

Nitrogen Mineralization and Different Methods of Ammonium Determination of Some Paddy Soils in the North, Central, and Northeast Regions of Thailand

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ABSTRACT

High yields of rice are needed for farmer profitability and to provide this most important staple food and cash export crop of the country. Nitrogen fertilizer management is one of the key factors for high yielding of rice. Good management will reduce the contamination of the environment. Nitrogen mineralization or ammonium release after submergence is a useful index of nitrogen supplying capacity of the soils. The data is useful for effective fertilizer application. The study on ammonium release of 18 soil series which are the representative rice soils in the North, Central and Northeast regions of Thailand was performed. The results showed that ammonium release from 18 soils increased with time of submergence and the content reached the steady state at 4 weeks of submergence. The amount released of the soils followed the equation : $Y = A - Be^{-ct}$ except in the four soils. The higher ammonification percentage was found in soils lower in total N and clay content. Mehlich 1 and 0.25 M H₂SO₄ were the promising extracting solutions for assessing the initial amount of ammonium in the dry soils.

Key words: nitrogen mineralization in paddy soils, incubation under submerged condition, extracting solutions for soil ammonium, nitrogen fertilizer

INTRODUCTION

Thailand is one of the world's greatest rice exporters with 10.4 million hectares of rice acreage. About 1.28 million hectares of land is used for irrigated rice in the dry season (Royal Irrigation Department, 2003). Farmers grow 2-3 crops of rice in one year in this area. About one half of the total rice production in the country is produced from this irrigated area. The average yield of dry season rice is about 4,281 kg/ha

(Office of Agricultural Economics, 2002). The general fertilizer recommendation for non-photosensitive rice is 16-20-0 for clayey soils and 16-16-8 or 16-8-8 for sandy soils at the amount of 156-218 kg/ha in combination with urea at the rate of 63-94 kg/ha (Department of Agriculture, 2000). To produce one ton of rice, the nutrient requirement of NPK are 19, 5 and 36 kg, respectively (Yoshida, 1981). The current recommended fertilizer for rice is high in phosphorus (P) content, which has resulted in high accumulations of P in the soils.

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Most of the farmers in irrigated area also apply too much nitrogen (N) fertilizer – an estimated excess of 75-100 kg N/ha per one crop. They normally practice two or three cropping seasons in one year. They also use a lot of chemicals and soil amendments such as bio-fertilizer, hormones and surfactant. This excessive fertilization has resulted in a high cost of production and has led to pollution of the environment. Thailand imported 3.5 million tonnes of chemical fertilizer in 2002 which cost about US \$ 523 million, most of which was used on irrigated rice (Department of Agriculture, 2003). If one third of the chemical fertilizer could be reduced, we can save the foreign exchange deficit of about US\$ 174 million annually.

Many studies conducted in Japan showed that even in a field that has sufficient applied fertilizer, N uptake by rice through the mineralization of organic N well exceeds that from fertilizer (Kyuma, 2004). A study conducted by Koyama *et al.* (1973) in Thailand showed that more than 60% of total N taken up by rice plants by the time of harvest came from mineralization of soil organic N.

The mineralization of organic N stops at the ammonia stage in flooded soils because of the absence of oxygen to carry the process through nitrate. The kinetics of ammonia release in flooded soils is important in rice production. Ammonia released after 4 weeks of anaerobic incubation of the soil may be a useful index for available nitrogen and the capacity of a soil to supply ammonia and should be considered in N fertilizer experiments (Ponnamperuma, 1964). The most important factors influencing ammonia release in normal flooded soils are the nature and content of organic matter. Ammonia production follows an asymptotic course, and the kinetics of ammonia can be described as $\log(A-Y) = \log A - ct$ or $Y = A - Be^{-ct}$ where Y = Ammonium content at time t , A = maximum content of ammonium, B = initial ammonium content, c = constant, t = time of

submergence (Ponnamperuma, 1981). Rapid ammonium release was found within 20 days of submergence, the amount was about one half of the total ammonium release after 80 days of submergence (Cholitul, 1967). The study of Shiga and Ventura (1976) showed rapid release of ammonium occurred during 20-40 days after submergence and slow release after that. The amount of ammonium release of 410 soil samples from 9 countries was found between 0.3-26.5% of total nitrogen at two weeks of incubation at 40°C. This amount of ammonium can be utilized by the rice plants (Kawaguchi and Kyuma, 1977).

The ammonium release is, therefore, important to be studied for nitrogen fertilizer management of lowland rice. The ammonium released at 4 weeks after submergence was taken as the index of N supplying capacity of the soils in this study. The attempt was made to find out the suitable extracting solution of the dry soils to indicate the soil initial available nitrogen. The suitable method will replace the mineralized ammonium at 4 weeks of submergence which is not practical for the routine use. The results of the study will lead to the efficient use of nitrogen fertilizer, and the suitable extracting solution for ammonium of the dry soils for assessing the available nitrogen content in the rice soils.

MATERIALS AND METHODS

Ammonium release pattern in some important paddy soils

Eighteen paddy soils which were the representative irrigated paddy soils were identified and collected from farmers' fields in the lower northern, central and northeastern region of Thailand. The soils were air dried, ground and sieved. The air dried samples were analyzed for some important chemical and physical properties. The air dried soil samples were incubated under submerged condition for 0-70 days at 30°C. The incubated soils were analyzed for ammonium

content every week using Mehlich 1 (0.05 M HCl+0.0125 M H₂SO₄) as the extracting solution. The amount released was used to fit the equation: $Y=A-Be^{-ct}$ for each soil using the Statistical Analysis System (PROC NLIN) (SAS, 1985). The residual mean square error was computed to indicate the deviation of the ammonium release from the equation.

Comparison of ammonium extracted by different extracting solutions

Four extracting solutions, namely, 2 N KCl which is the conventional method for soil available N (Knudsen *et al.*, 1982), Mehlich 1, one of the methods for available P measurement (Jones, 1985), 0.25 M H₂SO₄, the promising method for soil available N in Japan (Fujii *et al.*, 1990) and 1% ascorbic acid, the promising method for soil available P in Japan (Nanzyo *et al.*, 1996) were used to extract the ammonium in 18 dry soils. The extracted ammonium of the dry soils was correlated with the ammonium released after 4 weeks of incubation.

Field tests on nitrogen response

The field tests on nitrogen response were conducted on Saraburi, Nan, Kula Rong Hai, Nong Boon Nak, Pimai and Tung Samrit soils. Different nitrogen fertilizers were applied based on DSSAT recommendation (Tsuji *et al.*, 1994) and arranged it in factorial combination to get the nitrogen response curve. The phosphorus and potassium were applied according to the PDSS (Yost *et al.*, 1992) and Mitscherlich equation, respectively (Attanandana and Yost, 2003). The plot size is 5×7 m² and the randomized complete block design was used in this study with four replications.

RESULTS AND DISCUSSION

Ammonium release pattern

The 18 soils behaved differently on ammonium release. The ammonium release is

processed by microorganisms, thus soil pH is one of the critical factors affecting the amounts of ammonium release under submerged condition. We could divide the soils studied into two groups based on the amount of total N. The first group contained soil total N ranged between 0.9-2.0 g/kg which released ammonium amount of 50-140 mgN/kg. They were Bang Nam Preo (Bp), Bangkok (Bk), Ratchaburi (Rb), Uttaradit (Utt), Chacheongsao (Cc), Rangsit (Rs), Saraburi (Sb). Three soils of this group which contained relatively similar range of total N (0.9-1.8 g/kg) but the ammonium released was less than 60 mg N/kg at 4 weeks of submergence, they were Ayutthaya (Ay), Sena (Se) and Maha Phot (Ma) soils. This was attributed to the abnormal pH increase of Ay and Se soils, the pH of these two soils showed no increment until 56-70 days of incubation and the pH increase only 0.5 unit from the beginning of the incubation. The Ay and Se soils are very acid soils with the pH of 3.7-4.5. This very low pH might inhibit the ammonification process in the soils, resulting in low ammonium release. In the case of Ma soil, the pH increase of 1.3 unit after 7 days of incubation and no further increase of pH after that period. The general properties of the first group soils were: pH of 3.7-6.6, organic matter of 17-36 g/kg and they were sandy loam, loam and clayey soils. The second group of soils which contained 0.1-0.5 g/kg total N showed the amount of ammonium released at 10-50 mg N/kg, they were Roi Et (Re), Siton (St), Pimai (Pm), Pratai (Pt), Kula Rong Hai (Ki), Nong Boon Nak (Nbn) and Tung Samrit (Tsr) soils. In the case of Nan (Na) soil which belong to group 2 containing 0.5 g/kg total N showed ammonium release of 90 mg/kg. The pH of this soil increased markedly from 5.6 to 7.0 within two weeks of incubation resulted in high ammonium release. The optimum pH for ammonification resulted in high ammonium release although the soil is low in total N content. The general properties of the second group soils were: pH of 4.1-6.0, organic matter content of 4-

19 g/kg and they were sandy loam, loam and clayey soils. All of the soils released about 2.2-30.6% of their total nitrogen at 4 weeks after submergence. The important chemical properties and texture of all soils studied was shown in Table 1.

Soils vary widely in their capacity to

produce ammonium when kept submerged. Soils rich in organic matter rapidly released ammonium and attained concentration of 141.5 mg/kg in the soil at 4 weeks after submergence, the example of Bp soil which contained highest organic matter among all soils studied. The organic matter of this soil was 36 g/kg (Figure 1, Table 1). Soils

Table 1 Some chemical properties and textures of the soils studied.

Soil series	Order	pH _{water} (1:1)	OM.* (g/kg)	Total N** (g/kg)	Extractable P # (mgkg ⁻¹)	Extractable K § (mgkg ⁻¹)	Texture ¶
Bang Nam Preo (Bp)	Inceptisols	5.3	36	2.0	115	159	Clay
Bangkok (Bk)	Inceptisols	4.2	30	1.7	58	150	Clay
Cha Cheong Sao (Cc)	Inceptisols	4.2	34	1.7	116	20	Clay
Rangsit (Rs)	Inceptisols	4.3	32	1.6	118	102	Clay
Ratchaburi (Rb)	Inceptisols	4.3	32	1.5	6	265	Clay
Uttaradit (Utt)	Ultisols	4.1	19	0.9	26	40	Loam
Saraburi (Sb)	Inceptisols	6.6	19	0.9	14	26	Sandy clay loam
Ayuthaya (Ay)	Inceptisols	4.5	23	0.9	5	134	Clay
Sena (Se)	Inceptisols	3.7	17	1.1	3	168	Clay
Maha Phot (Ma)	Inceptisols	4.0	34	1.8	7	52	Clay
Roi Et (Re)	Ultisols	4.6	9	0.4	9	156	Sandy loam
Tung Samrit (Tsr)	Vertisols	4.7	9	0.4	5	102	Clay
Pimai (Pm)	Vertisols	4.7	18	0.3	4	57	Loam
Pratai (Pt)	Alfisols	5.7	6	0.2	7	48	Loam
Kula Rong Hai (Ki)	Alfisols	4.9	13	0.2	5	29	Sandy loam
Siton (St)	Inceptisols	4.2	4	0.1	3	19	Loam
Nong Boon Nak (Nbn)	Alfisols	6.0	4	0.1	4	39	Sandy clay loam
Nan (Na)	Alfisols	5.6	14	0.5	17	30	Loam

* Wet oxidation (Walkley and Black, 1934)

** Micro-Kjeldahl method (Bremner, 1965)

Bray II (Bray and Kurtz, 1945)

§ 1.0 M NH₄OAc pH 7.0 (Knudsen *et al.*, 1982)

¶ Hydrometer method (Day, 1965)

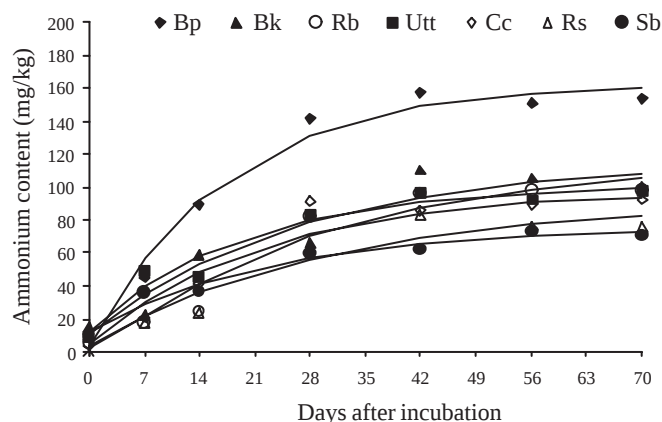


Figure 1 Moderately to high ammonium release in total N soils higher than 0.9 g/kg.

low in organic matter liberated much smaller amounts of ammonium at a slower rate which are the Nbn, Ki, Pt, Pm, St and Re soils (Table 1, Figure 2). The pattern of ammonium release followed the equation: $Y=A-Be^{-ct}$ with 14 soils among 18 soils studied (Figure 1, 2). The ammonium released in Ay, Se, Tsr and Na soils did not follow the equation (Figure 3) because their pH increased very slowly after submergence compared with the other soils in which the pH increased normally after incubation (Figure 4, 5).

The regression between A, B, and C coefficient and soil properties indicated the peak concentration of ammonium release and initial

amount of ammonium increased with increasing total N and decreasing clay percentage. The soil pH, clay content, organic matter are the factors affecting the C constant. The C constant of the soil increased with increasing clay content and pH but decreased with the increasing amount of organic matter. The regression of A, B, and C coefficient were given in the following equations.

$$A=47.38-1.50 \% \text{ clay} + 88.05 \text{ total N, } adjR^2=0.7320$$

$$B=38.55-1.25 \% \text{ clay} + 82.13 \text{ total N, } adjR^2=0.7352$$

$$C=0.00335 + 0.0006 \% \text{ clay} + 0.0142 \text{ pH}-0.0019 \text{ OM, } adjR^2=0.4437$$

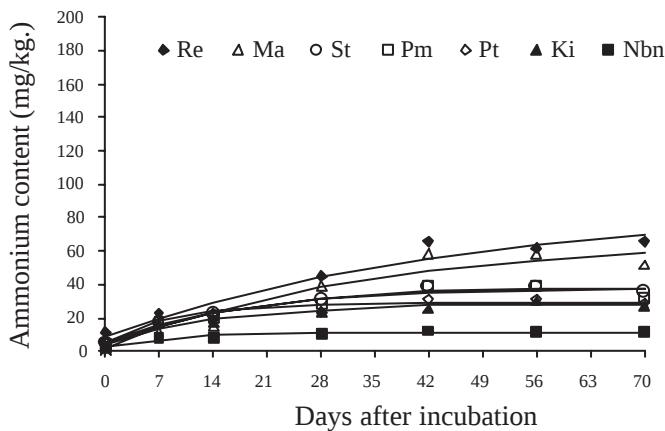


Figure 2 Low ammonium release in total N soils lower than 0.9 g/kg.

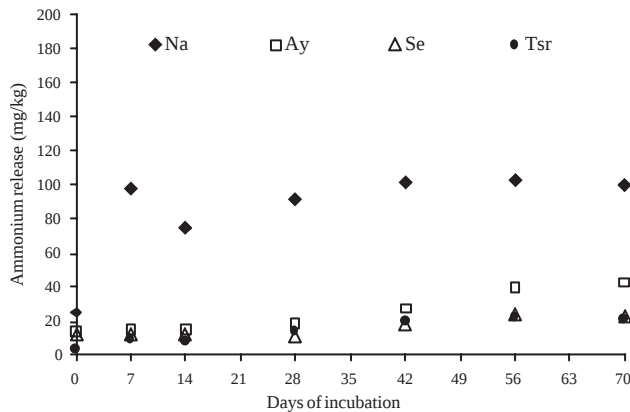


Figure 3 Ammonium release of four soils which did not follow the release pattern.

The constant value and the equation of ammonium release calculation is shown in Table 2. The different c values for different soils was observed, this was due to the different pH, clay and organic matter in the soils as shown in the multiple regression equation. The Residual Mean Square (RMS) of each soil is also shown in this table. We can see that the RMS of Bk, Rb and Cc soils were higher than the other soils. This was due to the higher deviation between the calculated and observed ammonium release of these three soils. The least RMS was found in Nbn soil, indicating the observed ammonium release closely with the amount calculated from the equation.

The high soil total N resulted in high mineralized ammonium at 4 weeks of incubation (Table 3). The ammonification percentage was calculated from the mineralized ammonium at 4 weeks of incubation as percentage of total N. The results showed higher ammonification percentage with lower total N content (Figure 6a). One soil from the northeast region which was low in total N and clay content showed abnormal high ammonium release (Table 3) so the negative correlation between ammonification percentage and total N and % clay was not found in this soil. The same evidence was reported by Kawaguchi and Kyuma (1969). The low total N content of a

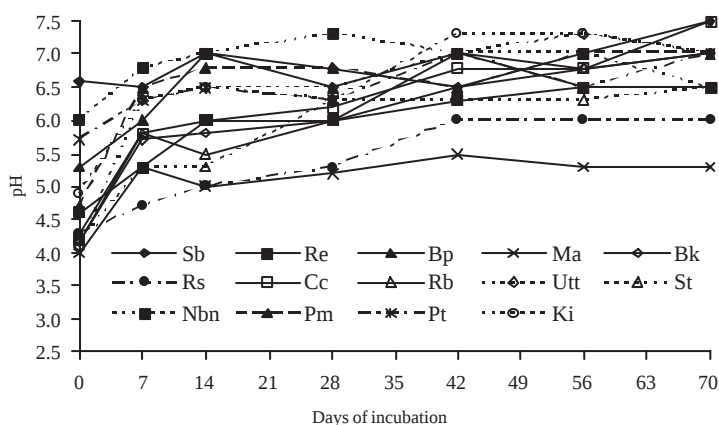


Figure 4 pH of the soils which increased gradually after incubation.

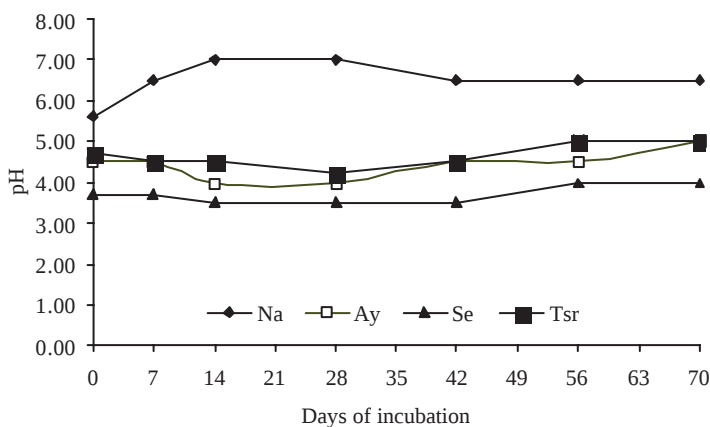


Figure 5 pH of some soils which did not increase until after 56-70 days of incubation except Na soil.

soil imply a low capacity of a soil to retain or fix or protect organic matter, and so any organic matter that may be present in a soil is ready to undergo microbial decomposition. It was also noted that

the lower clay content soils showed higher ammonification percentage (Figure 6b). A low clay content is also related to a low capacity of organic matter retention of a soil.

Table 2 The constant value (c) for calculation of equation, $Y=A-Be^{-ct}$ and Residual Mean Square (RMS) of 14 soil series.

Soil series	Constant c	equation $Y=A-Be^{-ct}$	RMS
Bang Nam Preo (Bp)	0.0579	$Y=162.80-159.10e^{-0.0579t}$	72.67
Bnagkok (Bk)	0.0354	$Y=117.80-106.20e^{-0.0354t}$	112.50
Cha Cheong Sao (Cc)	0.0460	$Y=97.42-92.43e^{-0.0460t}$	98.59
Rangsit (Rs)	0.0319	$Y=91.90-88.06e^{-0.0319t}$	78.11
Ratchaburi (Rb)	0.0336	$Y=116.60-119.80e^{-0.0336t}$	108.63
Uttraradit (Utt)	0.0521	$Y=101.10-89.19e^{-0.0521t}$	54.64
Saraburi (Sb)	0.0475	$Y=73.83-61.90e^{-0.0475t}$	33.95
Mahaphot (Ma)	0.0302	$Y=66.44-65.25e^{-0.0302t}$	46.59
Roi Et (Re)	0.0234	$Y=83.59-75.29e^{-0.0234t}$	43.04
Pimai (Pm)	0.0552	$Y=37.73-33.16e^{-0.0552t}$	13.62
Pratai (Pt)	0.1140	$Y=28.95-24.41e^{-0.114t}$	6.77
Kula Rong Hai (Ki)	0.0705	$Y=27.89-23.86e^{-0.0705t}$	4.92
Siton (St)	0.0591	$Y=38.27-33.76e^{-0.0591t}$	3.58
Nong Boon Nak (Nbn)	0.1082	$Y=11.02-8.83e^{-0.1082t}$	0.42

Table 3 Ammonium released, ammonification percentage, pH, % clay and total N of the soils studied.

Soil series	pH	% clay	Ammonium release at 4 weeks of incubation (mg/kg)	Total N (g/kg)	Ammonification percentage
Bang Nam Preo (Bp)	5.3	68	141.52	2.0	7.1
Bangkok (Bk)	4.2	60	65.79	1.7	3.9
Cha Cheong Sao (Cc)	4.2	60	91.92	1.7	5.4
Rangsit (Rs)	4.3	60	59.05	1.6	3.7
Ratchaburi (Rb)	4.3	44	82.17	1.5	5.5
Uttraradit (Utt)	4.1	20	82.73	0.9	9.2
Saraburi (Sb)	6.6	22	59.37	0.9	6.6
Mahaphot (Ma)	4.0	66	39.96	1.8	2.2
Roi Et (Re)	4.6	21	44.77	0.4	11.2
Pimai (Pm)	4.7	23	27.88	0.3	9.3
Pratai (Pt)	5.7	19	22.55	0.2	11.3
Kula Rong Hai (Ki)	4.9	15	23.64	0.2	11.8
Siton (St)	4.2	19	30.59	0.1	30.6
Nong Boon Nak (Nbn)	6.0	29	9.96	0.1	10.0

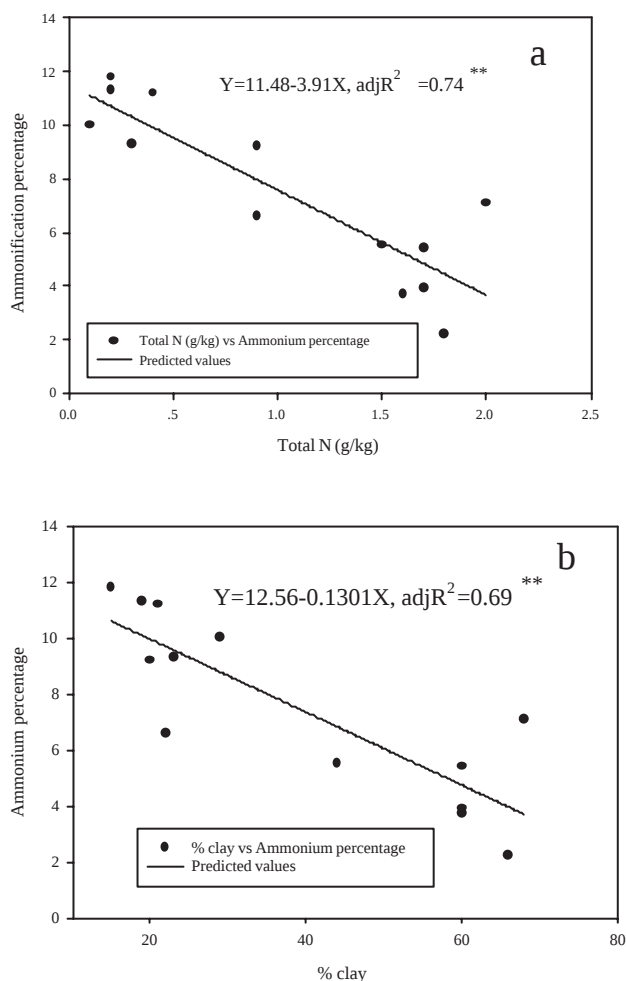


Figure 6 Correlation between ammonification percentage and total N (a) and clay content (b), ** indicates highly significant difference (99%), $\text{adj}R^2$ =adjusted R^2 , it indicates there is a penalty for adding many variables to the regression equation.

The amount of ammonium release has some effects on the nitrogen response of rice although there were other factors contributing to the rice yield. The field tests of Sb and Na soils showed low response of nitrogen fertilizer (27.5 and 16.3 kg/ha) due to the high release of ammonium while the high response of nitrogen fertilizer were observed in Ki and Nbn soils (87.5 and 141.9 kg/ha) which had the low ammonium release. The nitrogen response was regressed by LRP model using SigmaPlot. Koyama *et al.*, (1973) reported that more than 60% of total N

taken up by rice plants by the time of harvest came from mineralization of soil organic N. The exception were found in Pm and Tsr soils which showed low nitrogen response (12.3 and 12.1 kg/ha) although the ammonium release in these two soils were low. This might be attributed to the good water management of Pm soil and in the case of Tsr soil, the farmer applied organic fertilizer, resulted in low response of nitrogen fertilizer (Table 4). The rice yield of no N plots in Sb and Na soils was higher than those of other soils. This was due to the non-photosensitive

Table 4 Response to nitrogen of rice yield of no N plot in some soils studied.

Series	Response rate of nitrogen (kg/ha)*	Yield of no N plot (kg/ha)
Saraburi (Sb)	27.5	3,875
Nan (Na)	16.3	6,119
Kula Rong Hai (Ki)	87.5	1,563
Nong Boon Nak (Nbn)	141.9	1,931
Pimai (Pm)	12.3	2,238
Tung Samrit (Tsr)	12.1	2,363

* -SigmaPlot (LRP model)

variety and it was the irrigated rice. In opposite, the photosensitive variety was used in the other soils and it was the rain fed rice.

Comparison of ammonium extracted by different extracting solutions

The extractable ammonium of the 18 dry soils by four different extracting solutions showed different amounts. The amount extracted by 2 N KCl, Mehlich 1, 0.25 M H₂SO₄ and 1% ascorbic acid were 25.0-75.3, 3.7-67.3, 5.2-54.7 and 0.24-8.6 mg/kg, respectively. The amount extracted by these four extracting solutions was correlated with the ammonium released after 4 weeks of incubation. The results revealed that Mehlich 1 and 0.25 M H₂SO₄ extractable ammonium had significant correlation with the ammonium release at 4 weeks of incubation with the correlation coefficient of 0.75 and 0.77, respectively (Figure 7a, 7b). The 2 N KCl extractable ammonium showed correlation coefficient of 0.65 (Figure 7c) while there was no correlation between 1% ascorbic acid and the ammonium released at 4 weeks of incubation (Figure 7d). The yield of rice on no N plots of six soils was plotted against the various extractants. The results revealed the highly significant correlation of yield and Mehlich 1, 0.25 M H₂SO₄ extractable ammonium (Figure 8a, 8b). The 2N KCl extractants were low in correlation coefficient and there was no correlation between 1% ascorbic acid extractable ammonium and yield of no N plots. The further study should be made to find out the extraction method for ammonium

of the dry soils which will be the index of available nitrogen for rice.

CONCLUSIONS

Ammonium production followed an asymptotic course, and the kinetics of ammonium followed the equation: $\log (A-Y)=\log A-ct$ or $Y=A-Be^{-ct}$. There were some soils which did not follow the equation, this might be due to the slow increase of pH in these soils after incubation. The ammonium reached the steady state at 4 weeks of submergence. The ammonification percentage of the soils study showed higher values with the soils low in total N and low in clay content. The low nitrogen response on rice in some soils was partly due to high release of ammonium. The amount released might be useful for rice growth so the response to chemical fertilizer was low. In contrast, the high nitrogen response on rice in some soils was due partly to low release of ammonium. The high soil total N resulted in high mineralized ammonium at 4 weeks of incubation. Higher ammonification percentage was found in soils low in total N and clay content. The C constant of the release pattern depended on clay content, pH, and organic matter content. The significant correlation was observed between the amount of ammonium extracted by Mehlich 1 and 0.25 M H₂SO₄ with the ammonium released at 4 weeks of incubation. Mehlich 1 and 0.25 M H₂SO₄ seemed to be the promising extracting solutions for initial content of ammonium in the dry soils for assessing the

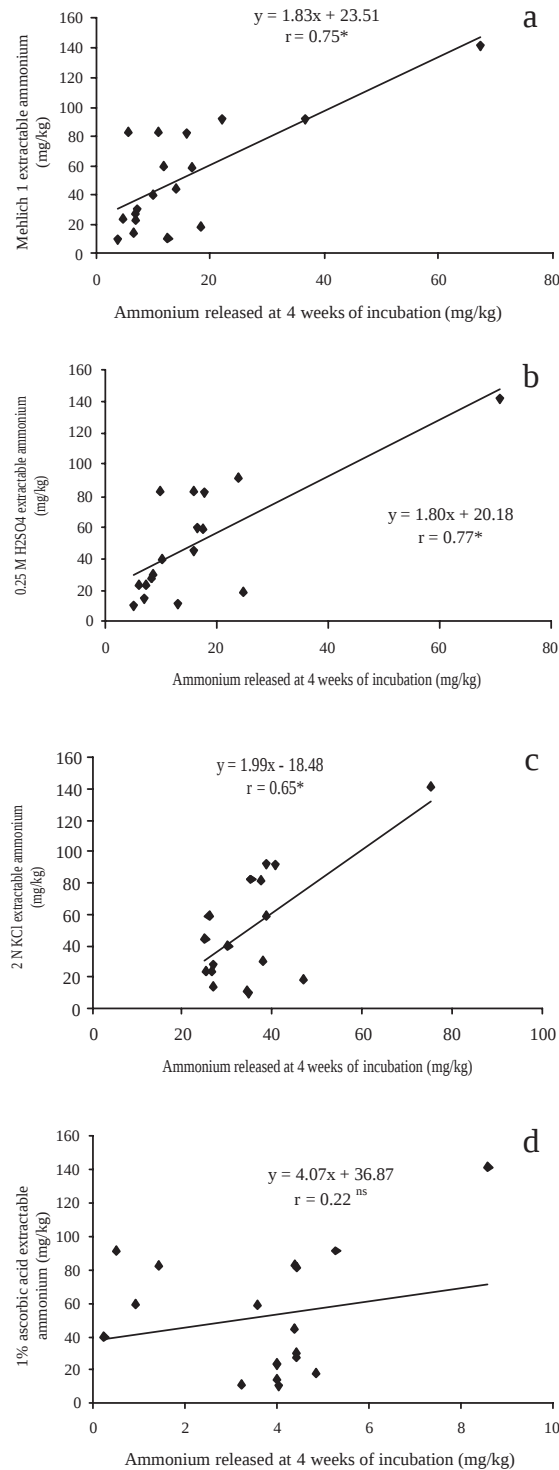


Figure 7 Correlation between extractable ammonium by four different extraction solutions (a) Mehlich 1 (b) 0.25 M H₂SO₄ (c) 2 N KCl (d) 1% ascorbic acid and ammonium released at 4 weeks of incubation, * indicates significant difference (95%), ns indicates non-significant difference.

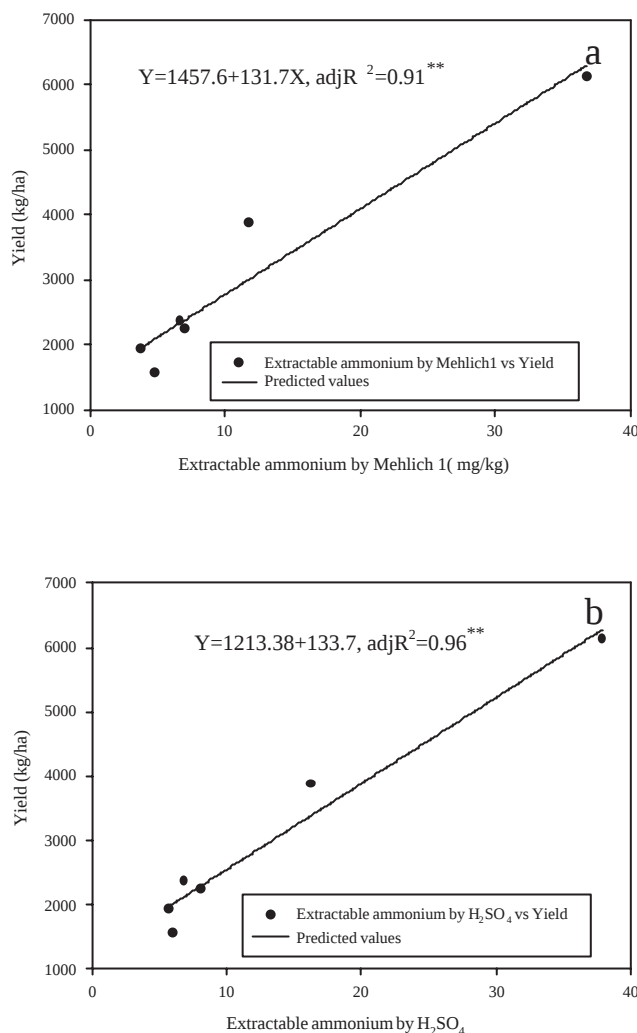


Figure 8 Correlation between Mehlich 1, 0.25 M H_2SO_4 extractable ammonium and rice yield in six soils studied (a) Mehlich 1 (b) 0.25 M H_2SO_4 , ** indicates highly significance (99%) $\text{adj}R^2$ =adjusted R^2 , it indicates there is a penalty for adding many variables to the regression equation.

available nitrogen index for paddy soils. The further study should be carried out.

ACKNOWLEDGEMENTS

The authors would like to express their sincere thanks to Thailand Research Fund for the financial support and to Dr. B. Boonsompopphan,

advisor of Land Development Department for assistance in collecting the soil samples from the rice fields. We also thank Ms. J. Chuenrung, Department of Agriculture for providing the incubator used in this study. Thanks also due to Prof. Dr. K. Kyuma, Emeritus professor of Kyoto University on the advice of manuscript preparation.

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