Roots and Nitrogen in Cropping Systems of the Semi-Arid Tropics

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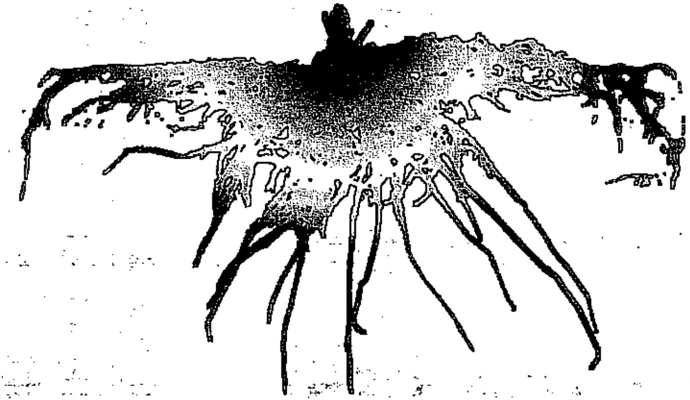

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Nitrogen Budget in Soil Under Different Cropping Systems

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Abstract

To understand the contribution of legumes in terms of nitrogen (N) addition, and to determine a N-budget, we used soil collected after the harvest of the ninth season of cropping from a long-term field experiment with eight cropping systems at ICRISAT Asia Center (IAC), India.

Mineral-N content in the soil under legume-based cropping systems was higher than that in soil under nonlegume-based cropping systems. The N-mineralization potential (N_o) of the soils under pigeonpea (PP)-based cropping systems was twice that of the soils under a fallow-sorghum (F-S)-F-S system. Such increased values in N_o were not observed for chickpea (CP)-based cropping systems. The active N fraction (N_o/N_{total}, expressed as a percentage) varied between 9 and 17% for different cropping systems.

Sorghum was grown as a test crop in these soil samples in a greenhouse. Sorghum grown in the soil collected from the plots under pigeonpea-based cropping systems yielded 36 to 63% more than sorghum grown in soil from sorghum-safflower (S-SF)-S-SF plots. Sorghum in chickpea-based cropping systems yielded 18 to 24% less than that of S-SF-S-SF plots. ^{15}N isotope dilution studies showed that 8.4 to 20% of the total-N in sorghum grown in soil from pigeonpea-based cropping systems was derived from N that was either fixed previously and had accumulated, or from soil-N that was made more available due to the presence of pigeonpea in the rotation. The N supplying capacity of the soil i.e., the 'A' values for the soil from pigeonpea-based cropping system plots were higher by 25.6 to 76.3 mg N per pot (equivalent to 4.5 to 13.3 kg N ha^{-1}) than those for the S-SF-S-SF treatment. The fertilizer-N replacement values calculated for these treatments using soil from S-SF-S-SF treatment as a control ranged from 65 to 161 mg N per pot (equivalent to 11.4 to 24 kg N ha^{-1}). Total-N budget for the soil-plant system for the soil from pigeonpea-based systems was significantly higher ($P \leq 0.01$) than that for the soil from either S-SF-S-SF or chickpea-based systems.

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Introduction

Legumes are generally grown as either intercrops or in rotation with cereals and other nonlegumes. In the tropics, nitrogen (N) is the nutrient that is most limiting for nonlegume crop production. Rainfed crops depend largely on biologically fixed and native soil-N. Intensive agricultural systems are expanded nutrient cycles involving the export of crops from a farm and require continued import of nutrients to the farm. To develop integrated soil fertility management (ISFM) strategies, increasing the productivity of different cropping systems in the semi-arid tropics (SAT) depends on understanding the N-budgets of such systems. In addition, various processes of N-cycling need to be understood so that such processes can be exploited for ISFM strategies. In this paper, we present results of N-budgeting for different cropping systems and discuss N-behavior in legume-based cropping systems.

Nitrogen balance for different cropping systems

For intensively cultivated farms, fertilizer application often results in considerable nitrogen accumulation in the system. Based on the mean of 17 data sets published by Frissel (1978), Sanchez (1994) showed that intensively managed arable farms had an average positive balance of 61 kg N ha^{-1} per year. Such positive balances continuing for several years in many farms would invariably result in nutrient contamination of ground water. In marginal areas of the tropics the opposite is usually the case, i.e., there is net mining of soil nutrients primarily due to low rates of fertilizer application, crop removal, runoff, and erosion (Sanchez, 1994). In natural ecosystems (i.e., grasslands or forests) the losses due to leaching, runoff, and erosion are small enough so that they can be compensated by additions from atmospheric deposition, N_2 fixation, or from weathering of soil minerals. Therefore, significant losses occur in agroecosystems but not in natural ecosystems (Table 1). Assessment of the depletion rates of soil in Sub-Saharan Africa (SSA) indicated that soils in SSA are losing their fertility at exceedingly high rates (Stoorvogel and Smaling 1990). Vlek and Koch (1992) estimated a net negative balance of 3 million tons of nutrients (N, P, and K) through harvest of 4 million tons of nutrients annually in SSA. In Asia, fertilizer inputs far exceed those in SSA; however, the balance may not be favorable when erosion losses and declining soil organic matter levels are considered. For sustainable crop production in all marginal soils of the tropics, external nutrient inputs in the form of fertilizers, organic inputs, and biological nitrogen fixation (BNF) are necessary.

Table 1. Comparative nitrogen balances of an undistrubed tropical raiforest, a small farm and intesively managed agroecosystems.

	Nitrogen (kg ha^{-1})		
Source	Amazon forest[1]	Kenyan farms[2]	Intesively Managed[3] arable farms
Inputs			
Atmospheric deposition	6.1	6	-
Nitrogen fixation	16.2	8	-
Organic manure	-4	24	-
Mineral fertilizers	-	17	156
Other	-	-	32
Total	22.3	55	188
Outputs			
Crop harvest removal	-	55	103
Crop residue removal	0	6	-
Runoff and erosion	-	37	-
Leaching	14.1	41	-
Denitrificaiton	2.9	28	-
Other	-	-	24
Total	17.0	167	127
Balance	17.0	-112	61

1 Oxisol in Venezuela (Jordan 1989).
2 Kisii district (Smaling 1993).
3 Mean of 17data sets (Frissel 1978).

Source: Derived from Sanchez 1994.

Legumes are important components of agriculture in the SAT because of their N_2-fixing ability. Kumar Rao et al. (1996) have discussed N_2-fixation by legumes in different cropping systems. For different grain legumes the plant-N derived from BNF ranges from 22 to 92% for groundnut, 10 to 88% for pigeonpea, 10 to 71% for common bean, 17 to 85% for chickpea, 0 to 95% for soybean, and 8 to 89% for cowpea (Peoples and Crasswell 1992). Net N-balances [total plant-N-removed - amount of N-fixed + fertilizer-N applied] for different chickpea and pigeonpea cultivars grown in India indicated that all the studied varieties depleted soil-N (Wani et al. 1994b). Different maturity groups of pigeonpea cultivars fixed 4 to 53 kg N ha^{-1} per season and an additional requirement of 20 to 49 kg N ha^{-1} was met from the soil-N pool. Different chickpea cultivars fixed 23 to 40 kg N ha^{-1} and removed an additional 63 to 77 kg N ha^{-1} from the soil. Groundnut fixed 190 kg N ha^{-1} at Patancheru, however, 20 to 40% (47 to 127 kg N ha^{-1}) of the N-requirement was met from the soil leading to a negative N-balance. Such negative N-balances occur particularly for legumes grown on high-fertility soils. Positive N-balances of up to 136 kg ha^{-1} for several legume crops following seed harvest have been reported by Peoples and Crasswell (1992). Using the same data, Wani et al. (1994b) recalculated the N-balances by assuming that crop residues were removed from the field. The net N-balances were -27 to -95 kg ha^{-1} for groundnut, -28 to -104 for soybean, -28 for the common bean, -24 to -65 for greengram, and -25 to -69 for cowpea. At IAC, Patancheru, negative N-balances occurred for different cropping systems in which pigeonpea and groundnut were grown as intercrops (Lee et al. 1993). A positive balance of 18 kg N ha^{-1} occurred for a 2-year crop rotation in which a sole pigeonpea crop was followed by a sole castor crop. A long-term crop rotation experiment started in the rainy season of 1983 at IAC showed increased soil-N content with pigeonpea-based systems at the end of the ninth year (i.e., 1992). In the same experiment, chickpea-based systems maintained soil-N content (Rego and Burford 1992). Therefore, when crop residues are removed, grain legumes only slow the decline of N-fertility of the soil rather than enhancing it, except in cases where a considerable amount of root biomass and fallen leaves are added to the soil (e.g., medium-duration pigeonpea-based systems).

N-mineralization potential of soil under different cropping systems

The total quantity of organic matter changes more slowly than do the most active components such as microbial C, microbial N, and mineralizable N. Potentially mineralizable-N, i.e., the initial pool of mineralizable-N at time zero (N_0), serves as an indicator for the active fraction (McGill et al. 1988, Wani et al. 1994a). From a long-term crop rotation experiment conducted at IAC from the 1983 rainy season, eight cropping systems with 2-year rotations were selected (Table 2). All the crops were grown rainfed, and no mineral-N was applied to any plots for the duration of the study. After the harvest of the ninth-year crops, soil samples were collected from the plow layer (0-20 cm depth) in early May, 1992. The first-order exponential model described net accumulation of mineral-N during decomposition of N from a potentially mineralizable-N source:

$$N_t = N_0 \, [1 - \exp(-k \times t)]$$

where N_t is the cumulative net N mineralized (mg kg^{-1}) over time t (wk) and k is the first-order rate constant (wk^{-1}). The exponential model yielded N_0 values ranging from 40 to 100 mg kg^{-1} soil for six soil samples collected from plots of different cropping systems (Table 2). Nitrogen-mineralization potential of the soils under pigeonpea-based cropping systems was almost twice that of the soil under F-S-F-S system. The active N fraction is defined as the quotient of N_0 and N_{total} expressed as percentage. This fraction varied between 9 and 17% with higher values observed for the soil under pigeonpea-based cropping systems (Table 2). Using N_0 and k values, we ranked the cropping systems in order of the time required to mineralize 25 mg N kg^{-1} soil. Soils from pigeonpea-based cropping systems mineralized N faster than either chickpea-based or nonlegume-based cropping systems (Table 2). Such increased N_0 values (N_0 values ranged from 50 to 60 mg N kg^{-1} soil) did not occur with the application of 20 and 40 kg N ha^{-1} yr^{-1} with pearl millet grown on Alfisol in a long-term trial started in 1980 (Wani, S.P., Bidinger, F.R., and Lee, K.K. unpublished results). In temperate regions of Canada, N_0 values for a system in which one cycle of an eight-year rotation using two crops of fababean as green manure were nearly twice that for a system in which 60 years of a 5-year rotation involved forage and cereal crops but without returning the crop residues to the soil (Wani et al. 1994a). Increased N_0 values for pigeonpea-based systems at Patancheru, when all the above-ground plant parts except fallen leaves and roots were removed indicate the extent of benefits pigeonpea contributes to the soil fertility in the tropics.

Table 2. Nitrogen mineralization potential (N_0), mineralization rate constant (k), active N fraction, and time (wk) required to mineralize 25 mg N kg^{-1} soil, for soil samples under diffemt cropping systems based on an exponential model (see text).

Treatment[1]	N_0 (mg kg^{-1} soil)	N-mineralization rate constant (k)	Active-N fraction (%)	Time (wk) to mineralize 25 mg N kg^{-1} soil
S/PP-S/PP	94.6±15.98	0.030±0.006	13	10.3
COP/PP-S+SF	86.1±19.90	0.223±0.148	17	1.5
S/PP-S+CP	100.0±10.04	0.021±0.005	16	13.8
S/PP-S+SF	67.3±13.46	0.046±0.013		10.1
S+CP-S+SF	-[2]	-	-[2]	-[2]
S+CP-S+CP	56.1±20.98	0.030±0.014		19.6
S+SF-S+SF	-[2]	-	-[2]	-[2]
F+S-F+S	40.5±8.06	0.045±0.012	9	21.4

1 S, sorghum; PP, pigeonpea; F, fallow during rainy season; COP, cowpea; SF, safflower; CP, chickpea; /, intercropped; +, sole crop grown during postrainy season.

2 Not estimated because the exponential model was not superior to the linear model.

Mineral-N content in soil

Mineral-N content in surface soil samples collected after the ninth season in the long-term crop rotation experiment at IAC showed generally a higher amount of mineral-N in the soil from legume-based cropping systems than that in nonlegume-based cropping systems (Table 3). Similarly, Rao and Singh (1991) reported that inclusion of greengram in the cropping sequence increased the available-N in the soil at harvest, i.e., 12.6% higher than in the non-fertilized control plot. Similarly, mineral-N content in soil under an eight-year rotation using fababean as green manure was five times that in soil under continuous barley treatment fertilized with 90 kg N ha^{-1} yr^{-1} (Wani et al. 1991).

Major avenues for N loss from SAT soils are leaching and removal of N in crop harvests. Small amounts are lost through burning and denitrification. Managed systems have greater inputs of N than unmanaged systems; consequently, greater losses of N occur under steady-state conditions. Under anaerobic conditions, after a heavy rainfall NO_3^- frequently is lost rapidly from soil through denitrification (Firestone, 1982), particularly when energy for denitrification is available in the form of organic residues. Losses are

Table 3. Total N-uptake by sorghum plants and different soil-N fractions (mg N pot^{-1}) in the soil from different cropping systems plots.

N fraction	Treatments							
	S/PP-S/PP	S+CP-S+CP	S/PP-S+CP	S-SF-S+SF	COP/PP-S+SF	S+CP-S+SF	S/PP+S-S+SF	SE±
Total plant-N uptake	106.1	78.9	103.5	73.7	108.2	60.2	78.4	3.82
Mineral-N at sowing	145.8	104.2	158.2	91.8	126.3	92.4	52.1	12.50
Mineral-N at harvest	56.8	26.0	56.1	49.1	20.4	38.9	55.1	9.08
Microbial-N at harvest	394	321	424	239	399	266	396	24.5
Non-microbial organic-N at harvest	6962	6068	7082	6303	7007	6010	6877	120.7
Net-N mineralised	17.1	0.8	1.3	31.0	2.3	6.7	81.4	16.32
Total-N in the soil plant system	7519	6494	7666	6665	7534	6375	7407	124.1

For details of cropping systems refer Table 2.

generally negligible at moisture levels below about two-thirds of the water-holding capacity of the soil. The process may also occur in anaerobic microenvironments of well-drained soils, such as small pores containing water and in the vicinity of roots and decomposing residues. Although few measurements are available, denitrification is believed to be small (Greenland, 1962). However, except that when large amounts of N fertilizer were added to a sandy ferruginous Dior soil in Senegal, denitrification was 45% of the total-N loss (Ganry et al. 1978). Wetselaar (1961) found that in semi-arid northern Australia at Katherine, nitrate moved towards the soil surface by capillary action during the dry season. Simpson (1963) showed similar results for Uganda. They concluded that although there may be rapid leaching of the nitrate built up by mineralization early in the season, this nitrate in the soil may not become totally unavailable to plants.

Residual effects of legumes

Legumes grown either as intercrops or in rotation with cereals often increase the yield of a subsequent cereal crop grown on the same soil when compared with the yield of a cereal grown after a nonlegume crop (Kumar Rao et al. 1983, Wani et al. 1991, 1994b). Yields of succeeding nonlegume crops are reported to increase by 0.5 to 3 t ha^{-1}, representing a 30% to 350% increase over yields in cereal-cereal cropping sequences (Peoples and Crasswell 1992). Such increased nonlegume yields following legume crops have been attributed to the N contributed by the legumes (Kumar Rao et al. 1983; Nambiar 1990) and to the rotational effects of legumes other than N effects (Wani et al. 1991; Danso and Pappastylianou 1992; Wani et al. 1994b).

We studied effect of different cropping systems from the long-term rotation experiment on sorghum yield and behavior of soil and applied-N by using sorghum as a test crop in a greenhouse pot experiment. The soils were from the long-term rotation experiment on a Vertisol at IAC. Eight cropping systems with 2-year rotations were selected: a) two rows of sorghum (S) intercropped with one row of pigeonpea (PP) every year (S/PP-S/PP); b) two rows of cowpea (COP) intercropped with one row of PP followed by S in the rainy season and SF in the postrainy season (COP/PP-S-SF); c) S/PP in the first season followed by S in the next rainy season and then CP in the postrainy season (S-CP); d) S/PP-S-SF; e) S-CP-S-CP; f) S-CP-S-SF; g) S-SF-S-SF; h) fallow 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. In each pot, two sorghum plants were grown using 13 kg of soil. Ten kg N ha^{-1} equivalent was added as potassium nitrate (99 atom % ^{15}N excess).

Sorghum grain yield was significantly ($P \leq 0.001$) affected by the previous cropping history (Fig. 1). A maximum grain yield of 8.6 g pot^{-1} occurred for the COP/PP-S-SF system, and in decreasing order, S/PP-S-CP, S/PP-S/PP, S/PP-S-SF > S-CP-S-SF, S-SF-S-SF, and S-CP-S-CP. Grain yield for COP/PP-S-SF treatment was 63% higher than the sorghum grown in the S-SF-S-SF treatment. In other pigeonpea-based cropping systems, grain yield was 36-56% higher than in S-SF-S-SF treatment soil. In chickpea-based cropping systems sorghum yielded 18 to 24.5% lower than that for S-SF-S-SF plot soil. Total plant biomass (above-ground + roots) of sorghum was also significantly ($P \leq 0.001$) influenced by cropping history. The COP/PP-S-SF treatment had the highest total plant biomass, 30.2 g pot^{-1}, was followed by S/PP-S-CP, S/PP--S/PP > S/PP-S-SF > S-CP-S-CP, S-SF-S-SF, and S-CP-S-SF (data not shown).

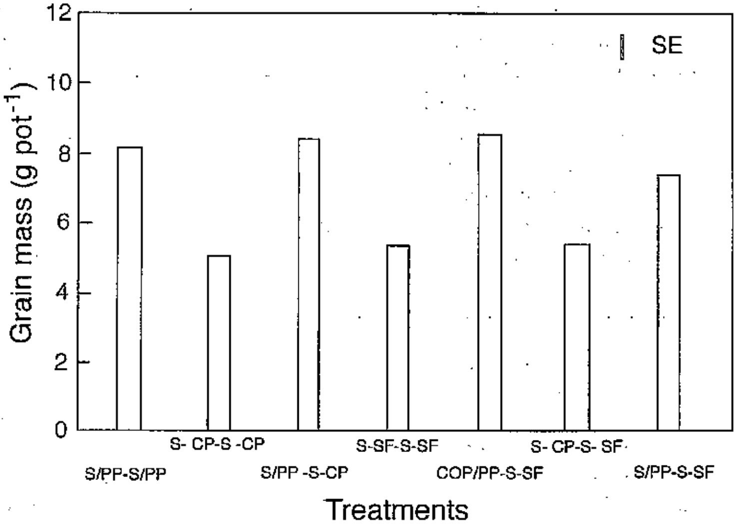

Fig.1. Grain weight of sorghum grown in surface soil samples collected from different cropping systems plots.

Total plant-N uptake of sorghum plants also varied significantly ($P \leq 0.05$) due to the cropping history of the soil (Table 3). The COP/PP-S-SF system had the maximum total N uptake 108.2 mg pot^{-1}, followed by S/PP-S/PP and S/PP-S-CP > S-CP-S-CP, S/PP-S-SF, S-SF-S-SF, and S-CP-S-SF.

Residual-N in sorghum and the 'A' values of soil

The term 'fertilizer N replacement value' (FRV) or 'N equivalent' (Hesterman et al. 1987) refers to the amount of additional inorganic-N required to obtain the same level of yield for a non-legume crop from a plot grown with a non-legume crop and the yield from a plot grown with a legume crop preceedingly. This concept is based on the hypotheses that all the benefits of legumes on succeeding cereals/nonlegume crop are solely due to a N-effect and legume-N that is just as available as fertilizer-N (Hesterman et al. 1987). However, recent literature based on ^{15}N methodology does not support this (Hesterman et al. 1987; Danso and Papastylianou 1992; Wani et al. 1991, 1994b).

The FRV method overestimates the N-contribution (Hesterman et al. 1987, Wani et al. 1991). The FRV methodology gives various estimates depending on the test crop used (Blevins et al. 1990). We related a linear response function of the observed yield to the expected N-requirement, based on the assumption that the N-supply alone causes the differences in yields observed between cropping systems. The FRV thus calculated for different systems using S-SF-S-SF system as control varied from 65 to 161 mg N pot^{-1} (11.4 to 28 kg N ha^{-1} equivalent). Recently, labeled ^{15}N has been used to measure the residual effects of legumes to overcome the problems with non-isotopic methods (Wani et al. 1991; Danso and Papastylianou 1992). Using ^{15}N dilution technique with S-SF-S-SF treatment as a control, we estimated that 8.4 to 20% of the total sorghum plant-N for plants grown in soil from pigeonpea-based systems was derived from the N that was either fixed previously and had accumulated, or from soil-N that became available due to the presence of pigeonpea in the rotation.

The N-supplying capacity of the soil i.e., the "A" value of these soils varied significantly ($P < 0.001$) with the cropping history. The S-CP-S-SF plots had the lowest A value, 191.2 mg N pot^{-1} (33.5 kg N ha^{-1} equivalent). For pigeonpea-based systems, A value varied from 249 to 300 mg N ha^{-1} (43.7 to 52.6 kg N ha^{-1} equivalent) as seen in Figure 2. The A values for the soil from pigeonpea-based cropping system plots were higher by 25.6 to 76.3 mg N pot^{-1} (4.5 to 13.4 kg N ha^{-1} equivalent) than that from the S-SF-S-SF plot. If the increased sorghum yields following pigeonpea-based systems were solely due to increased N-availability from the soil, as assumed in the FRV method, then the difference between the A values for soil from pigeonpea-based systems and those for soil from an S-SF-S-SF plot would be equal to or larger than the FRV estimates. However, the FRV estimates are 2.5 times higher (11.4 to 28 kg N ha^{-1}) than the difference between the A values for pigeonpea-based systems and those for the S-SF-S-SF system (4.5 to 13.4 kg N ha^{-1} equivalent) as determined by the ^{15}N-based technique. These results indicate that increased sorghum yields from pigeonpea-based cropping systems (compared with the S-SF-S-SF system) were not solely due to the increased N-availability. Furthermore, the FRV method overestimated pigeonpea's N contribution by 150% determined using ^{15}N-based methods.

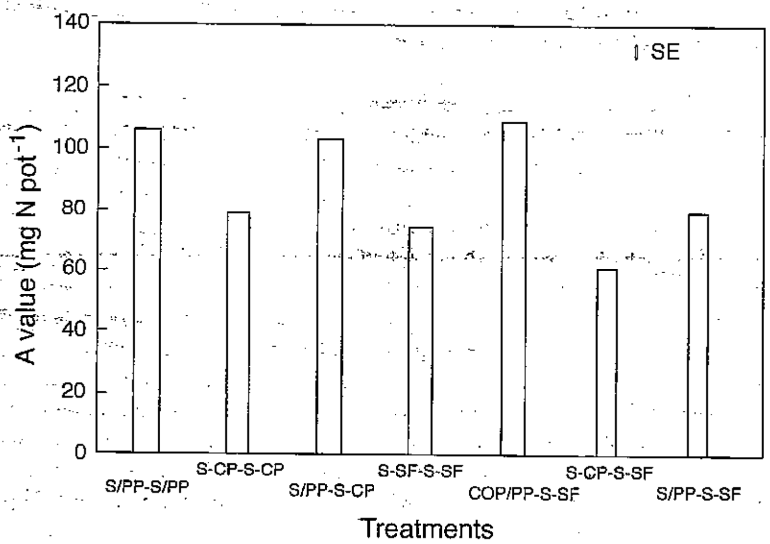

Fig. 2. The A value (N suplying capacity) of soils from different cropping systems, measured 106 days after emergence.

Grain-N content, atom % ^{15}N excess and ^{15}N-recovery

At harvest stage, N-content in grains, shoots, and roots was significantly higher for pigeonpea-based systems compared with the other systems. Grain-N content in pigeonpea-based system was 1.4 to 1.9 times higher than that in the S-SF-S-SF system.

The atom % ^{15}N excess in grain and shoots from the pigeonpea-based systems was lower compared with other treatments. Such dilution of ^{15}N in the plant tissues from the plots of pigeonpea-based systems indicated additional ^{14}N in such systems, exceeding the amount of N present in the S-SF-S-SF and chickpea-based systems. The ^{15}N recovery in grains from pigeonpea-based systems was 1.3 to 1.72 times higher than that from S-SF-S-SF system. The total ^{15}N fertilizer recovery in plants ranged 33% for COP/PP-S-SF and 24.7% for S-CP-S-SF system. The amount of ^{15}N translocated to grains ranged from 43.8% for S-SF-S-SF to 61.6% for COP/PP-S-SF. These results indicate that the fertilizer-N usage efficiency was higher for pigeonpea-based systems than for the other systems. Such increased efficiency could be due to increased biological activity in the soil, which is evident from the microbial-N values and hormonal effects.

Nitrogen behavior during crop growth

Mean mineral (NO_3+NH_4)-N in soil decreased from 8.5 to 5.9μg g^{-1} soil at 30 days after emergence (DAE), and further decreased to 3.7μg g^{-1} soil at 58 DAE. At harvest at 106 DAE, mean mineral-N content in soil was 3.3μg g^{-1} soil (Fig. 3). The S/PP-S-SF system had the highest mineral-N content S-CP-S-CP the lowest. Mean net N-mineralization in soil was similar to that in samples collected prior to sowing and at 30 DAE, and decreased significantly at 58 DAE and then marginally increased up to harvest (data not shown). The mean net N-mineralization across the sampling times in pigeonpea-based systems was 9 to 13.8 times higher (2.10μg g^{-1} soil 10 d^{-1}) than that in the S-SF-S-SF system. Mean microbial-N, indicates the amount of labile-N pool in the soil. The COP/PP-S-SF system had the maximum mean microbial-N (399.4 mg pot^{-1}), and it was followed by S/PP-S-CP $\geq$ S/PP-S/PP, S/PP-S-SF > S-CP-S-CP, S-SF-S-SF, and S-CP-S-SF (Table 3). Mean microbial-N increased significantly at 58 DAE and either remained unchanged thereafter or increased marginally at harvest stage. We found that for microbial-N there was significant interaction between cropping systems and sampling dates. For all the pigeonpea-based systems, microbial-N increased at 58 DAE with a marginal increase at harvest, whereas in other soils, microbial-N remained unchanged at 30 to 58 DAE (data not shown). We calculated the net N mineralized in the soil-plant system for the soil from different cropping systems

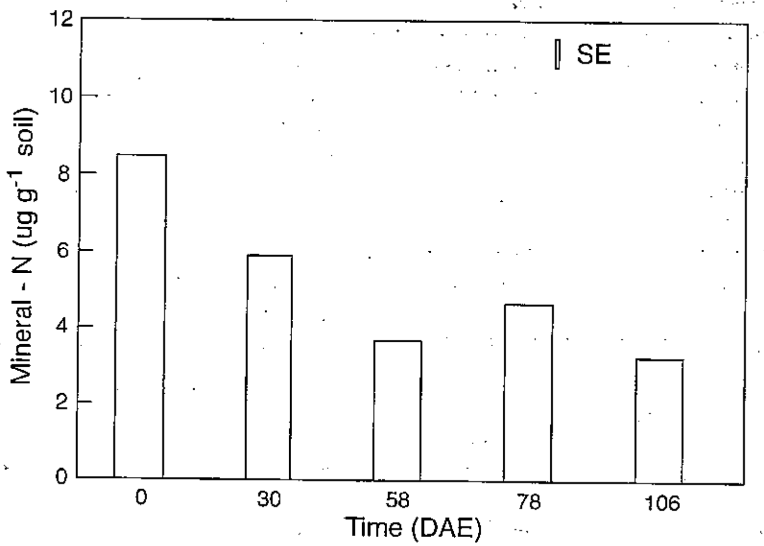

Fig. 3. Mineral ($NH_4 + NO_3$) - N content in soil from different cropping systems during sorghum growth.

as:

Net N mineralized = Total plant-N uptake + mineral-N in soil at harvest - mineral-N in soil prior to sowing.

The S/PP-S-SF had the maximum net N-mineralization followed by S-SF-S-SF, S/PP-S/PP ≥ S-CP-S-SF, COP/PP-S-SF, S/PP-S-CP, and S-CP-S-CP. These results indicate that neither mineral-N in soil nor net N-mineralization in soil in isolation provide proper insight into the N-behavior in soil and total-N in soil-plant system under different cropping systems.

Nitrogen budget for soil-plant system

We evaluated the total N in soil-plant systems for soils from different cropping systems by adding different forms of N in the soil and plant-N uptake. The total-N in the soil-plant system for pigeonpea-based systems was significantly ($P \leq 0.01$) higher than that for S-SF-S-SF or chickpea-based systems (Table 3). This indicates that increased sorghum yields in pigeonpea-based systems are due to increased N-availability by PP through BNF. Such increased total N values for pigeonpea-based soil-plant systems (compared with other cropping systems) along with the increased N_o values and quantification of N benefits (estimated using ^{15}N-based methods) indicate that increased sorghum yields for pigeonpea-based systems are partly due to increased N-availability. Other mechanisms, such as increased biological activity, increased fertilizer-N uptake, and N usage, are also responsible for increased sorghum yields in pigeonpea-based systems.

Conclusion

Legumes are important components in the agriculture of the SAT because of their N_2-fixing ability. Compared with both chickpea- and nonlegume-based cropping systems, pigeonpea-based cropping systems show positive effects on soil fertility in terms of increased mineral-N content in soil, higher N-mineralization potential, increased N-availability to the succeeding crop, increased microbial-N and increased fertilizer-N uptake, and increased total-N in soil-plant system. Pigeonpea has an important role in the ISFM strategies for developing sustainable management practices in the SAT. The beneficial effects of pigeonpea-based systems based on ^{15}N-based techniques in pot culture studies could not be fully explained in terms of either N-sparing effect or BNF inputs. Mechanisms, such as increased biological activity, increased fertilizer-N uptake, and N-usage efficiency, are responsible for such benefits from pigeonpea in addition to BNF benefits in the cropping systems.

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Improvement of Soil and Fertilizer Nitrogen Use Efficiency in Sorghum/Pigeonpea Intercropping

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Abstract

Nitrogen (N) fertilizers play a key role in the burgeoning grain-food production in the semi-arid tropics (SAT). Low commodity prices and relatively high cost of N-fertilization, and increasing concern about the impact of modern agriculture on environmental quality suggest that agriculture should emphasize resource management to either explore more effective and efficient ways to utilize soil- and fertilizer-N, or exploit opportunities for biological N_2*-fixation that can augment or substitute for N-fertilizers.*

Field experiments were conducted in shallow and medium-deep Alfisols for 3 years to evaluate cereal/legume crop combinations and fertilizer management strategies to improve soil and fertilizer N use efficiency (NFUE), and also to enhance N_2*-fixation. The NFUE of sorghum and the dependency of pigeonpea on* N_2 *from fixation were enhanced by intercropping compared with that in a sole crop. Band-placement of fertilizer-N to sorghum resulted in 36% recovery compared with 19% in split, and 13% in broadcast compared with basal application. Delay of urea-N application until 40 days after sowing (DAS) resulted in a higher grain yield and NFUE in sorghum. Fertilizer-N rate of 50 kg N* ha^{-1} *applied as band-placement resulted in the highest grain yield and total N accumulation by sorghum and not by pigeonpea. The results suggest that more efficient utilization of N can be achieved by appropriate combination of component crops of intercropping and their management.*

Introduction

Semi-arid tropical (SAT) soils are usually low in organic matter (less than 1%) as compared with soils in temperate environments (2-4%). Because organic matter is a source of available-N in the soil, many soils in the SAT are incapable in maintaining N in adequate amounts, and N fertilization is therefore necessary for reasonable high yields on SAT soils.

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