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Potentially mineralizable nitrogen in West African lowland rice soils

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Abstract

Nitrogen (N) deficiency is a major constraint to rice production in West Africa. Little information is available on the N supplying capacity of soils used for wetland rice production in West Africa. Potentially mineralizable N, as a measure of N supplying capacity, was determined employing an anaerobic incubation test in 15 diverse soils from 5 major rice producing countries in the sub region. Mineralized N contents of the soils varied widely (21 to 166 mg kg^{-1} of soil) and the ammonium N released constituted 2 to 7% of the total N. Mineralized N was significantly correlated with pH, organic C, total N, clay and CEC but not with extractable iron and C/N ratio of the soils. Multiple regression analysis of mineralized N with soil characteristics showed that inclusion of C/N ratio and extractable iron improved the prediction of mineralized N. The results underscore the importance of organic matter (organic C and total N) in controlling potentially mineralizable N in wetland rice soils. The main soil factors affecting N mineralization, identified by principal components analysis, accounted for over 97% variation in potentially mineralizable N in the soils.

Keywords: N mineralization capacity; waterlogged incubation; principal components analysis; soil characteristics; wetland soils

1. Introduction

Mineralizable N pool in wetland rice soils plays a dominant role in the N nutrition of rice even in fertilized paddies (Sahrawat, 1983a). Several studies have shown that a crop of wetland rice obtains half to two-thirds of its N requirement from the native soil N

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pool through mineralization (Broadbent, 1978; IAEA, 1978; Ando et al., 1992; Manguiat et al., 1994). A biological index of N supplying capacity based on the release of ammonium under waterlogged conditions in a laboratory incubation test has been reported to be useful in reflecting a soil's N supplying capacity provided the temperature is in the optimum range (Ponnamperuma, 1972; Sahrawat, 1983a).

There is lack of data on the size of pools of potentially mineralizable N in West African wetland rice soils despite its paramount importance in meeting the N requirement of rice. It is known that soils differ greatly in their ability to supply N to wetland rice (Sahrawat, 1983a). A knowledge about soils' mineralizable N pool size should help in judicious use of N fertilizer which is becoming an increasingly costly input in the subregion.

The aim of the work reported in this paper was to determine potentially mineralizable N in wetland rice soils from five major rice producing countries in West Africa. Since iron toxicity is a major nutrient disorder in wetlands of West Africa, a number of soils included in the study were known to cause varying degrees of iron toxicity stress to rice plants (Sahrawat et al., 1996).

2. Materials and methods

2.1. Soils

The soils used in the study were surface (0–15 cm) samples collected from 15 different rice growing locations in five countries of West Africa. The soil samples were air dried and ground to pass through a 2 mm sieve before analysis.

Background information about the location, classification (FAO, 1988) and some important physical and chemical characteristics of the soils are summarized in Table 1. The soils had a wide range in pH (4.3–7.7), organic C (7.4–46.0 g kg^{-1}), total N (500–3300 mg kg^{-1}), CEC (0.8–30 cmol kg^{-1}), clay (45–510 g kg^{-1}) and extractable Fe (24–486 mg kg^{-1}).

For the soil analyses reported in Tables 1 and 2, pH was measured by a glass electrode using a soil to water ratio of 1:2.5. Particle size analysis was made using the pipette method (Gee and Bauder, 1986). Organic C was determined using the Walkley and Black method (Nelson and Sommers, 1982). Total N, NH_4^+–N and NO_3–N determinations in soil samples were made using the methods described by Bremner (1965a,b). Cation exchange capacity (CEC) of the samples was determined as described by Chapman (1965) and the DTPA extractable Fe was measured by the method described by Lindsay and Norvell (1978).

2.2. Incubation method

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

Table 1
Some important physical and chemical properties of the soils used in the study

Soil No.	Location	Classification	Texture	pH	Clay ($g\,kg^{-1}$)	Sand ($g\,kg^{-1}$)	CEC ($cmol\,kg^{-1}$)
1	Edozhighi, Nigeria (96°6′N, 5°59′E)	Dystric Gleysol	Silt loam	4.29	163	333	5.60
2	Ikot–Obong, Nigeria (5°01′N, 7°56′E)	Dystric Gleysol	Loamy sand	5.20	53	815	1.40
3	Ifaki–Ekiti, Nigeria (7°14′N5°8′E)	Eutric Gleysol	Clay	7.69	510	38	30.0
4	Itoikin (6°36′N, 3°32′E)	Dystric Gleysol	Silt loam	4.92	215	419	6.50
5	Fumesua, Ghana (6°54′N, 1°35′W)	Gleyic Arenosol	Loamy sand	5.39	45	813	0.80
6	Kikam, Ghana (4°53′N, 2°14′W)	Dystric Gleysol	Clay loam	5.14	350	160	17.0
7	Kou valley, Burkina Faso (11°11′N, 4°18′W)	Dystric Gleysol	Silt loam	6.05	262	182	11.1
8	Karfiguela, Burkina Faso (10°36′N, 4°45′W)	Dystric Gleysol	Silt loam	5.56	308	165	14.50
9	Korhogo, Ivory Coast (9°22′N, 5°31′W)	Dystric Gleysol	Silt loam	5.44	275	350	12.5
10	Kilissi, Rep. of Guinea (10°3′N, 12°49′W)	Dystric Gleysol	Sandy clay loam	5.56	220	562	12.7
11	Farannah, Rep of Guinea (10°01′N, 10°47′W)	Dystric Gleysol	Silty clay loam	5.54	330	150	16.8
12	Kissidougou, Rep of Guinea (9°48′N10°8′W)	Dystric Gleysol	Silt	5.29	60	691	8.80
13	Bouake, Ivory Coast (7°42′N, 5°00′W)	Dystric Gleysol	Clay loam	6.06	318	241	8.70
14	Bouake Ivory Coast (7°42′N, 5°00′W)	Eutric Leptosol	Sandy loam	6.29	88	686	2.02
15	Man, Ivory Coast (7°31′N, 7°37′W)	Ferric Acrisol	Loam	5.00	298	408	8.55

Table 2
Organic carbon, DTPA extractable Fe, total and mineralizable N contents of 15 West African rice soils

Soil No.	Org. C ($g kg^{-1}$)	Total N ($mg kg^{-1}$)	Mineralizable N ($mg kg^{-1}$)	% Mineralizable N of total N	Fe (DTPA) ($mg kg^{-1}$)
1	7.8	750	48	6.4	339
2	11.4	600	31	5.2	63
3	46.0	3300	166	5.0	178
4	9.8	900	50	5.5	178
5	8.8	700	39	5.6	112
6	35.2	2700	55	2.0	264
7	13.4	1100	77	7.0	295
8	9.2	800	55	6.9	340
9	20.0	1500	94	6.3	486
10	25.2	1800	86	5.3	485
11	23.2	1500	65	4.3	415
12	19.6	1200	65	5.4	236
13	23.0	1800	86	4.8	284
14	7.4	500	21	4.4	24
15	15.6	1200	36	3.1	166
Mean			65.8		
LSD ($p < 0.05$)			6.5		
CV (%)			5.5		

Portions of soil (10 g) were placed in test tubes (15 × 2.4 cm) containing 20 ml of distilled water to give a standing water layer of 2–3 cm. The soil samples were slowly and carefully transferred to the test tubes containing water to minimize trapping of air. The test tubes were covered with aluminium foil and incubated at 30°C for 2 weeks in an incubator. After incubation, the soil samples were extracted with 2M KCl, keeping the final soil to KCl solution ratio 1:5. A 20 ml aliquot of the filtered extract was distilled with MgO to determine the ammonium N released (Bremner, 1965b).

All determinations were made in triplicate and the mineralized N values reported are the net amounts of ammonium N released (the difference between the amounts of ammonium released after incubation and that initially present), expressed on dry soil weight basis, during incubation.

To identify the soil factors controlling potentially mineralizable N in the soils studied, the data matrix of the 15 soils and 19 soil characteristics (physical and chemical) was processed by principal components analysis. The soil chemical and physical characteristics included organic C, CEC, DTPA Fe, C/N ratio, total N, pH water, pH KCl, Clay, sand, silt, exchangeable K, Mg, Ca, Na, total P, Bray 1 P, Olsen P, extractable Zn and Mn. Only salient results from this analysis that aid in interpretation of the results are presented. The data were statistically analysed using the program of SAS (1987).

3. Results and discussion

The amounts of NH_4^+-N released during the anaerobic incubation of the soil samples varied from 21 to 166 mg kg^{-1}, indicating a wide range in their ability to release mineral N under flooded conditions and hence N supplying capacity to wetland rice (Table 2). The mineralized N constituted 2–7% of total N content of the soils. Sahrawat (1983a) reported that total N recovered as ammonium during anaerobic incubation of a large number of Philippine wetland soils varied from 1.8 to 26.0%. Our results in this study suggest that somewhat lower proportion of the total N was recovered as mineralized N in the West African soils.

Mineral N released in the soils was significantly ($p < 0.01$) positively correlated with clay (Fig. 1), organic C (Fig. 2), total N (Fig. 3), CEC (Fig. 4) and pH (Fig. 5) but was not significantly ($p < 0.05$) correlated with extractable iron and C/N ratio. Soil pH was positively correlated with the mineralized N, indicating that soils with low pH will release less mineral N than soils with higher pH (Fig. 5).

Stepwise multiple regression analyses of the mineralized N with various combinations of soil characteristics showed that 78% ($R^2 = 0.78$) of the variabilty in mineralized N was accounted for by the following equation:

$$\text{mineralized N} = -148.3 + 0.11\,\text{Fe} + 0.54\,\text{clay} + 31.0\,\text{pH} \qquad (1)$$

Most variability ($R^2 = 87\%$) in the mineralized N was accounted for by the following regression equation:

$$\text{mineralized N} = -14.33 + 67.68\,\text{organic C} + 0.8\,\text{Fe} + 24.64\,\text{pH} - 0.15\,\text{clay} - 7.61\,\text{C/N} - 0.07\,\text{total N} \qquad (2)$$

These results are in accord with those reported by Onikura et al. (1975) who found that the mineralization of organic N under lowland paddy conditions was correlated positively to total N, CEC and clay content of the soils. It has been observed that fine

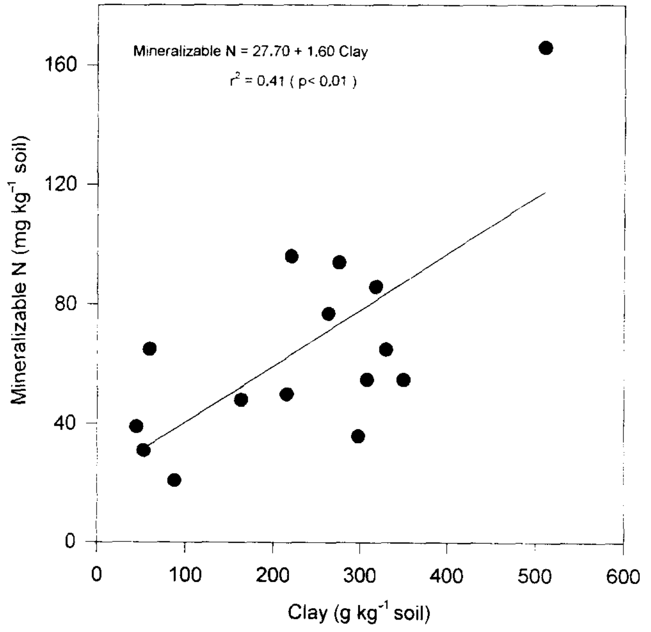

Fig. 1. Relationship between mineralized N and clay content in 15 West African wetland rice soils.

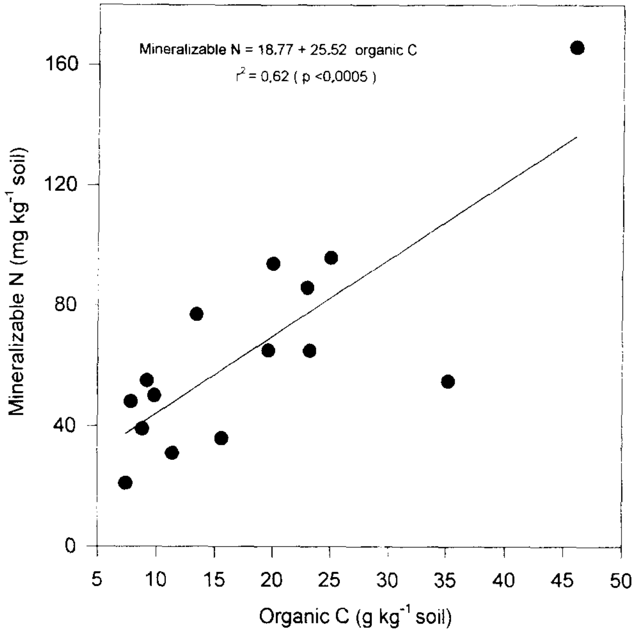

Fig. 2. Relationship between mineralized N and organic C content in 15 West African wetland rice soils

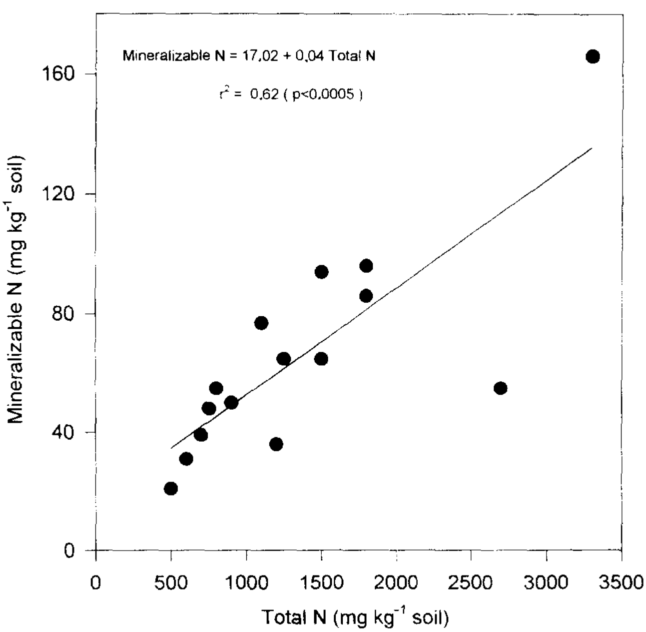

Fig. 3. Relationship between mineralized N and total N content in 15 West African wetland rice soils.

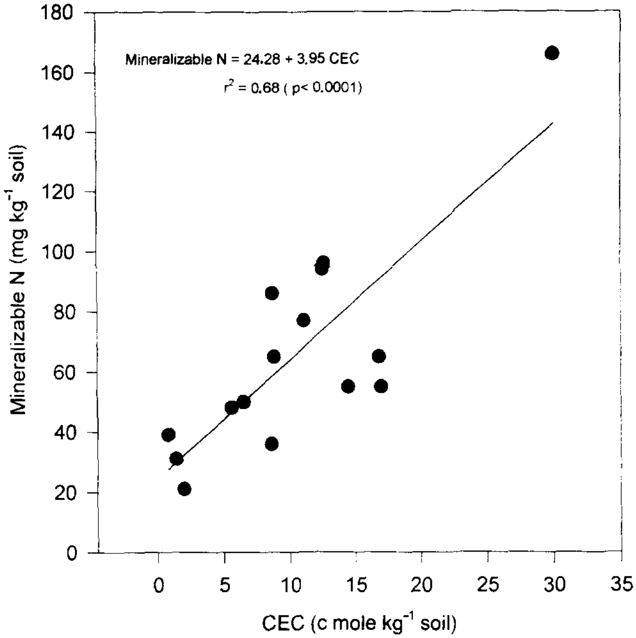

Fig. 4. Relationship between mineralized N and CEC in 15 West African wetland rice soils.

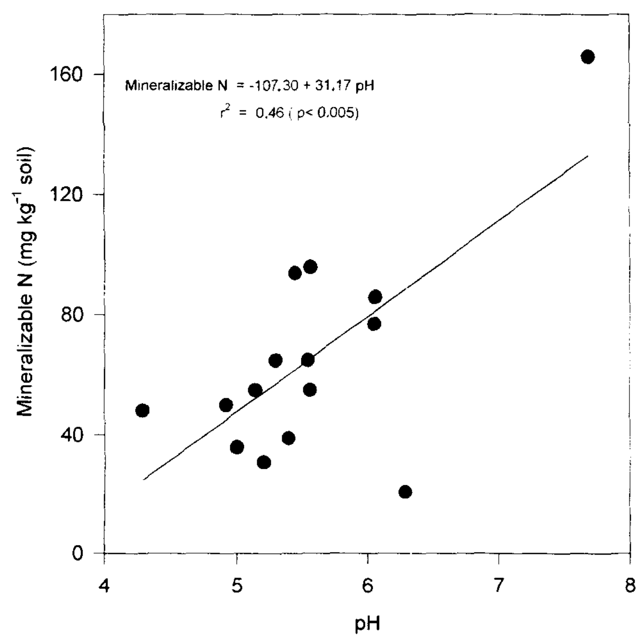

Fig. 5. Relationship between mineralized N and pH in 15 West African wetland rice soils.

textured soils generally have high organic matter content and may thus explain close relationship between organic matter and clay content in soils (Broadbent, 1979; Sahrawat, 1983b). Our results showed that organic C, total N, clay and CEC were not only correlated with the mineralized N (Figs. 1–5) they were also significantly correlated among themselves (Table 3).

In a study of 39 diverse Philippine wetland rice soils, Sahrawat (1983b) found that mineralization of soil organic N under waterlogged incubation was highly positively correlated with organic C and total N, and was negatively correlated with the C/N ratio of soils. Other soil characteristics, such as pH, clay and CEC were not significantly correlated with ammonium production. Multiple regression analyses showed that organic matter (as measured by organic C and total N) accounted for most of the variation in mineralizable N. But perhaps more importantly, it was noted that although simple correlation analyses showed that pH, clay and CEC were not significantly correlated to mineralized N, multiple regression showed that pH, clay and CEC had significant effects on the release of mineral N in the soils.

In this study the principal component analysis including 19 soil characteristics, one index of potentially mineralizable N, and all 15 soils showed that the first principal component (PC 1) accounted for 96.6% (soil 14) to 99.8% (soil 4) of the variation in potentially mineralizable N contents of the soils. The most important soil parameters controlling the mineralizable N in the soils were: organic C, CEC, clay, silt, pH, extracable P, Mn and Zn. These results reinforce the conclusions reached with the simple and multiple regression analysis of the data. Gonzalez-Prieto et al. (1992) used principal components analysis to identify main soil factors affecting N mineralization capacity (aerobic incubation for 15 days at 28°C and 75% of field capacity soil water content) of 41 temperate humid-zone soils of NW Spain. It was found that the chief factors responsible for poor N mineralization were exchangeable H and the abundance of Al and Fe gels. Accumulation of organic matter, which opposes N mineralization, was affected by the nature of parent material on which the soil was developed. The second source of variation in N mineralization was caused by the composition of the exchange complex, which was related to soil usage (under natural vegetation or pasture). The third factor causing heterogeneity in N mineralization was texture of the soils. These results illustrate the use of principal components analysis in the identification of main soil factors that affect the dynamics of organic N in soils.

Our results, in general, are in accord with those reported by Sahrawat (1983b) for the Philippine wetland rice soils. They suggest that a reasonable prediction of potentially mineralizable N in the selected West African wetland rice soils for the purposes of

Table 3
Matrix of correlation coefficients (r) between organic carbon, CEC, clay and total nitrogen of 15 West African rice soils (probability levels in parentheses)

Soil property	Org. C	CEC	Clay
Org. C	–	–	–
CEC	0.85 (0.0001)	–	–
Clay	0.69 (0.0005)	0.84 (0.0001)	–
Total N	0.98 (0.0001)	0.86 (0.0001)	0.75 (0.001)

wetland rice culture can be made from organic matter content of the soils. It is realized that the soil tests for N do not always provide reliable estmates of crop yields. This concern stems from a lack of association between potentially mineralizable N and crop yields and fertilizer recommendations. There are several factors that affect assessment of N availabilty to crops (Sahrawat, 1983a). Because soil mineral N status and the soil tests for N are greatly affected by soil water interactions in the field. The same interactions also greatly affect the amount of N eventually made available to the crop. However, if the soil water is controlled, through water management in rice paddies, soil tests can provide useful guidelines for judicious use of chemical or organic fertilizers (Sahrawat, 1983a). Certainly, soils differ considerably in their capacities to supply N and hence they would need different levels of applied N to achieve a target yield. Soil N tests, such as those based on waterlogged incubation of soils, could be useful in assessing the N supplying capacity of soils under different management and may lead to judicious and efficient use of chemical fertilizer.

However, it must be pointed that the real value of assessing the size of potentially mineralizable N in soils should be in delineating soils deficient in N supply from those "not so deficient" in N supply, and the N fertilization of crops based such information would eventually lead to judicious and efficient use of costly, chemical ferilizer inputs. Tentative guidelines on the N fertilization of lowland rice in the Philippines and India provide useful examples as to how soil N tests can be used for fertilization recommendations (Sahrawat, 1983a). For example, it was found that the lowland rice soils having potentially mineralizable N in the range of 100–150 mg/kg of soil gave rice yields varying from 3 to 4 t/ha, without application of N. On the other hand soils with potentially mineralizable N less than 50 mg/kg required both basal and top dressing of N to achieve the targetted yield levels. Soils in this group would be classified as deficient in N. Soils with N supplying capacity ranging from 50 to 100 mg/kg would perhaps require less basal N and main N application should be top dressed.

The West African rice soils in our study can be classified according to the guidelines provided by Sahrawat (1983a). Accordingly, five soils (soil Nos. 1, 2, 5, 14 and 15) out of the 15 included in our study contain less than 50 mg/kg of mineralizable N and they would classify as deficient in N supply for lowland rice. Nine soils (soil Nos. 4, 6 to 13) contain mineralizable N ranging from 50 to 100 mg/kg of soil and would classify as moderate in N supply (hence not so deficient). There was only one soil (soil No. 3) that contained potentially mineralizable N varying from 100–150 mg/kg of soil and may be classified as optimum in N supply to achieve rice grain yields of 3 to 4 t/ha. However, supply of other nutrients such as P, K and Zn is equally important in these soils. In iron toxic soils (soil no. 1 to 12) the requirement of lowland rice crop for nutrients such as P, K and Zn is considerably increased because of high amounts of iron in soil solution and this needs to be considered (Sahrawat et al., 1996).

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