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Available pool and mineralization rate of soil N in a dryland agroecosystem: Effect of organic soil amendment and chemical fertilizer

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Nitrogen is recognised as one of the most limiting nutrients for crop growth. Processes that govern soil nitrogen supply in agroecosystems, particularly in rice based agroecosystems, are poorly understood. Recent studies have hypothesised crop management practices to be one of the major factors governing soil N supply during the rice cropping period (Witt *et al.* 1998). In tropical arable soils available N is rarely adequate for plant growth unless it is replenished by exogenous nitrogen inputs. The application of chemical fertiliser generally improves crop production, however, concerns have been raised not only about the severe environmental problems posed by such practices but also about the long term sustainability of such systems (Mader *et al.* 2002). In the dryland agroecosystems, not only the accessibility of fertilisers is limited but also their use is much less rewarding due to soil moisture scarcity through most parts of the year. On the other hand, use of organic materials (e.g. animal manures, crop residues, green manures, etc.) as an alternative source of nutrients holds promise. To manage the short and long-term N availability to crops in tropical drylands, an understanding of the seasonal rates of N-mineralization and the pools of available N in soil is required. This long-term investigation was conducted in a tropical dryland agroecosystem (with rice-lentil crop sequence) to evaluate the effects of addition of organic input in the form of farmyard manure (FYM) and chemical fertiliser to soil on: (a) available N pool and (b) N-mineralization rate.

This work was carried out in the agricultural farms of the Banaras Hindu University. The experimental design included following treatments: (1) Control without FYM or fertiliser; (2) Chemical fertiliser (NPK: 40 kg N ha^{-1}, 20 kg P ha^{-1} and 15 kg K ha^{-1} through Urea, single superphosphate and muriate of potash), and (3) FYM (containing N equivalent to that of 2). The C:N ratio (mean ± SE) of the FYM applied was 25.3 ± 1.4. The test crops sown were rice (*Oryza sativa* var. *Akashi*) during the rainy season and lentil (*Lens esculenta* var. Pant 209) during the winter. Every year fields were optimally tilled and the inputs were applied only once annually, 1 or 2 days before sowing of the rice crop. FYM was surface applied and lightly incorporated in the soil, whereas fertiliser was surface applied only. The treatments were applied continuously in the respective plots for six years. Thereafter soil samples were collected from 0-10 cm depth every month (except in June, July and November) for the determination of N-mineralization rate and available N pools. NO_3-N was measured by Phenol disulphonic acid method (Jackson 1958). NH_4-N was estimated by Phenate method (APHA 1985). The sum of NH_4-N and NO_3-N was considered as the available N. Buried bag technique of Eno (1960) was used for the measurement of N-mineralization rate. At time zero and after 30 days field incubation, soil available N contents were measured by the method described above. Net N-mineralization rate was estimated as the increase in the concentration of available N during 30 days (Melillo 1981). All results were expressed on oven dry (105°C, 24 h) soil basis.

After six years continuous exogenous inputs, the rate of N-mineralization differed widely in the initial stage in various treatments (Table 1). In control and fertiliser amended plots the progress of N-mineralization with time followed the classical pattern of initial rapid release of N followed by a slower, linear release, as also reported by El-Haris *et al.* (1983) and Bonde & Rosswall (1987).

Application of FYM, in contrast, showed initial slow N release or an initial lag phase, followed by a rapid N release phase and subsequent lowering of the rate (Table 1). Chae & Tabatabi (1985), investigaing N-mineralization patterns in a series of aerobic incubation experiments (26 weeks) on soils amended with animal manure, also reported similar temporal pattern of N release. The initial lag phase is generally ascribed to microbial immobilization of N, denitrification and /or volatilization of ammonia. Since in this experiment the manure was incorporated in the soil, the loss of N through gas exchange is expected to be minimum and it seems most likely that immobilization of N was the primary reason for the initial low N-mineralization rate. Epstein *et al.* (1978) also reported that organic amendments high in readily oxidizable carbon can induce N-immobilization. Unlike the other high quality resources where the nutrient release is rapid during the early phase of decomposition, the FYM showed immobilization of N in the initial phase of the crop cycle. This probably helps in conservation of N which would otherwise be lost as the plant demand for nutrients is minimum during this phase.

Table 1. Impact of different soil amendments on the N-mineralisation rate (μg g^{-1} mo^{-1}); values in parentheses show the percent increase over control following various treatments in different seasons. Code: C, control; F, fertiliser; FYM, farmyard manure.

Month/ Crop	Treatments			LSD*
	C	F	FYM	
Rice				
Aug	10.44	16.42	10.22	2.21
Sep	10.04	14.42	14.72	2.24
Oct	8.56	10.85	13.35	2.20
Mean	9.68	13.90 (43.6)	12.76 (31.8)	
Lentil				
Dec	6.60	9.80	12.00	1.72
Jan	6.05	7.89	9.63	1.35
Feb	6.50	8.00	10.02	1.41
Mar	4.35	5.52	6.02	1.01
Mean	5.88	7.80 (32.7)	9.43 (60.4)	
Summer Fallow				
Apr	2.16	2.22	2.72	0.45
May	1.50	1.60	1.99	0.30
Mean	1.83	1.91 (4.4)	2.36 (28.7)	
Annual	6.24	8.52 (36.6)	8.97 (43.7)	

* LSD, least significant difference, $p < 0.05$

The mean enhancement in the N-mineralization rate over the control during the rice crop period was greater in fertiliser (43.6%) than in FYM (31.8%) plots (Table 1). The trend was, however, reversed with higher enhancement due to FYM through the lentil crop (FYM 60.4%, Fertiliser 32.7%) and summer fallow (FYM 28.7%, Fertiliser 4.4%) periods. Chae & Tabatabai (1985) reported that addition of cow manure increased the amounts of N mineralized by 60-166% over the control, depending upon the type of soil. Bonde & Rosswall (1987) found that N-fertilisation (80 kg N $ha^{-1}yr^{-1}$) increased the mineralization potential by about 7% over the control whereas FYM application with the same amount of N increased it by as much as 54%. Of the total amount of N-mineralized, 56-81% was accounted by ammonification and the remaining by nitrification in different months.

Marked seasonality was found in N-mineralisation rate. N-mineralization rate was highest during the wet phase supporting the rice crop and thereafter it consistently declined towards the summer fallow barring a small peak in February (Table 1). Among the factors stimulating N-mineralization rate, rewetting of a dry soil is considered to be a major one (Canbera 1993; Dalal & Mayer 1987). Upon drying and rewetting, the new pool of readily mineralizable N becomes available to the microorganisms, derived both from the previously inaccessible soil organic matter and from dead N-rich microbial cells (Campbell & Biederbeck 1982).

After the rainy season, there was a continual decrease in soil moisture content during the rest of the annual crop cycle, which resulted in decrease in N-mineralization during winter and summer. In this dryland soil, throughout the annual cycle, across all the treatments, N-mineralization was found to be influenced strongly by the variation in soil moisture content. The soil moisture content was higher during the rice crop period (28-17%) and it decreased through the lentil crop period (17-3%) to the minimum during summer fallow (2-0.7%). Throughout the annual cycle the soil moisture content was found to be higher in the FYM amended plots. Strong positive correlation was found between the rate of N-mineralization and soil moisture content ($r = 0.86$, $p < 0.01$).

Considerable variation in available N pool was found within the annual cycle. NH_4-N was the predominant available form of N (Fig. 1). At different times in the annual cycle NH_4-N constituted 65-97% of the total available N. Domergues *et al.* (1978) found that due to low water potentials under dryland condition, the activity of the nitrifying bacteria in contrast to diverse ammonifying microbes, is retarded and thus results in accumulation of NH_4-N in the dryland soils. The maximum accumulation of NH_4-N occurred during the wet season with crop rice and then its level decreased during the lentil crop. Thereafter slight increase occurred during the summer fallow. In contrast, in the case of NO_3-N, the lowest levels were associated with the rice crop. NO_3-N increased through winter with lentil crop and then again decreased during the hot summer (Fig. 1).

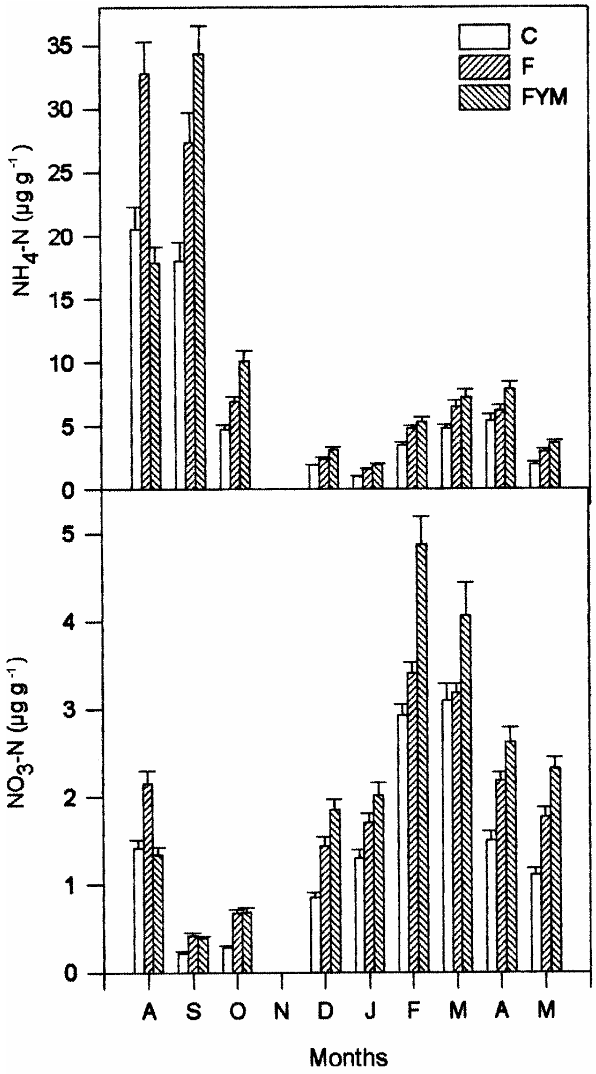

Fig. 1. Monthly variations in NH_4-N and NO_3-N pools in soil under various treatments; values are mean ± S.E. (code: C, control; F, fertilizer; FYM, farmyard manure).

Table 2. Variations in the levels of available N (µg g^{-1}) following various soil amendments; values in parentheses show percent increase over control in different seasons. Code: C, control; F, fertiliser; FYM, farmyard manure.

Month/ Crop	Treatments			LSD*
	C	F	FYM	
Rice				
Aug	22.00	34.95	19.24	6.41
Sep	18.22	27.82	34.75	5.70
Oct	5.02	7.76	10.72	2.60
Mean	15.08	23.51 (55.9)	21.57 (43.0)	
Lentil				
Dec	2.75	3.84	4.95	0.80
Jan	2.30	3.31	3.97	0.60
Feb	6.43	8.21	10.17	1.50
Mar	7.89	9.68	11.42	1.54
Mean	4.84	6.26 (29.3)	7.61 (57.2)	
Summer fallow				
Apr	6.97	8.58	10.50	1.48
May	3.89	4.77	5.77	0.87
Mean	5.43	6.68 (23.0)	8.14 (49.8)	
Annual	8.39	12.10 (44.2)	12.38 (47.6)	

* LSD, least significant difference, $p < 0.05$

The maximum accumulation of available N occurred during the wet phase of the soil (Table 2). In contrast to the control and fertiliser treatments, there was a sharp increase in the level of available N a month after the application of FYM. The pattern of available N pool was similar to the response obtained for N-mineralisation rate. In all the treatments, the level of available N decreased consistently during the rice crop period as well as early phase of lentil crop period that was certainly due to N-uptake by the actively growing crop. Some accumulation of available N occurred during the late phase of lentil crop and dry summer, which may be associated with the decreased N demand of the crop. The other factor may be the release of N from the decomposing roots of lentil, which are nitrogen-rich. The slight increase in the rate of

N-mineralization during that period may also have contributed to the accumulation of available N.

Through the annual cycle, across all the treatments a strong positive correlation (r = 0.82, $p < 0.05$) was found between available N and the rate of N-mineralization. The accumulation of available N is thus strongly regulated by N-mineralization in a dryland agroecosystem. The decrease in the available N pool through summer coincided with the rise in temperature (upto 45°C during the day) and was possibly related to ammonium volatilisation.

In this study considerable increase in the levels of NH_4-N, NO_3-N and consequently available N pools in the two treatments compared to the control were observed. Throughout the annual cycle the level of available N was significantly higher in the FYM treatment than the fertiliser treatment except in August (Table 2). However, during the rice period (mean of three months) relative to control, fertiliser (56%) caused greater enhancement than FYM (43%) treatment. The trend was, however, reversed during the lentil crop (FYM 57%, Fertiliser 29%) and summer fallow (FYM 50%, Fertiliser 23%). The overall increases in available N were greater for the FYM treatments that increased available N concentration by 48%, whereas the increase due to fertiliser treatment was 44%. Nitrogen from both manure and fertiliser is susceptible to leaching through the soil profile but leaching of NO_3 is reported to be greater from fertiliser than from manure plots (Comfort *et al.* 1987).

In conclusion, application of FYM not only increased the rate of supply and pool size of available N in the dryland but it also sustained the enhanced N pool throughout the annual cycle. In contrast, fertiliser application did increase the size of available N pool initially but could not sustain it. FYM application conserves N during the initial phase of crop cycle, reducing the N loss and providing a better synchronisation of N availability and crop demand during the later part of the annual cycle. There is need for the evaluation of various organic inputs in managing soil fertility in dryland agroecosystems.

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