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Mineralization of Soil Organic Nitrogen under Waterlogged Conditions in Relation to Other Properties of Tropical Rice Soils

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Abstract

The mineralizable nitrogen pool in wetland rice soils plays a dominant role in the nitrogen nutrition of rice even in fertilized paddies. There is a lack of information on how different soil properties affect ammonification of organic nitrogen in wetland rice soils. Surface samples of 39 diverse Philippine soils representing a wide range of pH, organic matter and texture were studied to determine the relationships between ammonification of organic nitrogen and soil properties.

Simple correlation analysis showed that ammonium production was correlated highly significantly with total nitrogen (r = 0·94**), organic carbon (r = 0·91**) and C/N ratio (r = −0·46**), but it was not significantly correlated with cation exchange capacity, clay or pH. Multiple regression analayses showed that organic matter (organic carbon and total nitrogen) accounted for most of the variation in mineralizable nitrogen. These results suggest that organic carbon content is a good index of mineralizable nitrogen in tropical wetland rice soils.

Introduction

Mineralization of soil organic nitrogen is very important for the nutrition of wetland rice because studies using ^{15}N labelled fertilizer, which permit distinction between soil and fertilizer nitrogen, have clearly shown that rice obtains half to two-thirds of its nitrogen requirement from the soil mineralizable nitrogen pool even in a well-fertilized paddy (Broadbent 1978; IAEA 1978).

Mineralization of organic nitrogen is affected by several environmental factors, the most important being temperature and moisture regimes. Studies made at the International Rice Research Institute (IRRI) showed that mineralization of organic nitrogen in four soils under anaerobic incubation increased with the increase in temperature from 15° to 45°C (IRRI 1974). Similarly, the importance of temperature on nitrogen mineralization in paddy soils has been brought out by studies made in Japan and elsewhere (Kai *et al.* 1969; Ponnamperuma 1972; Onikura *et al.* 1975; Yoshino and Dei 1977; Broadbent 1979). The influence of moisture regime is critical for mineralization of soil nitrogen because the pattern of mineral nitrogen release is affected by soil drying (Shiga and Ventura 1976). Soil drying prior to flooding enhances mineralization of organic nitrogen (Shioiri *et al.* 1941; Shioiri 1948; Ventura and Watanabe 1978; Sahrawat 1980*b*). Sahrawat (1981) reported that mineralization of organic nitrogen was very rapid in four Philippine organic soils when they were air-dried, but there was virtual absence of ammonification in the continuously wet Histosols.

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In a recent review, Broadbent (1979) has discussed the range of soil and climatic factors that affect mineralization of organic nitrogen in paddy soils, and concluded that the mineralization process is affected by soil temperature, moisture regime, organic amendments, wetting and drying, nature and amount of organic matter and

Table 1. Analyses of soils used

Soil No.	Texture	pH (1 : 1)	Org. C (%)	Total N (%)	C/N	CEC (m.e./100 g)	Clay (%)	Min. N[A] (μg/g)
1	Clay	4·5	1·54	0·17	9·0	23·5	62	63
2	Clay	4·3	1·94	0·18	10·8	16·5	71	75
3	Clay	5·3	1·48	0·16	9·2	30·3	57	73
4	Clay	4·4	1·98	0·20	9·9	30·5	53	82
5	Clay	5·4	2·44	0·31	7·9	36·2	49	332
6	Clay	5·8	3·36	0·33	10·2	43·0	60	279
7	Silty clay loam	5·5	5·46	0·60	9·1	44·3	22	428
8	Silty clay loam	5·6	4·76	0·48	9·9	40·9	24	315
9	Clay	4·7	2·42	0·26	9·3	36·8	74	147
10	Silty clay loam	6·4	1·76	0·18	9·8	29·3	33	49
11	Clay loam	7·4	1·97	0·18	10·9	35·9	33	103
12	Silty clay loam	5·5	2·05	0·16	12·8	37·7	27	118
13	Silty clay	6·9	1·69	0·16	10·6	36·2	47	50
14	Clay	5·1	0·93	0·08	11·6	25·5	56	32
15	Clay	4·8	0·95	0·08	11·9	23·9	55	36
16	Clay	7·0	1·89	0·16	11·8	45·4	68	47
17	Clay	6·4	0·83	0·08	10·4	35·5	60	24
18	Clay	4·8	1·42	0·15	9·5	18·2	68	39
19	Clay	5·6	1·15	0·10	11·5	51·3	68	23
20	Clay	6·6	2·14	0·21	10·2	50·8	68	52
21	Silty clay loam	7·2	0·84	0·07	12·0	39·5	41	17
22	Silty loam	7·5	0·63	0·06	10·5	35·5	23	17
23	Silty loam	7·9	0·63	0·06	10·5	35·5	23	20
24	Silty clay	5·7	1·03	0·09	11·4	36·1	48	24
25	Silty clay loam	7·0	0·91	0·08	11·4	42·3	44	21
26	Silty clay	5·7	0·83	0·06	13·8	33·8	47	19
27	Silty clay loam	4·8	1·11	0·07	15·9	27·0	42	19
28	Silty clay loam	6·1	1·09	0·08	13·6	25·8	30	24
29	Clay	4·9	1·63	0·13	12·5	44·3	62	41
30	Silt loam	5·2	0·72	0·06	12·0	9·9	13	26
31	Silt loam	6·5	1·89	0·16	11·8	20·2	24	54
32	Clay loam	6·5	0·75	0·08	9·4	30·5	35	20
33	Sandy loam	4·7	0·65	0·06	10·8	8·6	15	22
34	Loam	5·0	0·65	0·06	10·8	7·0	12	41
35	Loam	4·9	0·77	0·07	11·0	8·6	19	23
36	Silty clay loam	5·3	1·36	0·11	12·4	30·5	32	44
37	Clay	5·3	1·30	0·11	11·8	33·5	51	41
38	Silty clay	6·5	1·50	0·13	11·5	34·3	42	28
39	Silty clay	5·3	2·50	0·25	10·0	40·9	50	169

[A] Ammonium nitrogen released under anaerobic incubation of soils at 30°C for 2 weeks.

clay content. It also becomes evident from this review that the relationships between ammonification of organic nitrogen and soil properties have not been clearly established, and this is reflected in a considerable degree of uncertainty with simple and rapid predictive tests for characterizing potentially mineralizable nitrogen.

Limited studies of the relationship between mineralizable nitrogen and soil properties indicate that mineralizable nitrogen is related to organic matter and total nitrogen (Lopez and Galvez 1958; Onikura *et al.* 1975), cation exchange capacity (CEC) and clay content (Onikura *et al.* 1975). It has also been recognized that liming of acid soils improves nitrogen availability to rice probably due to enhanced mineralization of soil nitrogen (Ponnamperuma 1958; Borthakur and Mazumdar 1968). But the effects of liming may also be attributed partly to alleviation of toxicities of nutrients such as iron, and improvement in the availability of other nutrients due to a rise in soil pH which affects rice growth. It is, however, difficult to establish clearly the effects of soil pH on mineralization of organic nitrogen from such studies. In a recent study of two acid sulfate soils (pH 3·4 and 3·7), Sahrawat (1980*b*) reported that ammonification of soil organic nitrogen was active in these soils. The aim of the work reported here was to study the relationships between mineralizable nitrogen and soil properties using 39 Philippine rice soils having a wide range in properties.

Materials and Methods

Soils

The soils used were surface (0–15 cm) samples collected shortly before the study from different rice growing parts of the Philippines. The soil samples were air dried and ground to pass through a 2-mm sieve before use. Table 1 shows that the soils used in the study differed markedly in pH (4.3–7.9), organic carbon (0·63–5.46%),
(7·9–15·9) and clay content (12–71%).

For soil analyses reported in Table 1, pH was measured (1:1 soil to water) by a glass electrode, organic carbon and total nitrogen were determined by the methods of Walkley and Black (1934) and Bremner (1965*a*) respectively. CEC and particle size analysis were done as described by Chapman (1965) and Day (1965) respectively.

Incubation Method

The incubation method used was adapted from that described by Waring and Bremner (1964). The major modification in the method was that, instead of directly distilling the incubated soil samples with MgO, they were first extracted with 2 N KCl and the filtered extracts of soils were used for determination of ammonium released, as suggested by Sahrawat and Ponnamperuma (1978).

Soil (10 g) was placed in a test tube (16 by 2 cm) containing about 15–20 ml of distilled water to give a standing water layer of 2–3 cm. The soil was slowly and carefully transferred to the test tube containing water to minimize trapping of air. The test tube was covered with aluminium foil and incubated at 30°C for 2 weeks in an anaerobic incubator.

After incubation, the soil samples were extracted with 2 N KCl, keeping the final soil to KCl solution ratio of 1 : 10. A 20-ml aliquot of the filtered extract was distilled with MgO to determine the ammonium nitrate released (Bremner 1965*b*). All the determinations were made at least in duplicate.

Results and Discussion

The amounts of NH_4^+ released during anaerobic incubation of the soils varied between 17 and 428 $\mu g\ g^{-1}$ soil (Table 1).

Table 2 shows that mineralizable nitrogen released was correlated highly significantly with both organic carbon ($r = 0 \cdot 91^{**}$) and total nitrogen ($r = 0 \cdot 94^{**}$). Mineralizable nitrogen was also correlated highly significantly but negatively with C/N ratio ($r = -0 \cdot 46^{**}$), but was not significantly correlated with pH, CEC or clay content. These results are in agreement with the observations made by Lopez and Galvez (1958), who reported that organic matter and total nitrogen were related with the mineralization of organic nitrogen under submerged conditions. Onikura *et al.* (1975) also reported that ammonium production in wetland soils was related to total nitrogen content.

Summary of the data on the distribution of mineralizable nitrogen in the 39 soils further brings out its association with organic carbon and total nitrogen (Table 3). While 24 soil samples having total nitrogen varying between 0·06 and 0·16% released less than 50 μg ammonium nitrogen/g soil, on the other hand four soil samples containing total nitrogen greater than 0·31% produced more than 200 μg ammonium nitrogen/g soil. Soil samples having total nitrogen contents varying between 0·16 and 0·26% produced ammonium nitrogen ranging from 50 to 200 μg/g soil. Since organic carbon and total nitrogen content are indexes of organic matter content, the highly significant simple correlations between mineralizable nitrogen and organic carbon content and total nitrogen content (Table 2) suggest that organic matter accounted for most of the variation in the mineralizable nitrogen in the soils studied. Organic carbon was very highly correlated with total nitrogen ($r = 0·99$**), which is reflected in very high significant correlations between mineralizable nitrogen and total nitrogen, and organic carbon.

Table 2. Correlations between mineralizable nitrogen and other soil properties ($n = 39$)

Soil property	Correlation coefficient (r)	Soil property	Correlation coefficient (r)
Total N	0·94**	CEC	0·30 n s
Organic C	0·91**	pH	−0·14 n s
C/N ratio	−0·46**	Clay	−0·05 n s

**$P = 0·01$; n.s , not significant

Table 3. Distribution of mineralizable nitrogen in 39 rice soils in relation to total nitrogen and organic carbon content

Mineralization N (μ/g dry soil)	No of samples	Associated soil properties Total N (%)	Organic C (%)
<50	24	0·06–0 16	0·63–1·15
50–100	7	0·16–0 21	1·48–2·14
100–200	4	0·16–0·26	1·97–2·50
>200	4	0·31–0·60	2·44–5·46

Mineralization of organic nitrogen occurs under a wide range of pH, and the results of the present study support this conclusion. As noted in the introduction, in an earlier communication I reported that though ammonification of soil nitrogen occurred in two acid sulfate soils (pH 3·4 and 3·7), both under aerobic and anaerobic conditions, nitrification was absent under aerobic conditions that stimulate nitrification (Sahrawat 1980*c*). Moraghan and Patrick (1974), who studied the release of ammonium in the Louisiana soil system at pH values of 5, 6 or 7 during anaerobic incubation, reported that the contents of ammonium nitrogen were initially reduced at pH 5 and 6, but the effect of pH was small by 30 days. But perhaps the differential salt contents in the soil resulting due to addition of NaOH and HCl to maintain different pH might have also affected the ammonification as suggested by these authors (Moraghan and Patrick 1974). These results indicate that ammonification is adapted in soils with a wide range in pH. The low pH conditions in wetland acid soils create conditions conducive for iron toxicity which limits rice growth, but once the iron concentration falls below toxic levels, these soils release enough ammonium to support a good crop of rice (Sahrawat 1980*a*).

Onikura *et al.* (1975) reported that mineralization of organic nitrogen under lowland paddy soil conditions was related positively to total nitrogen, CEC and clay content of soils. Observations made by Broadbent (1979) indicate that the relationship of mineralizable nitrogen with clay content in the study by Onikura *et al.* (1975) reflected the high organic matter content of the fine-textured soils. It thus appears that organic matter controlled ammonium production under lowland conditions in the soils studied by Onikura *et al.* because of association among clay, organic matter and CEC.

Stepwise multiple regression analyses of the mineralizable nitrogen (Min. N) with various combinations of soil properties showed that 88·3% mineralizable nitrogen was accounted for by total nitrogen alone by the following equation:

$$\text{Min. N} = -44{\cdot}4 + 792{\cdot}3(\text{Total N}).$$

While organic carbon alone accounted for 82·8% of the variability, a combination of organic carbon and total nitrogen accounted for 89·4% variability in the mineralizable nitrogen by the following equation:

$$\text{Min. N} = -29{\cdot}9 + 1336{\cdot}1(\text{Total N}) - 61{\cdot}0(\text{organic C}).$$

Most variability (R^2 = 91.8%) was accounted by the following regression equation, which was only slightly better than the variability accounted by total nitrogen alone:

$$\text{Min. N} = -68{\cdot}8 + 1969{\cdot}6(\text{Total N}) - 128{\cdot}8(\text{organic C}) + 9.9(\text{C/N}) - 9{\cdot}2(\text{pH}) + 0{\cdot}88(\text{CEC}) - 0{\cdot}75(\text{clay}).$$

A multiple regression analysis of CEC, pH and clay on mineralizable nitrogen (excluding total nitrogen and organic carbon) accounted only for 37.4% variability.

$$\text{Min. N} = 340{\cdot}2 + 7{\cdot}03(\text{CEC}) - 6{\cdot}34(\text{pH}) - 2{\cdot}8(\text{clay}).$$

It is, however, noteworthy that, though simple correlation analyses showed that pH, CEC and clay were not significantly correlated to mineralizable nitrogen (Table 2), multiple regression showed that pH, CEC and clay had significant effects on mineralizable nitrogen in different soils. However, both simple correlation as well as multiple regression analysis showed that total nitrogen and organic carbon (components of organic matter) accounted for the most variability in the mineralizable nitrogen in the 39 soils studied in the present study.

The results of this study suggest that organic matter content (measured by organic carbon and total nitrogen) is a good index for predicting the pool of potential mineralizable nitrogen in wetland rice soils.

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