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Nitrogen returns to soil by selected cropping systems on a Vertisol in the semi-arid tropics of India*

M. D. ABDURAHMAN, B. SEELING, T. J. REGO AND B. BHASKAR REDDY

Soils and Agroclimatology Division
ICRISAT, Pataneheru-502 324, India

ABSTRACT

Limited nitrogen (N) availability is a common constraint for crop production on Vertisols. Erratic rainfall in the semi-arid tropics and relatively high cost of N fertilizers make its application a risky investment, therefore, most farmers do not apply N fertilizer in dryland crops. Cropping systems which improve soil fertility can minimize the need for synthetic fertilizers. In a two-year experiment, four cropping systems and mirror images of two systems were examined for their returns of N to soil in roots and fallen leaves. Sorghum/pigeonpea intercrop for two years (S/PP S/PP) and cowpea/pigeonpea intercrop rotated with sorghum followed by safflower (COW/PP S+SAF) contributed around 54 kg N ha^{-1} in roots and fallen leaves when no nitrogen fetilizer was applied. The largest proportion of this N was returned to soil through fallen leaves of pigeonpea. In terms of root mass a rotation of sorghum followed by safflower in the post-rainy season (S+SAF S+SAF) deposited almost the same amount of N in roots if adequately fertilized. Under S/PP S/PP the soil mineral N content was measurable higher compared to other systems.

Key words : Cropping systems, nitrogen returns, semi-arid tropics, soil, Vertisol

INTRODUCTION

Most Vertisols of the Indian semi-arid tropics are deficient in nitrogen and crops respond to N application (Sing *et al.*, 1988). However, many farmers in the Indian SAT are resource-poor and cannot afford to apply optimum amounts of N. In addition farmers consider applying N fetilizers a risky investment because of the erratic rainfall. Many farmers rely on indigenous sources of N, like farmyard manure. In addition biological nitrogen fixation (BNF) is a potential source of N. However, farmers prefer grain legumes over green manures because of their higher economic value.

Many grain legumes add only small amounts of N to the soil since most of the fixed N is exported with the grain (Wani *et al.*, 1995). But even if no N addition takes place, growing a grain legume can still be beneficial for the following non-legumes because of the nitrogen saving effect. Since a considerable proportion of nitrogen in the legumes stems from atmospheric N_2 fixation, the depletion of the soil N pool is less compared to a non-legume crop (Peoples and Craswell, 1992).

Because of the high variability of rainfall and the difficulty in tilling wet

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Vertisols, farmers traditionally grow only a post-rainy season crop on stored soil moisture. However, Vertisols have the potential to support double cropping if rainfall is about 750-800 mm. For these areas the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has developed a technology that involves a rainy season crop followed by a sequential crop or intercropping of rainy season crops with a long duration crop (Virmani *et al.*, 1989). Three stemps all part of ICRISAT's Vertisol Technology package were essential for this achievement : (1) broadbed and furrow soil surface management, which allows fast drainage of the surface soil and prevents waterlogging; (2) dry seeding after the first pre-monsoon showers before the rainy season when soil conditions are optimum for tillage; and (3) grain mold resistant sorghum varieties, which provide grain quality when sorghum is grown under the more humid conditions in the rainy season. Employing these basic technologies several double and intercropping rotations became possible. In our experiment we tested three : (1) Sorghum/pigeonpea intercrop in both years (S/PP S/PP); (2) a rotation of cowpea/pigeonpea intercrop in one year and sorghum followed by safflower every other year; and (3) sorghum followed by safflower in both years (S+SAF S+SAF).

Low nutrient availability particularly of N is one constraint of this technology. Inclusion of legumes in these systems is seen as one possibility to alleviate this constraint.

The work of Rego and Seeling (1996), Wani *et al.* (1995) and Kumar Rao and Dart (1987) highlights the residual effect of pigeonpea-based cropping systems, but there is little quantitative information on the N returns to soil. Farmers remove crop residues because of fodder scarcity, therefore, only roots and in case of medium duration pigeonpea and cowpea fallen leaves are potential N sources. This study was designed to quantify the N returns of the different crops and cropping systems and study the soil N status after the experiment.

MATERIALS AND METHODS

The experiment was conducted at ICRISAT Asia Center (IAC), India on a deep Vertisol. Chemical properties of the field prior to sowing are shown in Table 1. Measurements were made during the rainy and post-rainy seasons of 1994-95 and 1995-96. The monthly rainfall and mean maximum and minimum temperature for the experimental period are given in Table 2.

Four cropping systems, and where appropriate their mirror images were evaluated at three nitrogen (N) levels (Table

Table 1. Chemical properties of the experimental field used prior to crop growth period

Soil depth (cm)	pH	E. C. (dSm^{-2})	NO_3 (mg kg^{-1})	Total N (mg kg^{-1})	OC (%)
0-15	8.19	0.26	2.67	639	0.62
15-30	8.33	0.17	<1	434	0.47
30-60	8.39	0.16	<1	370	0.44
60-90	8.23	0.23	<1	331	0.39

Table 2. Monthly rainfall (mm) and average maximum and minimum temperatures (°C) at ICRISAT Asia Center, June 1994-March 1996

Month	Rainfall during the season (mm)	Normal rainfall (mm)	Temperature (°C)	
			Maximum	Minimum
		1994		
June	144.4	104.4	33.7	23.6
July	142.9	191.2	29.4	22.4
Aug.	196.9	127.1	28.9	22.1
Sept.	66.0	162.6	30.4	20.9
Oct.	247.5	83.5	29.5	20.7
Nov.	9.6	20.9	27.1	15.6
Dec.	0	5.9	27.1	10.3
		1995		
Jan.	40.0	7.6	26.2	13.2
Feb.	0	9.5	31.0	16.0
Mar.	52.2	10.6	34.4	20.2
Apr.	8.8	28.5	37.0	22.6
May	43.8	31.2	36.9	23.7
June	136.2	104.4	36.5	25.0
July	252.0	191.2	30.1	22.8
Aug.	245.6	127.1	30.2	22.8
Sept.	112.9	162.6	30.2	22.1
Oct.	361.0	83.5	29.1	20.4
Nov.	13.0	20.9	29.3	16.2
Dec.	0	5.9	28.4	13.9
		1996		
Jan.	0	7.6	29.6	15.4
Feb.	0	9.5	31.4	16.8
Mar.	0	10.6	36.0	19.3

3) in a randomized complete block design (RCBD) with three replications. Nitrogen was applied only to the non-legume crops. During the rainy season, non-legume crops in the N_{40} and N_{80} plots, received 20 kg N ha^{-1} at the time of sowing, and the remaining quantity was applied at 21-24 days after sowing (DAS). Post-rainy season non-legume crops received the complete dose at the time of sowing. In intercrops the N application was placed close to the rows of the non-legume crop. All crops received a basal phosphorus (P) application of 20 kg P ha^{-1} at the time of sowing.

Measurements of Root Growth

Plant and root samples were taken from 1 m^2 sub-plots in N_0 and N_{80} treatments in all the three replications, except cowpea plots where roots were taken from one replication. Four root sampling soil cores of 7 cm diameter were taken to a depth of 120 cm except in case of pigeonpea where the sampling depth was 150 cm. Two cores were taken between rows and two cores on the rows between plants. A fifth core was taken on top of one plant.

Samples were combined and soaked in water overnight. Roots were washed over a sieve of 1 mm mesh, and then hand picked and stored in a mixture of ethyl alcohol and water at the ratio of 2 : 1 at 5°C. Fresh weights of the root samples were taken after blotting with filter paper. Subsequently roots were oven-dried at 60°C to constant weight, and dry weights were determined.

Table 3. Treatments, crop varieties grown and plant populations

Treatment No.	I Year		II Year	Abbreviations
A.	**Cropping systems**			
1.	Sorghum/Pigeonpea		Sorghum/Pigeonpea	S/PP S/PP
2.	Sorghum+Safflower		Sorghum+Safflower	S+SAF S+SAF
3.	Cowpea/Pigeonpea		Sorghum+Safflower	COW/PP S+SAF
4.	Sorghum+Safflower		Cowpea/Pigeonpea	S+SAF COW/PP
5.	Fallow+Sorghum		Fallow+Chickpea	F+S F+CKP
6.	Fallow+Chickpea		Fallow+Sorghum	F+CKP F+S
	/=Intercropping		+=Sequential cropping	
B.	**Nitrogen levels**			
1.	0 kg N ha^{-1} (N_0)			
2.	40 kg N ha^{-1} (N_{40})			
3.	80 kg N ha^{-1} (N_{80})			
C.	**Crops and varieties used were :**			
(i)	**Rainy season crops**			**Plant population established**
1.	Sorghum-CSH-6	(*Sorghum bicolor* L.)		120,000 plants ha^{-1}
2.	Pigeonpea-ICPI-6	[*Cajanus cajan* (L.) Millsp.]		60,000 plants ha^{-1}
3.	Cowpea-GC 82-7	(*Vigna unguiculata* L.)		80,000 plants ha^{-1}
(ii)	**Post-rainy season crops**			
1.	Sorghum-SPV 421	(*Sorghum bicolor* L.)		100,000 plants ha^{-1}
2.	Safflower-Manjera	(*Carthamus tinctorius* L.)		80,000 plants ha^{-1}
3.	Chickpea-Annegiri	(*Cicer arietinum* L.)		300,000 plants ha^{-1}

Leaf Fall Measurements

At weekly intervals, fallen leaves of medium duration pigeonpea and cowpea were collected from an area of 1 m x 1.5 m surrounded by plastic sheets. Collected leaves were oven-dried at 60°C and their dry weights recorded.

Nitrogen Determination

Nitrogen concentration of roots and fallen leaves was determined by the Kjeldahl method followed by colorimetric determination using a Technicon Autoanalyser (Technicon Industrial System, 1994). N content of roots and fallen leaves was calculated from N concentration and dry matter data.

Soil Chemical Analysis

At the end of the second year of cropping, soil samples were taken from all plots. Ten cores to a depth of 150 cm were taken from each plot. Samples were analyzed for NO_3-N by distillation and titration of 2M KCl extracts (Keeney and Nelson, 1982).

RESULTS AND DISCUSSION

Weather data for the experimental period (Table 2) show that rainfall was adequate and its distribution was normal during the rainy season in both years. Post-rainy season rainfall was erratic with high rainfall at the beginning of the season and little or none in the later part of the season.

Nitrogen application increased the N amount of roots in non-legumes. Mackay and Barber (1986) found similar results in corn. In both the years the highest amount of N in rainy season sorghum roots was reached at flowering. After flowering, the N amount of sorghum roots remained almost unchanged. The amount of N in roots of rainy season sorghum in N_0 treatments was similar in both the years (Table 4) but rainy season sorghum receiving 80 kg N ha^{-1} contained more N in roots in 1995 than in 1994. This could be due to the higher fertility after application of N for two years compared to the N_0. Although there is little reason to believe that fertilizer N has much residual value in these soils (Moraghan *et al.*, 1984) the reduced mining of soil N might account for this observation.

In the case of post-rainy season sorghum it is not clear in which stage of growth the maximum N accumulation in roots is usually reached. In 1994, both N_0 and N_{80} crops reached the highest amount of root N at flowering and it decreased slightly at maturity. In 1995, the highest amount of root N was found at maturity (Table 4). Because of the lack of rainfall in the later part of the season, the wetting front tends to move deeper. This can cause roots to grow and exploit deeper soil layers and subsequent increase in N uptake. Zaongo *et al.* (1994) found that, when there was shortage of rainfall, sorghum roots grew deeper and contained more N.

In both the years, safflower N content of roots increased till maturity but root N content was higher in 1995 as compared to 1994, particularly in the N_{80} crop.

In 1994, pigeonpea and cowpea root N content was highest at flowering but chickpea root N content was highest in the vegetative stage. In 1995, pigeonpea and chickpea had the highest root N content at the initial stages, whereas cowpea root N content was again highest at flowering.

The systems which involve medium duration pigeonpea or cowpea also contribute to soil N through leaf fall. Fig. 1 shows the amount of N returned to soil by medium duration pigeonpea and cowpea leaf fall. Leaf fall of medium duration pigeonpea contributed upto 40 kg N ha^{-1} to the soil. Sheldrake and Narayanan (1979) reported similar amounts of N returns through leaf fall. Cowpea leaf fall contributed around 6 kg N ha^{-1}.

The total N input of the different systems is shown in Table 5. When no fertilizer was applied S/PP S/PP and COW/PP S+SAF returned to the soil more root N compared to the other systems. Even the

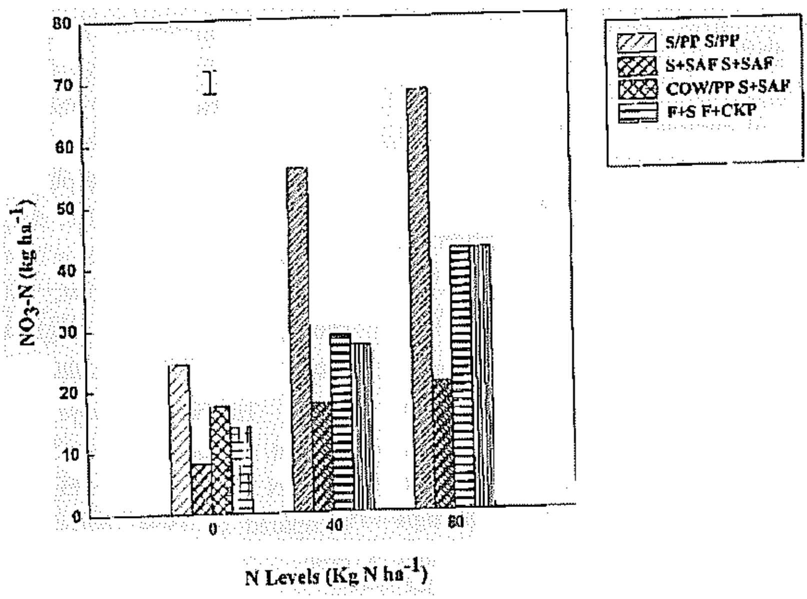


Fig. 1. Cumulative fallen leaves N content of pigonpea and cowpea.

Table 4. Root nitrogen content (kg ha⁻¹) of the different crops at flowering and maturity during 1994 and 1995

Crop	Fertilizer N (kg ha^{-1})	Growth stage: Flowering 1994	Flowering 1995	Maturity 1994	Maturity 1995
Rainy season sorghum	0	2.20	2.77	2.20	2.09
	80	3.80	6.12	3.70	6.10
	SE (±)	0.37	0.80	0.34	0.75
Post-rainy season sorghum	0	2.63	2.28	2.12	2.49
	80	4.32	4.59	3.79	5.33
	SE(±)	0.41	0.42	0.25	0.32
Safflower	0	0.87	1.70	1.50	2.28
	80	2.65	3.61	3.44	4.51
	SE(±)	0.62	0.54	0.57	0.87
Pigeonpea	0	8.00	7.51	6.50	7.43
	SE(±)	0.90	0.32	0.60	0.21
Cowpea*	0	3.34	6.38	2.07	4.86
Chickpea	0	2.62	7.00	2.24	4.54
	SE(±)	0.13	0.89	0.15	0.16

*Cowpea roots were taken from one replication.

Table 5. Nitrogen inputs of different cropping systems (kg ha⁻¹) in two years (1994 and 1995)

System	N levels (kg N ha^{-1})					
	N_0			N_{80}		
	Roots	Leaves	Total	Roots	Leaves	Total
S/PP S/PP	14	40	54	17	40	57
S+SAF S+SAF	8	-	8	13	-	13
COW/PP S+SAF[a]	14	46	60	16	46	62
F+S F+CKP[b]	8	-	9	9	-	9
SE(±) Systems	2.5					
SE(±) N levels	1.2					

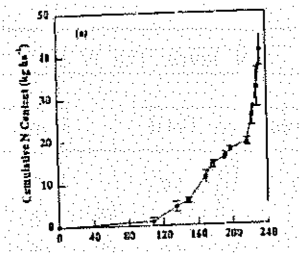
[a]Average of COW/PP S+SAF and its mirror image system S+SAF COW/PP.
[b]Average of F+S F+CKP and its mirror image system F+CKP F+S.

S+SAF S+SAF system fertilized with 80 kg N ha^{-1} had a lower root N content than that of S/PP S/PP and COW/PP S+SAF without N fertilization. The N returns through roots were smallest in the traditional F+S F+CKP rotation. These differences between systems were further amplified by the N returns through leaf fall in the treatments containing medium duration pigeonpea and cowpea. These treatments return 4-7 times the amount of N than S+SAF S+SAF and F+S F+CKP systems.

Nitrate in KCl extracts was measured to represent soil mineral N. Relatively high amounts of ammonium are extracted by KCl on Vertisols. However, soil NH_4-N usually changes little with soil depth or management in these soils, indicating that most probably a pool of NH_4-N is extracted by KCl which participates little in exchange processes with other N pools.

Fig. 2 shows the soil NO_3-N status at the end of the experiment. When no fertilizer was applied S/PP S/PP showed a marked increase in soil NO_3-N. The next best system in this regard was the COW/PP S+SAF system. Rego and Seeling (1996) reported similar increase in soil N in a S/PP system. In general, the systems which include legumes showed improvement in soil NO_3-N particularly in the upper 0-15 cm layer. The fertilized F+S F+CKP has nearly the same residual mineral N content as the S/PP S/PP. The reason for this observation is most likely, that in this rotation the applied N fertilizer is not fully utilized, because of the short crop duration and the receding moisture conditions in the post-rainy season.

It was concluded that cropping systems rotations containing pigeonpea are particularly useful to supply nitrogen in intensified cropping systems. Especially the property of medium duration pigeonpea to drop leaves after flowering guarantees N returns to soil under production conditions where farmers usually remove all above-ground biomass. Soil mineral nitrogen data show that fertilizer application in the intensified S+SAF S+SAF system was not sufficient to obtain the same level of residual



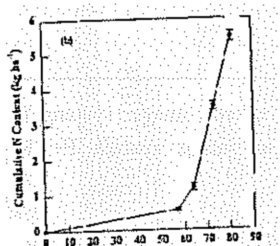


Fig. 2. Soil NO_3-N status at the end of the experiment.

mineral N as in the COW/PP or S/PP systems. This might indicate that these intensive systems are exhausting soil mineral N. On the other hand, application of 80 kg N ha^{-1} in the traditional F+S F+CKP system resulted in similar residual mineral N values to that in the S/PP system. However, in on-farm conditions these systems would receive considerably lower N application if at all and therefore are most likely also exhausting soil mineral nitrogen.

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