

Fixed ammonium and carbon–nitrogen ratios of some semi-arid tropical Indian soils

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Abstract

Relatively little is known about the fixed $\text{NH}_4\text{-N}$ status of soils in the semi-arid tropics (SAT) but information is needed in view of its role in N cycling and the N economy of the soils. The distribution of fixed $\text{NH}_4\text{-N}$ and C/N ratios of soil profiles from two benchmark Vertisols and one Alfisol in the Indian SAT were studied.

From 15.9 to 58.6% of the total soil N was present as fixed $\text{NH}_4\text{-N}$ in the Vertisol profiles; the range was from 13.3 to 30.8% in the Alfisol profile and a higher percentage of fixed $\text{NH}_4\text{-N}$ was found in the lower horizons. A method based on the extraction of soil samples with dilute HF solution was found suitable for determining fixed $\text{NH}_4\text{-N}$ in these soils as the values of fixed $\text{NH}_4\text{-N}$ determined by this method were in good agreement with those determined using the standard method. Organic C/total N ratios varied from 7.7 to 12.8 in the three profiles while the organic C/organic N ratios varied from 9.4 to 21.4.

The results of this study emphasize the importance of fixed $\text{NH}_4\text{-N}$ in assessing the N-status of the soils.

1. Introduction

Several reports support the view that many tropical soils contain a large amount of native fixed $\text{NH}_4\text{-N}$ (Rodrigues, 1954; Moore and Ayeke, 1965; Opuwaribo and Odu, 1974, 1975; Dalal, 1977). However, there are few reports on the fixed $\text{NH}_4\text{-N}$ status of SAT (semi-arid tropics) soils (Burford and Sahrawat, 1989). In view of the importance of fixed $\text{NH}_4\text{-N}$ in the overall N economy of soils (Nommik and Vahtras, 1982), it was decided to obtain data on the fixed $\text{NH}_4\text{-N}$ distribution in the profiles of two benchmark Vertisols and one Alfisol in the Indian SAT.

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2. Materials and methods

2.1. Soils

Soil profiles from the Kasireddipalli Series, Barsi Series (both Vertisols) and Patancheru (Alfisol) Series were studied. Some important characteristics of the soils in the three profiles are given in Table 1. The Kasireddipalli Series is a Typic Pellustert developed on basaltic alluvium on the lower pediments and in depressions in Medak and adjoining districts of Andhra Pradesh. The soil samples were collected from a profile at the ICRISAT Center, Patancheru. The Barsi Series is a Typic Chromustert developed on fine basaltic alluvium. It is a deep clayey, moderately well drained, calcareous soil and occurs widely in the Sholapur and Osmanabad districts of Maharashtra state in India. These soils have been cropped to cereal crops such as sorghum under rainfed conditions with relatively low inputs of chemical fertilizers. The soil used in this study was collected from Sholapur. The Patancheru Series (located at ICRISAT Center, Patancheru) is in the clayey–skeletal mixed isohyperthermic family of Udic Rhodustalfs developed on weathered granite. The dominant layer silicate minerals are of the montmorillonite-type in the Vertisols and of the kaolinite-type, with small proportions of 2:1 layer-lattice clays and sesquioxides in the Alfisol. The detailed description of these series including their mineralogy are available in Benchmark Soils of India (1982). In a recent study of the mineralogy of the clay fraction of the Kasireddipalli Series and the Patancheru Series, Dhillon and Dhillon (1991) found that the main clay mineral in the Kasreddipalli Series is smectite with small amounts of illite and the dominant clay mineral in the Patancheru Series is kaolinite with small amounts of iron

Table 1
Some physical and chemical characteristics of the soils

Soil Series	Classification	Soil depth (cm)	pH	Org. C (g/100 g)	Total N (mg/kg)	CEC (cmol/kg)	Clay (g/100 g)	Sand (g/100 g)
Kasireddipalli	Vertisol, Typic Pellustert, very fine montmorillonitic, isohyperthermic	0–15	8.3	0.66	600	47.5	51	24
		15–40	8.5	0.33	380	45.8	54	25
		40–90	8.9	0.37	330	50.4	56	22
		90–105	8.9	0.29	280	49.0	59	21
		105–150	8.7	0.18	210	48.0	65	14
Patancheru	Alfisol, Udic Rhodustalf, clayey–skeletal mixed isohyperthermic	0–10	6.3	0.62	530	10.7	19	75
		10–20	6.4	0.66	650	17.1	30	62
		20–49	6.7	0.63	780	21.9	41	48
		49–102	6.6	0.49	510	17.9	41	51
		102–145	7.4	0.20	190	26.2	24	62
		145–160	8.0	0.10	130	25.2	26	62
Barsi	Vertisol, Typic Chromustert, very fine montmorillonitic, isohyperthermic	0–20	8.9	0.45	390	76.3	55	22
		20–42	9.0	0.43	350	71.1	62	19
		42–103	9.1	0.46	360	74.6	64	20
		103–136	9.1	0.41	330	67.3	62	21
		136–160	9.2	0.32	270	62.9	57	33
		160–200	9.3	0.24	230	54.4	56	27

oxides and traces of vermiculite. On the other hand, Mengel and Busch (1982) reported that the Kasireddipalli Series contained small amounts of vermiculite along with the dominant clay mineral smectite. The Barsi Series has smectite as the main clay mineral with lesser amounts of illite (Benchmark Soils of India, 1982).

2.2. *Methods*

Soil samples were collected by horizon from the three profiles, air-dried and ground to pass through a 2-mm screen before analysis (Table 1). For organic C and total N analysis the samples were ground to pass a 0.25-mm sieve.

Soil pH was measured by a glass electrode using a soil:water ratio of 1:2. Organic C was determined following the method described by Walkley and Black (1934). The method used for total N was a macro-version of the Kjeldahl method modified to include nitrate and nitrite using thiosulfate (Dalal et al., 1984). In addition to effecting quantitative recovery of nitrate this method does not require pretreatment of soil samples with water, as is needed in case of the salicylic acid-thiosulfate or permanganate-iron modifications of the Kjeldahl method for some heavy clay soils such as Vertisols (Bal, 1925; Moraghan et al., 1983). Because the soils examined were low in total N contents, the macro-version of the Kjeldahl method was preferred for better precision in total N determination (Sahrawat et al., 1989). Cation exchange capacity of the soils was determined as described by Chapman (1965) and particle size was done by the hydrometer method (Day, 1965).

Fixed $\text{NH}_4\text{-N}$ in soil samples was determined using the method proposed by Silva and Bremner (1966). This method is very specific and is reported to measure fixed $\text{NH}_4\text{-N}$ only (Bremner et al., 1967). The samples were analysed in two replications and the determinations were repeated if the duplicates differed by more than 5%. The values of fixed $\text{NH}_4\text{-N}$ determined by the Silva–Bremner method were compared with those obtained by a method based on direct extraction of soil samples with dilute HF solution (Tilo et al., 1977). For the comparative evaluation of the two methods soil samples from the Kasireddipalli and Patancheru Series were used. Soil samples (5 g) were extracted with dilute HF solution (100 ml of 2.5 N HF + 0.1 N HCl) for 8 h on a shaker and $\text{NH}_4\text{-N}$ in the extracts was determined by steam distilling the extracts with MgO. The amount of fixed $\text{NH}_4\text{-N}$ in a sample was obtained by subtracting the amount of exchangeable $\text{NH}_4\text{-N}$ from HF-extractable $\text{NH}_4\text{-N}$. Exchangeable $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ in the samples were determined by steam distillation of extracts (obtained by 2 N KCl extraction) with MgO and Devarda alloy (Keeney and Nelson, 1982).

Organic N content in the samples was obtained by the difference between total N and inorganic N, where inorganic N constituted the sum of fixed $\text{NH}_4\text{-N}$ + exchangeable $\text{NH}_4\text{-N}$ + $\text{NO}_3\text{-N}$. All analyses were replicated twice and the results were expressed on a oven-dry weight basis.

3. *Results and discussion*

Total N and organic C contents of the soils are given in Table 1 and the distribution of fixed $\text{NH}_4\text{-N}$, organic N, organic C/total N and organic C/ organic N ratios are given in

Table 2. Preliminary experiments showed that the fixed $\text{NH}_4\text{-N}$ was fully recovered by the Kjeldahl method for total N and that prior treatment of the soil samples with HF was not necessary. In some soils, treatment with HF has been found to be necessary to fully recover fixed $\text{NH}_4\text{-N}$ in total N determination of the soils (Stewart and Porter, 1963; Dalal, 1977).

Fixed $\text{NH}_4\text{-N}$, as percent of total N varied from 22.3 to 58.6% in the Kasireddipalli, from 14.0 to 30.8% in the Patancheru and from 15.9 to 31.1% in the Barsi Series; the values generally increased with soil depth (Table 2). It is known that vermiculite has the highest capacity to fix $\text{NH}_4\text{-N}$. However, it has been shown that montmorillonite-containing soils can fix $\text{NH}_4\text{-N}$ when they are dried because soil drying results in dehydration of interlayer surfaces making partial contraction of the lattice possible (Nommik and Vahtras, 1982). Indeed, the review by Nommik and Vahtras cites several examples that clearly establish that alternate drying and wetting, as is common for the soils in the SAT, is effective in increasing $\text{NH}_4\text{-N}$ fixation. Similarly, illite-containing soils have been reported to have considerable $\text{NH}_4\text{-N}$ fixing capacity (Nommik and Vahtras, 1982).

The two Vertisols and the Alfisol series used in this study do contain significant but variable amounts of illite (Benchmark Soils of India, 1982; Dhillon and Dhillon, 1991) but the presence and content of vermiculite in the clay fraction of these soils is debatable (Mengel and Busch, 1982; Dhillon and Dhillon, 1991). Our results show that these soils, low in organic matter do have significant amounts of fixed $\text{NH}_4\text{-N}$ in their profiles.

Soil organic N constitutes up to 85% of total N in surface soils but the proportion generally decreased with soil depth. The decrease in organic N with depth was gradual especially in the Patancheru and Barsi Series but was rather steep in the Kasireddipalli Series. At the

Table 2
Distribution of fixed $\text{NH}_4\text{-N}$ and organic N, and C/N ratios of the soils

Soil Series	Soil depth (cm)	Fixed $\text{NH}_4\text{-N}^a$	Organic N ^{a,b}	Organic C/ Total N	Organic C/ Organic N
Kasireddipalli	0–15	22.3	76.7	11.0	14.3
	15–40	33.4	65.5	8.7	13.2
	40–90	37.3	61.2	11.2	18.3
	90–105	45.0	53.9	10.4	19.2
	105–150	58.6	40.0	8.6	21.4
Patancheru	0–10	14.0	85.5	11.7	13.7
	10–20	14.3	85.4	10.1	11.9
	20–49	13.3	86.6	8.1	9.4
	49–102	23.7	75.7	9.6	12.7
	102–145	28.9	70.0	10.5	15.0
	145–160	30.8	67.7	7.7	11.4
Barsi	0–20	15.9	82.8	11.5	13.9
	20–42	19.7	79.1	12.3	15.5
	42–103	18.9	80.0	12.8	16.0
	103–136	23.0	75.5	12.4	16.5
	136–160	31.1	67.4	11.8	17.6
	160–200	27.8	70.9	10.4	14.7

^aPercent of total N.

^bOrganic N = total N – inorganic N ($\text{NH}_4\text{-N}$ + $\text{NO}_3\text{-N}$ + fixed $\text{NH}_4\text{-N}$).

Table 3

Comparison of the Silva–Bremner and the HF extraction methods for determining fixed $\text{NH}_4\text{-N}$ contents in Kasireddipalli Vertisol and Patancheru Alfisol samples. The values in parentheses are S.D. of means

Soil	Soil depth (cm)	Fixed $\text{NH}_4\text{-N}$ content (mg N/kg soil)	
		Silva–Bremner	HF extraction
Vertisol	0–15	134 (2.8)	143 (2.8)
	15–40	127 (4.2)	123 (5.7)
	40–90	123 (4.2)	121 (5.7)
	90–105	126 (4.0)	121 (5.7)
	105–150	123 (5.7)	121 (5.7)
Alfisol	0–10	74 (4.2)	72 (4.2)
	10–20	93 (5.7)	79 (4.2)
	20–49	104 (5.7)	88 (7.1)
	49–102	121 (5.7)	99 (5.7)
	102–145	55 (5.7)	48 (7.0)
	145–160	40 (4.2)	37 (5.7)

lowest depth, organic N constituted only 40% of the total N in the latter. Dalal (1977) reported that in some Trinidad soils organic N constituted up to 80% of total N in surface soils, but only a maximum of 32% at the lowest depth.

The organic C/total N ratios varied from 7.7 to 12.8 in the three profiles and generally decreased with soil depth (Table 2) and this narrowing of the ratios has been attributed to fixed $\text{NH}_4\text{-N}$ (Moore and Ayeke, 1965; Dalal, 1977). On the other hand, the organic C/organic N ratios generally tended to increase with soil depth and the ratios varied from 9.4 to 21.4 in the three profiles.

The data for 11 soil samples on fixed $\text{NH}_4\text{-N}$ determined by the Silva–Bremner method and the direct HF extraction (Tilo et al., 1977) showed good agreement (Table 3). The relationship between data by the two methods can be described by the following regression equation:

$$\text{HF-fixed } \text{NH}_4\text{-N} = -8.3245 + 1.021 (\text{Silva–Bremner}) - \text{fixed } \text{NH}_4\text{-N},$$

$$r^2 = 0.94 \ (n = 11)$$

These results support the findings of Tilo et al. (1977) who reported that the dilute HF extraction method was suitable for extraction of fixed $\text{NH}_4\text{-N}$ in some Philippine soils.

Earlier studies showed that the use of strong acid mixtures such as $\text{HF-H}_2\text{SO}_4$ hydrolysed large amounts of organic N compounds during treatment of the soil samples with these acid mixtures (Bremner et al., 1967). The use of dilute acid mixtures such as 2.5 N HF – 0.1 N HCl used in the present study does not seem to cause much error in the soils examined that are low in organic matter. However, it is not possible to recommend this method for determining fixed $\text{NH}_4\text{-N}$ in all soils unless it is thoroughly evaluated using soils having a wide range in organic matter. Our results do, however, indicate that this method may be suitable for measuring fixed $\text{NH}_4\text{-N}$ in soils low in organic matter contents.

In conclusion, the results of this study suggest that the fixed $\text{NH}_4\text{-N}$ status of soils may be useful in assessing the probable availability of N.

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