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Predicting Nitrogen Availability to Rice: II. Assessing Available Nitrogen in Silt Loams With Different Previous Year Crop History[1]

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ABSTRACT

Soil test methods that measure NH_4^+-N in silt loams before and after incubation under waterlogged conditions were evaluated as predictors of N availability to 'Nato' rice (*Oriza sativa* L.) grown in the greenhouse. Eighteen soils for each of five previous year crop histories were utilized. All soils were from crop rotations containing rice.

Coefficients of determination (r^2) for the regression of N uptake by rice on NH_4^+-N after 6 days incubation of soil from the different crop histories increased in the order of cotton (*Gossypium hirsutum* L.) < rice < lespedeza (*Lespedeza striata* Thumb.) < soybean (*Glycine max* L.) < reservoir (irrigation water storage or fish production), and ranged from .12 to .77. Exchangeable Ca was inversely related to N uptake and accounted for significant percentages of variation in uptake on all soils except those from reservoirs. Exchangeable Ca was not related to NH_4^+-N production during incubation. For all previous year crop histories NH_4^+-N in soil after 6 days incubation was a better single predictor of N uptake by rice than soil organic matter values.

Initial NH_4^+-N content of reservoir soils was about 5 times greater than in soils of other crop histories. The amount in these silt loam soils from reservoirs (55 kg N/ha) was about half that found in previous studies for reservoir soils of clay texture. Multiple regression analyses indicated that including initial NH_4^+-N together with NH_4^+-N production during incubation improved the prediction of N uptake over NH_4^+-N production values alone. Including exchangeable Ca together with initial NH_4^+-N and NH_4^+-N production values improved the prediction on all soils except those from reservoirs.

Additional Key Words for Indexing: soil organic matter, ammonium.

Available N in soil after incubation under waterlogged conditions was a better predictor of N availability to unfertilized rice in the greenhouse than methods measuring soil organic matter or total N (5). Ninety-one percent of the variation in grain yield from 19 clay soils (some of which came from reservoirs) could be linearly accounted for by soluble plus extractable NH_4^+-N in soil after 6 days incubation. Only 41% of the variation in yield was accounted for by soil organic matter estimates.

Although available N methods provided good indexes for N availability on clay soils, soluble plus extractable NH_4^+-N after incubation under waterlogged conditions accounted for only 18 % of the yield variation on 42 silt loam soils. The poor correlations on silt loams as contrasted with clay or reservoir soils may have been due to (i) a narrow range of N contents, (ii) organic matter that was relatively more resistant to decomposition in the silt loams, and (iii) the influence of Ca or Ca-salts on N uptake.

The generally lower correlations for silt loams detracted markedly from the usefulness of the incubation method to assess N availability in rice soils even though a higher percentage of fertilization related problems (lodging, delayed maturity, and disease incidence) generally occur on clay and reservoir soils. Approximately two-thirds of the rice acreage of Arkansas is seeded on silt loam soils each year. On these soils rice is most commonly grown in rotation with oats (*Avena sativa* L.) and soybeans (*Glycine max* L.) although other crops such as lespedeza (*Lespedeza striata* Thumb.) cotton (*Gossypium hirsutum* L.) and fish (reservoirs) may appear in the rotation. Rice may also be grown two or more years in succession.

In the previous study (5) most all silt loam samples came from fields cropped to soybeans the preceding year. The present study was undertaken to evaluate incubation methods for assessing availability of N to rice in silt loam soils with different cropping histories. In view of the recently available methods for routinely measuring initial NH_4^+-N or NH_4^+-N production in soil, (1, 2, 7) the steam distillation procedure of Waring and Bremner (7) was modified and evaluated for assessing soil N availability to rice.

EXPERIMENTAL METHODS

Source of Soils

Bulk soil samples taken from the surface horizon in 90 different fields were air dried for use in greenhouse and laboratory analyses. All soils were loessial terrace soils; the majority were classified as Crowley silt loams, while the remaining soils were classified as silt loams in the Calhoun, Olivier or Richland series. The 90 samples were grouped into 5 previous year crop history categories each having 18 soils. The previous year crops were cotton, rice soybeans, reservoir (irrigation water storage or fish production), and lespedeza. Rice had been included in the crop rotation on all soils sampled. When possible, fields representing all five cropping histories were sampled on the same farm. Mean values and ranges for soil pH, P (Bray no. 1), exchangeable K and Ca for each crop category at sampling time are shown in Table 1.

Procedures in Greenhouse

Rice (*Oriza sativa* L.) was grown using procedures described previously (5). The variety (cultivar) used was 'Nato'. Yield of dry matter and N was obtained on each soil and previous year crop history wherein N was not added to the greenhouse cultures.

Grain weight was not determined as most florets failed to set seed. Flowering occurred when maximum greenhouse temperatures were as great as 42C. Therefore the straw and the immature panicle were harvested at the soft dough stage. Weight of plant material was determined after drying in the oven at 70C for 48 hours. Total N in plant materials was determined by digestion and Nesslerization as outlined in work by Walker and Pesek (6).

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Table 1—Means and ranges for pH, P, exchangeable K and Ca for soils of each crop category at sampling time

Previous year crop	Chemical property*			
	pH	P(kg/ha)	Exch. K(kg/ha)	Exch. Ca(kg/ha)
Cotton	6.33(5.3–7.6)	41(11–109)	188(78–403)	1546(785–3026)
Rice	6.26(5.1–7.5)	27(8–69)	170(56–426)	1446(672–2130)
Soybeans	6.26(5.0–7.9)	33(9–171)	169(67–628)	1606(560–3699)
Reservoir	6.06(5.2–7.5)	36(5–92)	142(78–213)	1527(560–2466)
Lespedeza	6.09(5.0–7.5)	17(4– 35)	141(67–269)	1446(448–2242)

* Values out of brackets are means; values in brackets are ranges.

LABORATORY MEASUREMENTS

Ammonium and NO_3^--N present in the soil initially as well as that extracted after 6 days incubation of soil under waterlogged conditions was determined in duplicate by methods 4, 5, and 6 as described previously (5). Ammonium production in soil was calculated by subtracting initial NH_4^+-N values from NH_4^+-N obtained after incubation for 6 days.

In addition,[3] NH_4^+-N was determined in duplicate on each soil after incubation under waterlogged conditions. The procedure of Waring and Bremner (7) was used but modified in the following manner. The incubation temperature was increased from 35 to 40C, time of incubation was shortened from 14 to 6 days, and NH_4^+-N was not determined prior to incubation. These modifications were made because previous data showed (i) soluble plus extractable NH_4^+-N from incubation periods $\leq$ 12 days had better predictive value than for longer periods, (ii) initial NH_4^+-N plus NH_4^+-N produced during incubation provided a better index of N availability to rice than NH_4^+-N production alone, and (iii) temperature in the range of 25 to 45C had little effect on the relation of N availability to plant growth even though NH_4^+-N production increased markedly with increasing temperature. A temperature of 40C was used to increase measureable amounts of NH_4^+-N from relatively small samples of soil (5 g).

Values by the modified procedure reflect the NH_4^+-N present after incubation, which was composed of (i) NH_4^+-N released from organic form during incubation, and (ii) that portion of NH_4^+-N present in soil prior to incubation, which remained in the soil in the NH_4^+ form during incubation.

Organic matter was determined by wet digestion[4] (modified Walkley-Black) and subsequent visual comparison of the sample digest with known standards.

RESULTS AND DISCUSSION

Soil and Plant Characteristics

Initial NH_4^+-N in reservoir soils was about five times greater than that in soils of other crop history (Table 2). Where cotton was the previous crop, initial NH_4^+-N was the least. Although soils from reservoirs contained more NH_4^+-N initially than other soils, during incubation they released no more NH_4^+-N than soils from lespedeza or rice fields. There were no statistically significant differences between soils of different previous history with respect to initial NO_3^--N or percent organic matter.

[3] NH_4^+-N by the modified steam distillation procedure of Waring and Bremner was closely related (Fig. 3) to NH_4^+-N as determined by distillation after extraction with acidified NaCl (r^2 = .84**). These data are of interest since the steam distillation procedure is rapid enough for routine testing of soils for initial NH_4^+-N content or NH_4^+-N production during incubation.

[4] Appreciation is expressed to the Eastern Arkansas Soil Testing and Research Laboratory, Marianna, Ark. for making these determinations.

Table 2—Mean values for plant and soil characteristics for each of 5 previous crop histories

Previous crop history	Soil N characteristics					Plant growth characteristics	
	Initial NH_4^+	Initial NO_3^-	6-day NH_4^+-N production	Soluble + Extractable NH_4^+-N 6 days	Organic matter	Dry weight	N uptake
	mg N/100 g	mg N/100 g	mg N/100 g	mg N/100 g	%	g/can	mg/can
Cotton	0.44 a*†	0.62 a	2.58 a	3.02 a	2.94 a	9.33 a	75.9 a
Rice	.48 a	.58 a	4.18 bc	4.66 bc	3.42 a	11.14 ab	96.7 ab
Soybeans	.48 a	.74 a	3.84 b	4.24 b	3.44 a	11.95 bc	101.2 bc
Reservoir	2.28 b	.72 a	5.24 c	7.52 d	3.08 a	14.15 cd	117.2 c
Lespedeza	.56 a	.54 a	5.12 c	5.68 c	3.38 a	15.02 d	125.2 c
Average	.84	.64	4.20	5.02	3.26	12.32	103.2

* Means followed by the same letter or letters within each column are not significantly different at the 5 percent level by Duncan's range test.
† Range of initial NH_4^+-N in soil was 4 to 26, 6 to 18, 1 to 18, 6 to 165, and5 to 33 kg/ha for cotton, rice, soybeans, reservoir, and lespedeza previous year crop histories, respectively.

Table 3—Linear regression estimates and coefficients of determination (r^2) for the relation of soil test values (X) and weight of N taken up (Y) (mg/can) by Nato rice grown in the greenhouse on silt loam soils of different previous crop history

Previous Crop history	Regression estimates for the indicated soil test method														
	% organic matter			Initial $NO_3^- - N$†			Initial $NH_4^+ - N$†			6 day soluble + extractable $NH_4^+ - N$†			Exchangeable Ca‡		
	Intercept	Slope	r^2	Intercept	Slope	r^2	Intercept	Slope	r^2	Intercept	Slope	r^2	Intercept	Slope	r^2
Cotton	46.6	20.7	.08	94.4	−27.7	.18	68.4	19.6	.03	45.7	10.5	.12	112.7	−11.1	.31*
Rice	30.7	39.1	.22*	109.1	−20.2	.07	91.3	12.8	<.01	47.7	10.7	.34*	103.3	−2.0	<.01
Soybeans	7.2	56.5	.27*	96.1	11.0	.01	68.7	87.4	.15	31.2	17.2	.53**	149.0	−13.4	.28*
Reservoir	21.5	64.0	.38**	99.7	28.6	.14	88.0	14.2	.28*	28.2	12.3	.77**	94.6	8.1	.09
Lespedeza	157.3	−18.4	.02	115.7	19.6	.04	98.5	50.4	.18	18.0	19.1	.38**	173.2	−15.7	.38**
All soils	13.3	56.3	.16**	101.6	5.4	<.01	93.5	14.0	.14**	45.4	11.9	.52**	127.5	−7.2	.06**

* and ** significant at .05 and .01 probability level, respectively.
† X expressed as mg N/100 g soil.
‡ X expressed as meq Ca/100 g soil.

Table 4—Linear regression estimates and coefficients of determination for silt loam soils calculated from regressions using 6-day NH_4^+-N production (X_1), initial NH_4^+-N (X_2), organic matter (X_3), initial NO_3^--N (X_4), and exchangeable Ca (X_5) as independent variables and N uptake (mg/can) by rice as dependent variable†

Previous crop history	Equation 1			Equation 2				Equation 3					Equation 4				
	b_0	b_1	r^2	b_0	b_1	b_2	R^2	b_0	b_1	b_2	b_4	R^2	b_0	b_1	b_2	b_5	R^2
Cotton	67.2	4.7	.04	17.8	14.1	66.4	.21	53.1	0.7	74.8*	−37.4*	.40**	56.0	15.7*	57.2	−11.8**	.54**
Rice	59.3	10.3	.32*	43.9	10.6*	29.4	.34*	40.8	10.9**	73.8	−32.6	.48**	66.7	12.5**	38.5	−11.9	.44**
Soybeans	45.3	17.2	.47**	23.5	16.0**	63.6	.55**	4.0	16.7**	60.7	24.6	.58**	72.1	15.2**	31.6	− 9.8*	.67**
Reservoir	101.3	6.4	.15	27.7	12.9**	23.8**	.78**	27.4	14.6**	25.7**	−12.4	.79**	32.5	13.8**	25.0	− 3.2	.79**
Lespedeza	59.3	14.6	.18	20.4	16.3*	56.3*	.41**	21.5	16.6*	67.5*	−15.7	.42**	83.5	11.3	41.4	−10.6*	.55**
All soils	69.3	10.6	.26**	41.6	13.8**	20.8**	.54**	44.8	13.9**	21.4**	− 6.7	.54**	67.3	14.3**	21.4**	− 9.0**	.63**

* and ** significant at the .05 and .01 probability levels respectively.

† Regression equations (1 through 4) are of the form $y = b_0 + b_1X_1$, $y = b_0 + b_1X_1 + b_2X_2$, $y = b_0 + b_1X_1 + b_2X_2 + b_4X_4$, and $y = b_0 + b_1x_1 + b_2X_2 + b_5X_5$, respectively. Dependent variables X_1, X_2, and X_4 expressed as mg N/100 g soil; X_5 expressed as meq Ca/100 g soil.

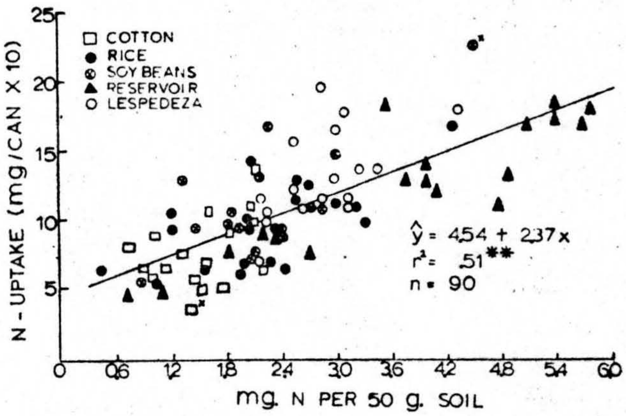

Fig. 1—The relation of N uptake by rice grown in the greenhouse and NH_4^+-N in soil after 6 days incubation under waterlogged conditions.

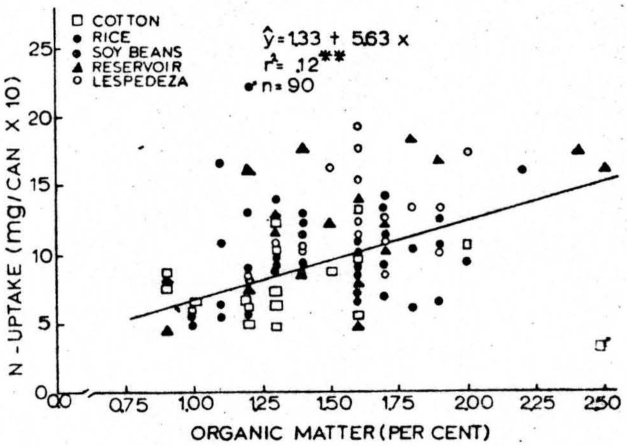

Fig. 2—The relation of N uptake by rice grown in the greenhouse and soil organic matter (%) content. Excluding the two dots ($\otimes^x$ and $\square^x$) marked with an x from the regression resulted in a value for r^2 of .30.

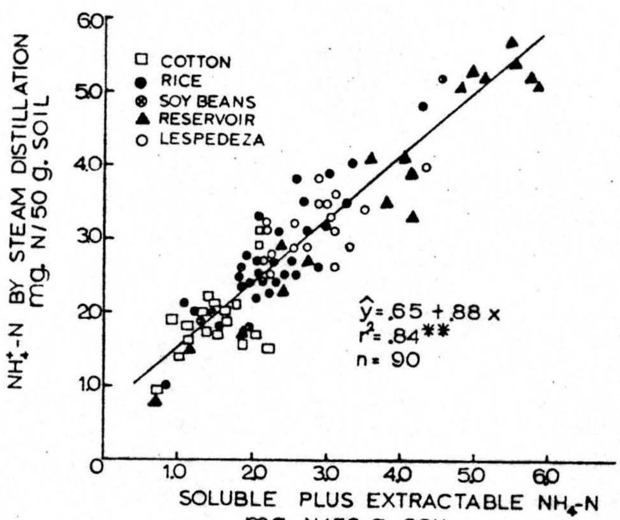

Fig. 3—The relation of NH_4^+-N in soil as determined by the modified Waring and Bremner steam distillation procedure and NH_4^+-N determined by acidified NaCl extraction and subsequent distillation.

The average initial NH_4^+-N content of these reservoir soils of silt loam texture (55 kg N/ha) was about half that accumulated in reservoir soils of clay texture flooded for about the same lengths of time (4). The source(s) of this NH_4^+-N that accumulated during submergence is not known with certainty. It is interesting that the amounts in silt loam soils are sufficient to make a sizeable contribution to the N needs of the rice crop while the amounts in clay soils often are excessive and cause lodging. Since clay soils generally contain more N than silt loams and NH_4^+-N production under flooded conditions was significantly related (1% level) to total N, (5), it is reasonable to assume that much of the accumulated NH_4^+-N was rel ased from native soil organic matter during submergence. However, it is known that certain blue green algae fix atmospheric N and these may have been a source of N in reservoirs (3).

The dry weight of plant material and N uptake by rice was greatest on soils from reservoirs and lespedeza fields and least on soils from cotton fields (Table 2). Nitrogen uptake from soils of cotton fields was only 60% of that from lespedeza fields. The percentage of N in plant materials did not differ statistically among the cropping histories.

Relations Between Plant Growth and Soil Measurements

The linear relation of soil test values (X) and N uptake by rice (Y) revealed little variation in slopes of regression lines among crop histories for tests of initial NO_3^--N, 6-day NH_4^+-N production, 6-day soluble + extractable NH_4^+-N, or exchangeable Ca (Table 3; Equation 1, Table 4). The variation in slopes among crop histories was greater when initial NH_4^+-N and the organic matter test were involved. However, statistical analyses revealed no significant differences (5% level) among slopes within any soil test.

Since the slopes did not differ among crop histories within either soil test, data for all crop histories were combined into a single regression of N uptake on soil test values (Fig. 1 and 2) for the organic matter and 6-day NH_4^+-N tests. Data of Fig. 1 indicates some curvilinearity but the coefficient for the quadratic term was not significantly different from zero.

Ammonium N values after 6 days incubation for reservoir soils generally were higher but below the regression line (Fig. 1). This indicates that plants were less responsive to the pool of 6-day NH_4^+-N in reservoir soils than to the same pool in other cropping histories. The range of NH_4^+-N values in reservoir soils was 0.42 to 5.8 mg N/50 g soil. The range for the other cropping histories was much narrower with the range for cotton soils being only 0.75 to 2.17 mg N/50 g soil.

Data shown in Fig. 2 reveal two extreme values for organic matter content and N uptake by rice. Eliminating these values from the regression increased the correlation coefficient (r^2) from .12 to .30. Noting these same two points in Fig. 1 reveals that one soil had a relatively high organic matter content (2.5%) but low NH_4^+-N content (1.4 mg N/50 g soil) after incubation; N uptake on this soil was small (3.3 mg N/can). The other extreme soil (Fig. 2) contained 1.2% organic matter, 4.5 mg N/50 g of soil after incubation and 22.2 mg N/can was taken up by rice plants. Nitrogen uptake on these two soils was much more closely related to NH_4^+-N after 6 days incubation than to organic matter.

Coefficients of determination (r^2) were greater for regressions involving NH_4^+-N after 6 days incubation in soil than for the other tests of N (Table 3). They were also greater for reservoir soils than for other crop histories within soil tests. This may be due in part to the greater range of soil test values found in reservoir soils than other categories in this particular study. Seventy-seven % of the variation in N uptake from reservoir soils could be explained by regression on 6-day NH_4^+-N values whereas only 12% of the variation in N uptake from cotton soils could be explained by regression on 6-day NH_4^+-N values. However, regression estimates and coefficients shown in Tables 3 and 4 reveal that exchangeable Ca may have influenced the uptake of nitrogen by rice in soils with crop histories other than reservoir. Exchangeable Ca was significantly related to N uptake for the cotton, soybean, and lespedeza previous crop histories and accounted for 28 to 38% of the variation in N uptake from these soils.

Multiple regression analyses were made using 6-day NH_4^+-N production (X_1), initial NH_4^+-N prior to incubation (X_2), organic matter (X_3), initial NO_3^--N (X_4), and exchangeable Ca (X_5) as independent variables and N uptake by rice (Y) as dependent variable for each previous year crop history category and for all soils combined (Table 4). Including initial NH_4^+-N together with 6-day NH_4^+-N production improved the prediction in most crop history categories and in regressions involving all soils, over that obtained by a simple regression of 6-day NH_4^+-N production values alone on N uptake. The effect of initial NH_4^+-N was greatest for the reservoir and lespedeza categories and least for the rice, cotton, and soybean categories. In contrast, the effect of initial NO_3^--N was greater for the rice, cotton, and soybean than for reservoir and lespedeza categories when initial NO_3^--N was included together with 6-day NH_4^+-N production and initial NH_4^+-N in regressions on N uptake. Including exchangeable Ca together with initial NH_4^+-N and NH_4^+-N production improved the prediction on all soils except those from reservoirs. Organic matter values in addition to 6-day NH_4^+-N production and initial NH_4^+-N did not improve the prediction in any case.

Coefficients of determination shown in Tables 3 and 4 indicate that a simple regression of N uptake with 6-day soluble + extractable NH_4^+-N provided predictions equal to those obtained by multiple regressions of N uptake with initial NH_4^+-N (X_2) and 6-day NH_4^+-N production values (X_1).

In an attempt to further elucidate the effect of Ca on N uptake by rice, additional regression analyses were made. Using data of the previous study (5) in which the average Ca content of silt loam soils was nearly double that of soils in the present study, analyses revealed that Ca was significantly related to grain yield ($\hat{y} = 4.59 - .20X$; $r^2 = .16^{**}$) on silt loam soils but these variables were not related on clay soils. Further, in the present study Ca was related to soil pH ($\hat{y} = 4.88 + .42X$; $r^2 = .60^{**}$) for all soils where $\hat{y}$ is the estimated pH and X the meq of Ca/100 g soil. In neither the previous study nor the present was exchangeable Ca related to NH_4^+-N production during incubation nor did iron chlorosis symptoms develop on the rice foliage in any treatment.

Consequently, the activity of the microbial population carrying out ammonification does not appear to have been affected by Ca. The low correlations obtained for N soil tests and N uptake on silt loam soils more likely resulted from the influence of Ca on plant growth and N uptake. The influence of Ca may be explained on the basis of either Ca-NH_4 ion antagonism or a cation-anion balance phenomena occurring when NH_4^+-N was the predominant form of N for the plant.

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