Dynamic Behavior of Soil Nitrogen in Paddy Soils of Thailand

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Lowland rice in Thailand has been cultivated mostly on the basis of natural supply of nutrients without application of fertilizers. Soil nitrogen which is one of the most important nutrients together with phosphorus[1] shows quantitative changes through nitrogen fixation, denitrification and leaching loss, and at the same time qualitative changes of soil nitrogen are brought out through the microbial metabolism which are also conditioned by the nature of the soil. Therefore, the dynamic behavior of soil nitrogen should be considered in relation to soil chemical and physical properties such as organic matter, available phosphorus, redox potential, pH, and moisture (particularly in the dry season), all of which affect the dynamic behavior of soil microorganisms[2], and also in relation to climatic conditions. Results[1,3,4,5] obtained in the course of twelve years of investigation conducted in Thailand under the joint research project between the Department of Agriculture of Thailand and the Tropical Agriculture Research Center of Japan are summerized in this report.

Chemical, physical and microbiological properties of great soil groups, as related to dynamic behavior of soil nitrogen

Values of total soil nitrogen content of surface soils ranged from 0.24% to 0.03%, with an average of 0.10%, whereas those of total carbon content ranged from 2.98% to 0.28%, with an average of 1.16% in paddy soils of Thailand. Carbon nitrogen ratios ranged from 10 to 17 with the highest value of 17.1 observed in Grumusols, and the lowest value of 9.7 in Hydromorphic Regosols. Amount of ammonium nitrogen released after 40 days' anaerobic incubation at 30°C, is generally used as an index of available form of nitrogen in soil. Its value in paddy soils of Thailand ranged from 79.7 ppm to 9.1 ppm, with an average of 38.2 ppm. The highest value was observed in Humic Gley Soils, and the lowest one in Hydromorphic Regosols. The ammonification rate, which is the percentage of ammonium nitrogen released after the anerobic incubation to the total nitrogen content, ranged from 4.4% to 2.5%, with an average of 3.9%. This value in Thailand was noticeably

Table 1. Soil chemical properties of great soil groups

Great soil group	n	T-N (%)		T-C (%)		C/N		Ava.-N (ppm)		% of T-N	
		x̄	σ	x̄	σ	x̄	σ	x̄	σ	x̄	σ
MAS	15	0.120	0.033	1.443	0.426	11.92	1.40	50.1	19.1	4.3	1.3
BWAS	9	0.155	0.026	1.975	0.531	12.58	1.48	37.6	28.8	2.5	1.9
FWAS	38	0.116	0.044	1.271	0.494	10.88	1.55	40.9	32.4	3.5	1.7
LHGS	80	0.093	0.052	1.024	0.603	11.18	2.15	38.8	13.9	4.4	1.9
HGS	2	0.239	0.011	2.984	0.208	12.50	0.30	79.7	7.1	3.4	0.2
HR	10	0.028	0.009	0.278	0.127	9.67	2.36	9.1	4.7	3.6	0.4
HGPS	3	0.087	0.023	1.16	0.284	11.67	0.34	24.1	14.9	3.5	0.2
HNCBS	5	0.086	0.023	1.057	0.356	12.14	1.78	33.1	10.8	3.7	0.5
Grumsols	4	0.095	0.037	1.613	0.169	17.08	1.17	27.5	10.6	3.1	1.4
Average	166	0.102	0.063	1.163	0.646	11.4	2.2	38.2	27.1	3.9	1.8

Abbreviation: MAS: Marine Alluvial Soil. BWAS: Brackish Water Alluvial Soils. FWAS: Fresh Water Alluvial Soils. LHGS: Low Humic Gley Soils. HGS: Humic Gley Soils. HR: Hydromorphic Regosols. HGPS: Hydromorphic Gray Podzolic Soils. HNCBS: Hydromorphic Non-calcic Brown Soils.

low compared with that observed in other south east Asian countries[6] (Table 1).

Populations of ammonifiers, ammonia oxidizers, nitrite oxidizers and denitrifiers showed differences among great soil groups, but populations of each group of these microorganisms increased generally in the rainy season to more than four times those in the dry season. Especially, nitrite oxidizers in the top soil of Low Humic Gley Soils increased by fifty times in the rainy season. Nitrite oxidizers which are non-spore forming, were supposed to die in the dry season because of severe lack of water especially in sandy soils. Average population of each of ammonifiers, ammonia oxidizers, nitrite oxidizers and denitrifiers per 1 g of dry soil in the soil layer of 10 cm depth in the rainy season reached the level of 10^4, 10^3, 10^4 and 10^5, respectively. The low level of ammonia oxidizers in tropical paddy soils was noticeable. Among great soil groups, both Brackish Water Alluvial Soils and Marine Alluvial Soils harboured low level of ammonia oxidizers (10^2, 10^1 respectively) and nitrite oxidizers (10^2 for both), whereas Grumusols showed high level of both groups. Brackish Water Alluvial Soils showed noticeably low level of denitrifiers. Populations of cellulose decomposers in Brackish Water Alluvial Soils in which organic matter accumulates, were about one-half to one-third of those in other great soil groups. Actinomycetes which is known to decompose soil humus was also not abundant in this soil. This was presumed to be caused by the low pH value of the soil (Table 2).

As for free living nitrogen fixers and their nitrogen fixing activity, some differences in seasonal changes of their populations were observed among nitrogen fixers and also among great soil groups. Populations of nitrogen fixing groups tended to increase generally at the later period of rice cultivation. Annual average of populations of Azotobacter (heterotrophic aerobe) was 10^1–10^4 per 1 g of dry soil, of Beijerinckia (acid tolerant-heterotrophic aerobe) less than 10^1, of Clostridium (heterotrophic anaerobe) 10^4, of Nonsulfur purple bacteria (photo-autotrophic anaerobe) 10^2–10^5, and of N-fixing blue-green algae 10^2–10^4, respectively. Population of Azotobacter, C. butyricum and blue-green algae showed a tendency to correspond to total and available phosphorus content in the plough-sole, and a large number of the former two heterotrophs were detected in the soils with high organic matter content, with the exception of acid soils. Apart from

Table 2. Average number ($\times 10^3$/1 g of dry soil) of each microorganisms related to the dynamic behavior of nitrogen in each great soil groug in respect of season and soil depth

	Number of soil samples	Rainy season				Dry season			
		0–1 cm		1–10 cm		0–1 cm		1–10 cm	
		Average	S. D.	Average	S. D.	Average	S. D.	Average	S. D.
(1) Ammonifier									
MAS	3	11.3	1.24	68.3	93.1	2.53	2.77	1.63	1.18
BWAS	4	32.0	30.6	307	156	0.593	0.366	0.905	0.368
FWAS	30	151	241	72.6	82.9	9.68	8.81	8.02	7.24
LHGS	56	109	238	62.3	79.7	14.0	20.3	9.59	15.8
HNCBS	4	47.5	22.2	26.8	6.61	2.48	1.36	4.38	1.23
Others	4	80.6	60.5	45.8	27.1	5.82	9.59	7.90	11.0
Total	101	112	224	72.5	95.5	10.9	16.4	8.20	12.8
(2) Ammonia oxidizer									
MAS	3	0.13	0.092	0.052	0.069	0.144	0.129	0.127	0.071
BWAS	4	1.55	2.68	0.12	0.202	0.236	0.315	1.94	3.16
FWAS	30	3.86	5.11	4.19	6.74	0.867	1.57	1.87	5.44
LHGS	56	2.41	6.81	1.65	4.09	0.675	2.28	0.280	0.909
HNCBS	4	2.59	2.38	0.623	0.175	0.183	0.201	0.144	0.139
Others	4	7.56	10.2	12.4	11.1	2.20	2.17	1.98	1.64
Total	101	2.95	6.30	2.68	5.77	0.748	1.98	0.879	3.20
(3) Nitrite oxidizer									
MAS	3	1.35	1.80	0.340	0.167	0.89	1.11	8.11	7.92
BWAS	4	2.68	2.47	0.337	0.387	1.11	1.61	6.79	6.81
FWAS	30	19.7	65.7	11.6	40.9	3.78	5.63	2.74	4.23
LHGS	56	74.8	162	13.9	42.5	1.50	3.26	1.56	3.26
HNCBS	4	28.0	41.8	53.7	90.3	0.074	0.095	0.059	0.024
Others	4	110	185	1.53	1.22	1.97	2.33	3.78	6.62
Total	101	53.3	135	13.4	43.6	2.08	4.08	2.60	5.28
(4) Denitrifier									
MAS	3	125	81.8	369	447	17.3	3.31	17.3	4.89
BWAS	4	134	88.2	132	125	1302	1813	183	118
FWAS	27	1077	1377	559	759	119	195	90.3	186
LHGS	50	941	2290	564	1600	193	793	169	977
HNCBS	4	316	389	687	991	181	166	59.0	24.8
Others	3	1710	1835	1483	1250	823	1440	25.0	37.5
Total	91	917	1910	573	1310	238	807	129	730

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the chemical factors of soil mentioned earlier, microbiological interaction among microorganisms was suggested to be one of the important factors determining the populations of nitrogen fixers in soil. Using the C_2H_2 reduction method, it was possible to demonstrate that nitrogen fixation in paddy soil in the rainy season was achieved mostly at the surface of the soil by anaerobic heterotroph, and that nitrogen fixation at the surface of the irrigated water by photoautotroph was found only in some locations. The amount of biological fixation was estimated to be 5.4–0.5 kg N/ha (average 7 kg N/ha), and was

Table 3. Population of nitrogen fixing microorganisms and amount of atmospheric nitrogen fixed in great soil groups

Great soil group	position	Nitrogen fixing microorganisms					Atmospheric nitrogen fixed N kg/ha/year range (mean)
		Azotobacter	Beijerinckia	Clostridium	Nonsulfur purple bacteria	Blue green algae	
MA	Water	$<10^1$	—	10^2-10^3	10^1-10^2	10^1-10^2	1.3-17.4
	Soil	$1-10^3$	—	10^4-10^5	10^3-10^4	10^1-10^4	(9.3)
BWA	Water	<1	—	10^2-10^3	10^1	$<10^1$	2.7- 4.3
	Soil	$\leqq 10^1$	—	10^4-10^5	10^2-10^3	10^2	(3.4)
FWA	Water	$<10^2$	—	10^2-10^4	10^1-10^3	10^1-10^3	4.2-53.9
	Soil	10^1-10^4	$\leqq 10^1$	10^4-10^5	10^3-10^5	10^3-10^4	(17.5)
LHG-I	Water	<1	—	10^2-10^3	10^1-10^2	$<10^1$	0.5- 3.9
	Soil	$<10^1$	$<10^1$	10^3-10^4	10^3-10^4	10^2-10^3	(2.1)
LHG-II	Water	$<10^1$	—	10^2-10^3	10^1-10^3	$<10^2$	2.4- 7.4
	Soil	10^1-10^2	$<10^1$	10^5	10^3-10^5	10^3-10^4	(4.2)
LHG-III	Water	$<10^1$	—	10^2-10^4	10^1-10^3	10^2-10^3	2.0- 9.9
	Soil	10^1-10^2	$\leqq 10^1$	10^5	10^3-10^4	10^3-10^4	(5.1)
HG	Water	10^1	—	10^3	10^1	10^3	16.0
	Soil	10^4	—	10^5	10^3	10^4	
NCB	Water	$<10^1$	—	10^3	10^3	10^2	4.4
	Soil	10^3	$<10^1$	10^5	10^3	10^3	
GP	Water	10^2	—	10^3	10^3	10^4	4.6
	Soil	10^3	—	10^5	10^4	10^4	
G	Water	10^3	—	10^3	10^2	10^3	8.3
	Soil	10^3	—	10^5	10^3	10^4	
R	Water	<1	—	10^1	10^1	<1	0.7
	Soil	10^1	—	10^3	10^2	10^2	

Abbreviation: MA: Marine Alluvial Soils, BWA: Brackish Water Alluvial Soils, FWA: Fresh Water Alluvial Soils, LHG: Low Humic Gley Soils, HG: Humic Gley soils, NCB: Noncalcic Brown Soils, GP: Gray Podzolic Soils, G: Grumusols, R: Regosols.

less than 10 kg N/ha in most soils. The highest value was obtained in Fresh Water Alluvial Soils, followed by Humic Gley Soils and Marine Alluvial Soils, whereas that in Brackish Water Alluvial Soils and Low Humic Gley Soils was very low (Table 3).

These data indicate clearly that chemical, physical and microbiological properties related to the dynamic behavior of soil nitrogen show distinctive characteristics among the great soil groups.

Behavior of nitrogen element in the soil-plant system

Using N^{15}-labelled fertilizer, the behavior of nitrogen was studied at Bangkhen field (Marine Alluvial Soils, HC). With the standard fertilizer application practice, i.e., 37.5 kg N/ha for basal-dressing and 37.5 kg N/ha for top dressing, an important variety P.B 76-63, absorbed 82 kg N/ha, of which 30 kg was derived from the fertilizer while the balance, 52 kg N/ha, was originated from the soil nitrogen. When the total quantity of fertilizers, namely 75 kg N/ha was applied as basal-dressing at one time, rice plants absorbed a total of 72 kg N/ha, of which 14 kg N/ha was derived from the fertilizer while the balance, 58 kg N/ha, originated from the soil. The above mentioned results clearly demonstrated that, like in Japanese soils, soil nitrogen

Table 4. The fate of nitrogen in the soil-plant system

	Bangkhen (Thailand)				Nagano	Saitama
	37.5 kg/ha N all basal	75 kg/ha N all basal	75 kg/ha N split 2 times	Non-N	82.5 kg/ha N all basal	75.0 kg/ha N split 2 times
Applied-^{15}N	37.5	75.0	75.0	0	82.5	75.0
Soil-^{14}N in rice plants	44.8	58.1	51.9	37.1	77.9	65.5
Applied-^{15}N in rice plants	6.2	14.0	29.8	0	25.8	32.0
$^{14}N+^{15}N$ in rice plants	51.0	72.1	81.7	37.1	103.7	97.5
Immobilization and lost-^{15}N from soil-plant system	31.3	61.0	45.2	0	56.7	43.0

played a crucial role in rice production even in the tropical paddy soils whose fertility was considered to be low (Table 4).

Comparison of ratios of absorbed soil nitrogen to total plant nitrogen at different stages of growth indicated 42% at the tillering stage, 66% at the panicle primordia initiation, 77% at the flowering stage and 80% at the harvesting stage, respectively, when 75 kg N/ha was applied as a basal dressing without top-dressing. The fact that the soil nitrogen accounted for high percentages of total plant nitrogen at the early period of growth when nitrogen fertilizer still remained abundantly, and also that the soil nitrogen constituted a major part of the total plant nitrogen at the later period of growth, clearly demonstrated how important is the role of the soil nitrogen for rice growth in tropical paddy soils. To clarify the ability of Bangkhen soil to supply nitrogen, the amount of available nitrogen in the soil (A-value) was calculated. The A-value of the Bangkhen soil which amounted to 131 kg N/ha was nearly half of that of fertile Nagano soil and slightly lower than that of infertile Saitama soil.

As for the percentage distribution of absorbed soil nitrogen in the whole growth period from the onset of growth to the harvesting time, 64% was absorbed during the period extending to the end of the tillering stage, 32% during the panicle formation stage, and 4% during the ripening period. Compared with the percentage distribution of 45 : 27 : 28% observed in the high-yielding Nagano soils in Japan, it is clear that the release of soil nitrogen during the late period of growth is very low in the Bangkhen soil. The above result gives a strong evidence that the optimum timing of top dressing of nitrogen to get the maximum yield is 30 days before flowering. From the analysis of yield componets, it was shown that top-dressing at this time maximized the number of spikelets per panicle. Furthermore, an experiment of two successive cropping of rice in the rainy season demonstrated that the second crop utilized 17% less soil nitrogen than the first crop. As the utilization of fertilizer nitrogen by the second crop was almost identical to that of the first crop, one could deduce that the amount of mineralized soil nitrogen available to the second crop was reduced due to the consumption by the first crop.

Effect of organic matter application on the dynamic behavior of soil nitrogen

Effect of city compost (C/N 11) and rice straw (C/N 55) applied at the rate of 6 tons/ha each on soil physical and chemical properties was compared between Surine (Low Humic Gley Soils, loamy fine sand with low organic matter content) and Bangkhen field (Marine Alluvial Soils, heavy clay). In case of Surine Soil, soil reduction developed noticeably after the organic matter application, and ammonium nitrogen content increased in the city compost plot but decreased in the rice straw plot due to high C/N ratio of the straw. In the late period of rice growth, however, ammonium nitrogen increased even in the rice straw plot. In case of Bangkhen soil with heavy clay and comparatively high organic matter content, soil reduction was less but the change of ammonium nitrogen content in the soil was similar to that of Surine soil.

Rice straw was applied at the rate of 6 tons/ha to Khok Samrong field (Low Humic Gley Soils) with clay content slightly higher than that of Surine soil and also to Khlong Luang field (Brackish Water Alluvial Soils) with high clay and organic matter contents. In both soils, nitrogen content of top soil (0–1 cm) was higher in treated plots than in control plots throughout the rice growing season. In case of sub-surface soil (1–10 cm), Khok Samrong soil which belongs to the same great soil group as Surine soil, showed a trend similar to that of Surine soil, but Khlong Luang soil showed high values of ammonium nitrogen in the rice straw plot. Quantity of volatile soil gas showed a peak at 3 to 5 weeks after the application of rice straw in both soils. Amount of volatile soil gas was much less in Brackish Water Alluvial Soils than in Low Humic Gley Soils and the pattern of soil gas generation against time in the former assumed the shape of a low declivity slope. The amount of volatile soil nitrogen in Low Humic Gley Soils was as much as twice that in Brackish Water Alluvial Soils. Application of rice straw (6 tons/ha) noticeably increased the amount of volatile soil nitrogen. In case of Low Humic Gley Soils, the amount of soil nitrogen volatilized in the rice straw plot was 14 times that in the control plot, whereas in case of Brackish Water Alluvial Soils the amount was 5 times that in the control plot. Application of phosphorus also increased the amount of evoluted soil nitrogen, as compared with the control plot.

As for the effect of rice straw on nitrogen fixation, it was observed that in Kohn Khen soil, which is sandy and acidic, application of rice straw caused an increase in populations of anaerobic heterotrophs, but with no effect on nitrogen fixation, whereas in Bangkhen soil with high organic matter and high base content application of rice straw increased nitrogen fixing activity determined by C_2H_2 reduction method.

Effect of lime application on the dynamic behavior of soil nitrogen

Development of soil reduction after flooding was depressed in Khlong Luang soil due to its low pH value of 4.2, but lime application was effective in promoting soil reduction. As a result, ammonium nitrogen in the soil increased. Also in Bangkhen soil, lime application increased ammonium nitrogen content. However, lime application was apt to impede soil reduction in Sakhon Nakhon soil (Hydromorphic Regosols) as a result of alkalization in that sandy soil with low buffer action. On the other hand, however, ammonium nitrogen content of this soil was increased by the lime application to more than twice that of the control plot.

It was considered that ammonium nitrogen

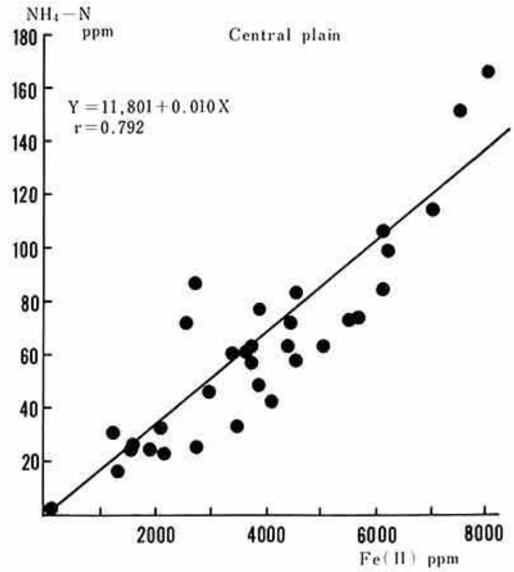

Fig. 1. Relationship between ferrous iron formation and ammonium production (in soils of Central Plain).

and ferrous ion contents can be regarded as an index of development of soil reduction. There was a high correlation between ammonium nitrogen and ferrous ion content (Fig. 1).

Lime application caused noticeably an increase in the population of autotrophic group along with an increased nitrogen fixing activity only when lime was applied together with phosphorus.

Conclusion

On the basis of experimental results, it could be clearly demonstrated that soil nitrogen played a crucial role in rice production even in the tropical paddy soils whose fertility is considered to be low. The dynamic behavior of soil nitrogen showed conspicuous differences among great soil groups owing to differences in soil chemical, physical and microbiological properties, which regulate the behavior of soil nitrogen. Effect of appliaction of organic matter or lime as a means of increasing soil fertility was also conditioned by the differences of properties among great soil groups.

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