1} y^{-1} was added to soil through root matter and leaf fall, whereas CP added around 10 kg N ha^{-1} y^{-1} to soil. Further, PP derived upto 88% of its N requirement through BNF whereas at Patancheru (Peninsular India) CP fixed 3-4 times less nitrogen than in the northern India (Nambiar

Table 4. Evaluation of models to describe N mineralization potential (N_o) and the rate constant (k) with time (t) for the soils under different cropping systems

Treatment	Model	RSS	RMS	F ratio	% TSS
S/PP-S/PP	Linear	154.2	5.3		96.6
	Exponential	85.2	3.0	22.7**	99.5
COP/PP-S+SF	Linear	81432	2808		3.4
	Exponential	68807	2457.4	5.1*	64.4
S/PP-S+CP	Linear	119.9	4.1		98.1
	Exponential	73.3	2.6	17.8**	99.7
S/PP-S+SF	Linear	454.0	15.7		89.2
	Exponential	304.7	10.9	13.7**	98.1
S+CP-S+CP	Linear	173.9	6.0		89.8
	Exponential	149.7	5.3	4.5*	97.5
S+CP-S+SF	Linear	65.3	2.2		95.4
	Exponential	62.3	2.2	1.3^{NS}	98.6
S+SF-S+SF	Linear	65.6	2.3		96.2
	Exponential	63.3	2.3	1.0^{NS}	98.9
F+S-F+S	Linear	149.4	5.1		89.9
	Exponential	109.4	3.6	13.7**	98.2

* = $p < 0.05$, ** = $p < 0.01$, NS - not significant, RSS - Residual sum of squares, RMS - residual mean square, % TSS - % total sum of squares.

et al., 1988). In case of PP leaf fall starts in the rainy season and lower layers of leaf matter start decomposing as moisture is available. During receding soil moisture and dry period considerable straw foraging activity of the termites in SAT fields was observed (Reddy et al., 1994). During eight rain-free weeks after incorporating labelled groundnut straw, 12% of ^{14}C added to Vertisol was lost and during next four wet weeks (rainy season), further 38% of added ^{14}C was lost. At the end of second year, in all 72% of added ^{14}C was lost from the soil (Stephan Singer, pers. commun.). In addition to the more quantity of organic matter added to soil by PP, the quality of PP dry matter also may have effect on increasing N_o estimates. Thus, it leads to a cumulative effect of N mineralization year after year in PP-based systems due to more addition and probably better quality of plant dry matter resulting in two times increased N_o values in PP-based systems than the N_o values in F+S-F+S and CP-based systems. Such increased N_o values were observed with green manuring over a continued wheat system without fertilizer addition for Black Chernozemic samples (Campbell et al., 1991). Similarly, for Gray Luvisols, legume-based rotations were associated with increased total soil N and a greater proportional increase in active N than in total soil N (Wani et al., 1994a). Although N_o values differed with the cropping systems, the leaching method could underestimate the mineralizable N content in soils as soluble organic N is also leached out with the mineral N. The values for the N mineralization rate constant (k) varied between 0.021 and 0.223 wk^{-1}, but, such differences were not statistically significant. The k values were higher (although statistically not significant) in soil from COP/PP plots, as compared to other treatments. This could be due to the succulent nature of COP roots and higher amounts of root nodules left in the top 20 cm layer. Also, COP was harvested two months earlier than PP, and the COP root

Table 5. Time (wk) required to mineralize a fixed amount of N in soil samples of different cropping systems incubated at 30° C using exponential and linear models

Treatment	Rank		Time (wk) to mineralize (mg N kg^{-1}) 25		50	
	Linear	Expo-nential	Linear	Expo-nential	Linear	Expo nential
S/PP-S/PP	3	3	10.95	10.26	21.91	25.15
COP/PP-S+SF	1	1	4.20	1.54	8.41	3.9
S/PP-S+CP	2	4	9.60	13.76	19.19	33.2
S/PP-S+SF	4	2	11.13	10.06	22.26	29.44
S+CP-S+CP	5	5	18.40	19.61	36.79	73.81
S+CP-S+SF	8	-[a]	20.99	-	41.98	-
S+SF-S+SF	7	-	18.85	-	37.71	-
F+S-F+S	6	6	18.82	21.4	37.65	-

[a] Not calculated as the exponential model was not superior to the linear model.

Table 6. Instantaneous rate of N mineralization (mg N kg^{-1} week^{-1}) in soils from different cropping systems using linear and exponential models

Treatment	Linear model	Exponential model (weeks) 0	2	8	16	20
S/PP-S/PP	2.28^{b}	2.83	2.66	2.23	1.75	1.55
COP/PP-S+SF	5.95^{a}	19.20	12.29	3.22	0.54	0.22
S/PP-S+CP	2,60^{b}	2.09	2.00	1.77	1.50	1.38
S/PP-S+SF	2.25^{b}	3.10	2.83	2.15	1.48	1.23
S+CP-S+CP	1.36^{c}	1.69	1.59	1.33	1.04	0.92
S+CP-S+SF	1.19^{d}	-[z]	-	-	-	-
S+SF-S+SF	1.33^{c}	-	-	-	-	-
F+S-F+S	1.33^{c}	1.82	1.66	1.27	0.89	0.74

Values with different letters varied significantly from each other.
[z] Not calculated as the exponential model was not superior to the linear model.

material in the soil could have decomposed more readily than that of PP. In other treatments which included S, net mineralisation in the presence of S plant roots with higher C:N ratio might have delayed N release through increased immobilisation. The instantaneous rate of N mineralization based on quantity of mineral N leached in COP/PP treatment was far lower than in other soils during later stages of incubation (Table 6). Soil organic C declined more rapidly in COP and soybean rotations than in maize (Lal, 1976). The relationship between the nature and quality of plant root material and rate of C and N mineralization, needs to be further investigated. For the semi-arid soils of Morocco, k values for 14 different soils ranged from 0.06 to 0.274 wk^{-1} as calculated by the exponential model and from 0.024 to 0.212 wk^{-1} according to the hyperbolic model (Soudi et al., 1990). For these soils k values ranged from 0.04 to 1.3 wk^{-1}, decreasing with the increasing soil depth. Wani et al. (1994a) observed a slightly higher rate constant for Gray Luvisols which had received fababean material as green manuring than the one which was continuously under continuous barley. Janzen (1987) found no effect of rotation treatments on k values. On the contrary, k has been reported to be a function of climate, soil type, and the length of incubation period used to determine this parameter (Cabrera and Kissel, 1988; Juma et al., 1984; Paustian and Bonde, 1987). Mineral N accumulation curves were described more closely by the exponential model than the linear model for six out of the eight soils used in this investigation and this is in conformity with the earlier findings (Gharous et al., 1990; Juma et al., 1984; Wani et al., 1994a). Based on N_o and k parameters, several criteria such as the amount of N mineralized during selected periods of time under controlled conditions (Stanford et al., 1973), the time required to mineralize a fixed amount of N (Gharous et al., 1990; Wani et al., 1994a) and the instantaneous rate of N mineralization at $t = 0$ (Campbell et al., 1991; Wani et al., 1994a) have been used to compare N availability for plant growth among soils. As reported by Wani et al. (1994a) we observed no differences among these criteria for distinguishing soils under diverse cropping systems. The "active fraction" calculated from the ratio of N_o/N_{tot} (McGill et al., 1988) constituted 8 to 16% of soil N in the present study and was affected by cropping history of the soil. The value was lowest in the F+S-F+S treatment, and higher in PP-component systems. The "active fraction" for Gray Luvisols under diverse cropping systems varied between 12-27%, and increased along with total soil N due to green manuring, straw application, manure and P application (Wani et al., 1994a). Consequently, there was a positive relationship between N_o/N_{tot} and total soil N for the eight soil samples investigated in this study. Simple linear regression on total soil N accounted for 76% of the variation in N_o/N_{tot} (data not shown). This relationship must be interpreted with caution as it is based on only eight data points. Our findings are consistent with the findings of Wani et al. (1994a) and also with the hypothesis of McGill et al. (1988) which stated that, until the active fraction reached a steady state, during transitions of soil to more or less organic matter, a direct relation would exist between the proportion of soil N which is active (using N_o as surrogate) and total soil organic N. This study showed that within nine years, PP-based cropping systems increased mineralizable N in the soil. Average N_o values for PP-based cropping systems were two-fold higher than in the F+S-F+S or S+CP-S+CP systems. These increases in mineralizable N contents were observed even when all the above-ground plant material, except fallen leaves, was removed from the plots. Increased N_o values in PP-based systems resulted in increasing yield of following sorghum crop (3.2 t ha^{-1} for COP/PP-S+SF and 2.3 t ha^{-1} for S/PP-S+CP as compared to 1.4 t ha^{-1} from S+SF-S+F and 1.9 t ha^{-1} from S+CP-S+SF systems). Under tropical conditions also, even with removal of the above ground plant material, mineralizable nitrogen contents in Vertisols could be increased by intercropping a cereal with PP. However, such increased N_o values at Patancheru were not associated with another legume (CP), which is grown during the postrainy season on residual moisture. At Patancheru temperatures are higher than in the chickpea-growing areas of northern India, and N_2 fixation for CP has been reported to be 3-4 times as high as in peninsular India (Nambiar et al., 1988). In conclusion, for Vertisols in the tropics PP-based cropping systems, which derive considerable nitrogen through BNF, can increase soil N availability and sustain productivity of cropping systems.

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