JARQ 29, 103-109 (1995)

Quantification of Effect of Temperature and Air-Drying Treatment in Paddy Soils on Mineralization of Soil Organic Nitrogen

Shigeru TAKAHASHI* and Shigekazu YAMAMURO

Department of Agro-Environmental Management, Chugoku National Agricultural Experiment Station (Fukuyama, Hiroshima, 721 Japan)

Abstract

In a laboratory experiment, mineralization rate of soil organic nitrogen under submerged conditions using ^{15}N tracer was studied. Mineralization rate increased with temperature. Cumulative amount of nitrogen mineralized was expressed as the product of effective temperature and the duration of incubation. The minimum threshold temperature was nearly 10°C in the range of 20-30°C. Air-drying of soil before submergence promoted mineralization within several weeks after submergence.

Discipline: Soils, fertilizers and plant nutrition
Additional key words: summation of effective temperature, tracer NH_4^+-^{15}N

Introduction

In soil a major portion of nitrogen is in the organic form. Mineralization is a process whereby organic nitrogen is transformed to an inorganic form (usually NH_4^+-N)[1] through microbial activity and mineralized nitrogen becomes available for plant uptake. It is important to determine the quantity and the pattern of mineralization to promote sustainable productivity.

Mineralization process is considered to be influenced by factors related to soil, organic matter, and agronomic management[3]. Among them, temperature and air-drying are of special interest and a large number of reports have been published on this subject[4,5,8,12].

In most of the studies on mineralization in paddy soils, the amount of accumulated NH_4^+-N is considered to reflect the amount of nitrogen mineralized. Ammonium pool is involved in processes where NH_4^+-N is both consumed (immobilization, nitrification-denitrification, etc.), and produced (mineralization). Therefore simple measurements of the changes in the amount of NH_4^+-N fail to reflect the situation in soil[2].

In recent years, Yamamuro[10] has developed a model for calculating the mineralization rate in paddy soils using ^{15}N tracer technique. The author carried out experiments on the effect of temperature and air-drying of soil on mineralization in paddy soils using this model[6,7]. In the current paper the results of these studies are briefly outlined.

Materials and methods

Topsoil samples of Gray Lowland soil were collected from paddy fields at Chugoku National Agricultural Experiment Station in Fukuyama, Hiroshima (abbreviated as Fukuyama soil) and Tohoku National Agricultural Experiment Station in Omagari, Akita (abbreviated as Omagari soil). Soil samples were sieved (< 2 mm) without air-drying (wet soil). Then a part of the wet soil was airdried at 30°C (air-dried soil). Fukuyama and Omagari soils contained 1.0 and 1.3 g N/kg, respectively. Water content in air-dried Fukuyama and Omagari soils was 28 and 36 g/kg, respectively.

The experiment included two treatments, differing in the incubation temperature and water content before submergence.

Treatment 1: Subsamples (300 g and 250 g of

*Present address: Department of Soils and Fertilizers, National Agriculture Research Center (Tsukuba, Ibaraki, 305 Japan)

wet Fukuyama and Omagari soils, respectively) were placed in a beaker (300 ml vol) and then submerged. Fukuyama soil samples were incubated at 25 and 30°C, and Omagari soil samples were incubated at 20 and 30°C.

Treatment 2: Subsamples (100 g of air-dried Fukuyama and Omagari soils) were placed in a beaker and then submerged. Soil samples were incubated at 30°C. The purpose of this treatment was to compare the results obtained in air-dried and wet soils incubated at 30°C.

The experimental period covered a consecutive seven-day period. Period T_j referred to $7(j-1)$ to $7j$ days after submergence ($j=1,2,3...$), e.g. T_1 covered 0–7 days, T_2 covered 7–14 days. The beginning and the end of the period T_j were designated by t_{j0} and t_{jn}, respectively. At t_{j0}, each soil sample received 0.3 mg N of tracer $^{15}NH_4Cl$ (99.4 or 99.8 atom% ^{15}N). Then at t_{jn}, NH_4^+–N in soil was extracted with 100 g/l KCl. The amount of

Table 1. Amount of NH_4^+–N and mineralization rate (Fukuyama soil)

Period	N_{jo}	N_{jn}	$^{15}N_{jn}/^{15}N_{jo}$	^{15}R	M_j
Wet soil, 25°C					
T_1	17.3	17.5	0.790	0.701	0.86
T_2	17.5	16.3	0.627	0.623	0.96
T_3	16.3	18.1	0.619	0.620	1.44
T_4	18.1	18.6	0.621	0.625	1.33
T_5	18.6	19.5	0.629	0.645	1.38
T_6	19.5	20.4	0.661	0.678	1.30
T_7	20.4	20.0	0.696	0.666	1.01
T_8	20.0	19.6	0.637	0.640	1.22
T_9	19.6	20.5	0.644	0.681	1.35
T_{10}	20.5	24.0	0.721	0.712	1.54
T_{11}	24.0	27.0	0.703	0.702	1.64
T_{12}	27.0	27.6	0.701	0.701	1.47
T_{13}	27.6	27.3	0.700	0.700	1.36
Wet soil, 30°C					
T_1	17.3	23.0	0.807	0.716	1.52
T_2	23.0	22.7	0.635	0.603	1.47
T_3	22.7	21.0	0.571	0.609	1.45
T_4	21.0	22.7	0.649	0.644	1.61
T_5	22.7	24.3	0.640	0.633	1.74
T_6	24.3	27.0	0.626	0.643	2.08
T_7	27.0	29.2	0.661	0.659	1.98
T_8	29.2	29.8	0.657	0.688	1.82
T_9	29.8	28.9	0.720	0.708	1.27
T_{10}	28.9	29.5	0.695	0.694	1.60
T_{11}	29.5	30.5	0.693	0.676	1.73
T_{12}	30.5	31.9	0.686	0.684	1.83
T_{13}	31.9	30.4	0.683	0.683	1.51
Air-dried soil, 30°C					
T_1	19.4	23.9	0.492	0.537	2.75
T_2	23.9	31.2	0.587	0.598	3.13
T_3	31.2	34.9	0.610	0.587	2.92
T_4	34.9	26.8	0.565	0.558	1.34
T_5	26.8	23.8	0.551	0.574	1.68
T_6	23.8	21.6	0.598	0.608	1.33
T_7	21.6	21.9	0.618	0.595	1.57
T_8	21.9	20.7	0.573	0.592	1.49
T_9	20.7	20.6	0.611	0.613	1.45
T_{10}	20.6	19.6	0.614	0.611	1.25
T_{11}	19.6	19.1	0.608	0.608	1.29

N_{jo}, N_{jn}: NH_4^+–N (mg/kg), M_j: Mineralization rate (mg/kg/day).
Period T_j: $7(j-1) \sim 7j$ days after submergence.

NH_4^+-N in the solution was determined by steam distillation and atom% ^{15}N was determined by emission spectrometry[9].

Mineralization rate was calculated based on the equation derived by Yamamuro[10] as follows:

$$M_j = [\{N_{jn} - (^{15}N_{jn}/^{15}N_{j0})N_{j0}\} \cdot \ln(1/^{15}R)]/(1 - ^{15}R)/7$$

where M_j: mineralization rate during the period T_j (mg/kg/day),

N_{j0}: amount of NH_4^+-N at t_{j0} (mg/kg),
N_{jn}: amount of NH_4^+-N at t_{jn} (mg/kg),
$^{15}N_{j0}$: amount of tracer NH_4^+-^{15}N at t_{j0} (mg/kg),
$^{15}N_{jn}$: amount of tracer NH_4^+-^{15}N at t_{jn} (mg/kg),
$^{15}R = (^{15}N_{jn}/^{15}N_{j0})^{0.5}(^{15}N_{j+1\ n}/^{15}N_{j+1\ 0})^{0.5}$.

The amount of nitrogen mineralized during the period T_j was $7M_j$ mg/kg and cumulative amount of

Table 2. Amount of NH_4^+-N and mineralization rate (Omagari soil)

Period	N_{jo}	N_{jn}	$^{15}N_{jn}/^{15}N_{jo}$	^{15}R	M_j
Wet soil, 20°C					
T_1	2.1	2.7	0.487	0.493	0.34
T_2	2.7	3.0	0.500	0.509	0.32
T_3	3.0	3.5	0.518	0.537	0.37
T_4	3.5	3.8	0.557	0.583	0.34
T_5	3.8	4.2	0.610	0.598	0.35
T_6	4.2	4.6	0.585	0.597	0.38
T_7	4.6	5.1	0.608	0.631	0.42
T_8	5.1	5.5	0.655	0.672	0.37
T_9	5.5	6.2	0.690	0.685	0.41
T_{10}	6.2	6.5	0.680	0.695	0.39
T_{11}	6.5	7.2	0.710	0.700	0.43
T_{12}	7.2	7.0	0.689	0.675	0.36
T_{13}	7.0	7.6	0.661	0.661	0.52
Wet soil, 30°C					
T_1	2.1	3.9	0.367	0.419	0.67
T_2	3.9	5.2	0.478	0.512	0.65
T_3	5.2	6.8	0.548	0.580	0.73
T_4	6.8	8.4	0.615	0.651	0.74
T_5	8.4	10.8	0.690	0.665	0.86
T_6	10.8	11.6	0.640	0.652	0.82
T_7	11.6	13.8	0.665	0.690	1.05
T_8	13.8	16.1	0.716	0.717	1.04
T_9	16.1	18.4	0.718	0.730	1.13
T_{10}	18.4	19.0	0.743	0.763	0.87
T_{11}	19.0	21.3	0.784	0.766	1.04
T_{12}	21.3	23.7	0.749	0.743	1.28
T_{13}	23.7	26.4	0.738	0.738	1.48
Air-dried soil, 30°C					
T_1	6.1	18.1	0.718	0.806	2.14
T_2	18.1	38.8	0.903	0.912	3.35
T_3	38.8	62.0	0.922	0.908	3.96
T_4	62.0	65.0	0.895	0.876	1.67
R_5	65.0	69.4	0.858	0.867	2.22
T_6	69.4	68.9	0.877	0.891	1.52
T_7	68.9	66.1	0.905	0.888	0.79
T_8	66.1	65.2	0.872	0.890	1.32
T_9	65.2	63.6	0.909	0.916	0.93
T_{10}	63.6	62.9	0.923	0.913	0.82

N_{jo}: NH_4^+-N (mg/kg), M_j: Mineralization rate (mg/kg/day).
Period T_j: $7(j-1) \sim 7j$ days after submergence.

nitrogen mineralized was expressed as the summation of $7M_j$, e.g. $7(M_1+M_2+M_3)$ for 21 days.

Results and discussion

1) Effect of temperature on mineralization

As shown in the method for the determination of the effect of temperature increase, the increase in the amount of accumulated NH_4^+-N was determined at a high temperature ($\geqq 30°C$). The temperature ranges selected for the present study (i.e. 20–30°C) were similar to the soil temperature during the rice-growing season in Japan[6,12,13].

Data in Treatment 1 showing the effect of the changes in the temperature on the amount of NH_4^+-N and mineralization rate are summarized in Tables 1 and 2. The amount of NH_4^+-N increased during the experimental period. The amount of NH_4^+-N was larger at 30°C in both Fukuyama and Omagari soils.

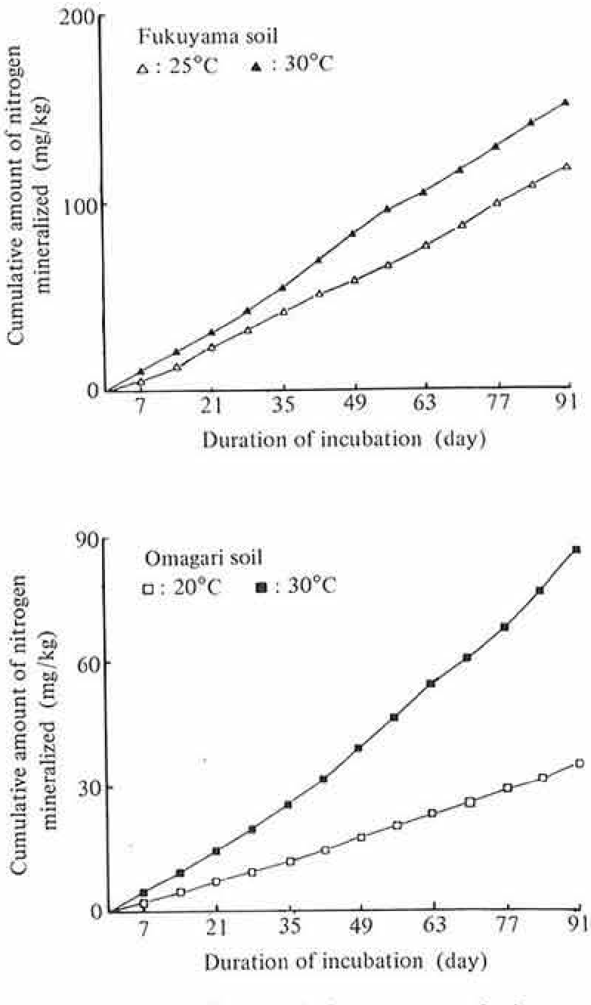

Fig. 1. Changes in cumulative amount of nitrogen mineralized in wet soil

Mineralization rate also increased with temperature in the range of 20–30°C. Cumulative amount of nitrogen mineralized increased linearly in the Fukuyama soil and exponentially in the Omagari soil (Fig. 1).

Based on these findings, the authors applied the concept of summation of effective temperature to analyze the relationship between mineralization and temperature, according to the following mathematical model:

$$Y = k\{(T-T_0)\cdot D\}^n$$

where Y: cumulative amount of nitrogen mineralized (mg/kg),
T: incubation temperature (°C),
D: duration of incubation (D),
T_0: minimum threshold temperature (°C),
k, n: constant,
$T-T_0$: effective temperature (°C).

Curve fitting and determination of T_0, k and n were achieved based on a nonlinear regression analysis.

Fukuyama soil: $Y = 0.0565\{(T-10.56)\cdot D\}^{1.06}$
Omagari soil : $Y = 0.0078\{(T-9.94)\cdot D\}^{1.24}$

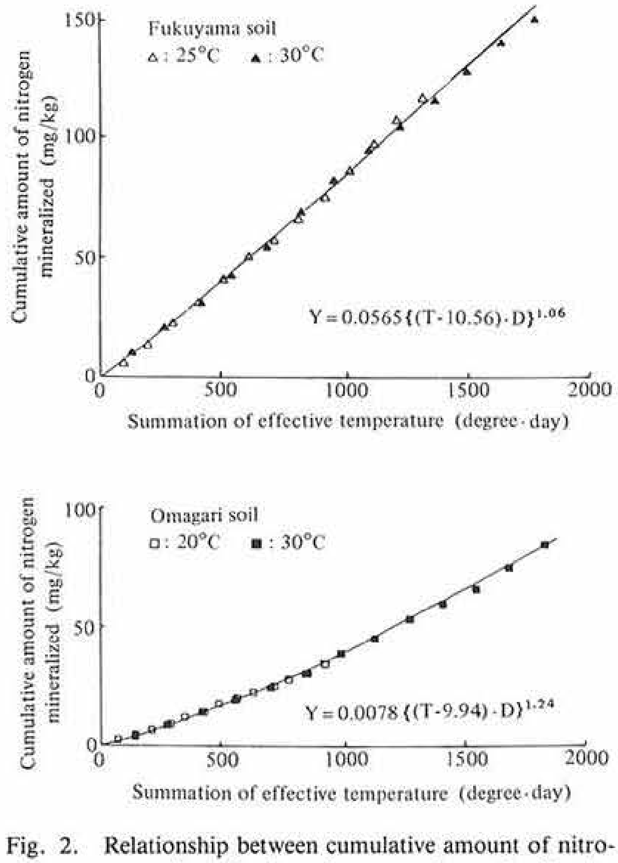

Fig. 2. Relationship between cumulative amount of nitrogen mineralized and summation of effective temperature in wet soil

Table 3. Mineralization rate at a low temperature

Period	Temp. (°C)	N_{jo}	N_{jn}	$^{15}N_{jn}/^{15}N_{jo}$	M_j*
T_5	5	8.1	8.8	0.888	0.25
	10	9.3	10.3	0.868	0.34
	15	12.9	14.6	0.849	0.55
	20	17.2	20.1	0.809	0.97
	25	19.0	21.0	0.776	1.01
	30	27.5	27.6	0.728	1.27
T_{11}	5	12.1	12.4	0.909	0.21
	10	13.6	14.1	0.865	0.36
	15	17.0	18.2	0.844	0.60

N_{jo}, N_{jn}: NH_4^+-N (mg/kg), M_j: Mineralization rate (mg/kg/day).
Period T_j: 7 (j-1) ~ 7j days after submergence.
*M_j is calculated according to the basic formula of Yamamuro[10].

As shown in Fig. 2, this equation coincided well with the results obtained. Yamamuro[11] reported that the mineralization rate by incubation and in a paddy field was nearly constant, suggesting that it may be possible to predict the changes in mineralization with time in paddy fields by monitoring the soil temperature. Since T_0 is 10.56°C for the Fukuyama soil and 9.94°C for the Omagari soil, it was suggested that the minimum threshold temperature (i.e. T_0) could be nearly 10°C. However, mineralization continues at temperatures below T_0. The mineralization rate was considerably lower at 5-10°C than that at 20-30°C (Table 3, data from another experiment similar to Treatment 1). Therefore, mineralization occuring below 10°C may not play a major role in the prediction of changes in mineralization in the range of 20-30°C.

As deduced from Fig. 1, the value of n in the Omagari soil was higher than that in the Fukuyama soil. Constant n is related to the pattern of changes in mineralization and a characteristic parameter of soil. As n is calculated by regression analysis, the value of n may vary with the experimental period. It is thus preferable to set up a certain experimental period in order to compare the values of n in different soils.

2) Effect of air-drying on mineralization

The increase in the amount of accumulated NH_4^+-N in soil which is air-dried before submergence is referred to as "air-drying effect" and is considered to be due to the promotion of mineralization. The amount of accumulated NH_4^+-N (AN) is expressed as follows:

$$AN = M - G$$

and the increase in the amount of accumulated NH_4^+-N in air-dried soil is expressed as follows:

$$AN_D - AN_W = (M_D - M_W) - (G_D - G_W)$$

where M is the amount of nitrogen mineralized, G is the amount of nitrogen transferred from the ammonium pool and the suffixes, W and D, denote wet and air-dried soils, respectively. Therefore, the increase in $AN_D - AN_W$ ("air-drying effect") is not simply related to the promotion of mineralization. The author attempted to evaluate the changes in mineralization.

Data in Treatments 1 and 2 showing the effects of air-drying before submergence on the amount of NH_4^+-N and mineralization rate are summarized in Tables 1 and 2. The amount of NH_4^+-N in the air-dried Fukuyama soil increased and reached a maximum value at the end of period T_3, and then decreased. After the end of period T_5, the amount of NH_4^+-N in the air-dried soil was smaller than that in wet soil.

In the Omagari soil, the amount of NH_4^+-N increased and reached a maximum value at the end of period T_5, and then decreased slightly.

The maximum difference between the amount of NH_4^+-N in the air-dried and in the wet soils was 8.5 mg/kg at the end of period T_3 and 59 mg/kg at the end of period T_5 in the Fukuyama and Omagari soils, respectively.

Mineralization rate in the air-dried Fukuyama soil was 2 times higher than that in wet soil for the period T_1 to T_3, and thereafter lower than that in wet soil. In air-dried Omagari soil, the mineralization rate was 2-5 times higher than that in wet soil for the period T_1 to T_6, and thereafter the mineralization rate in both air-dried and wet soils was nearly

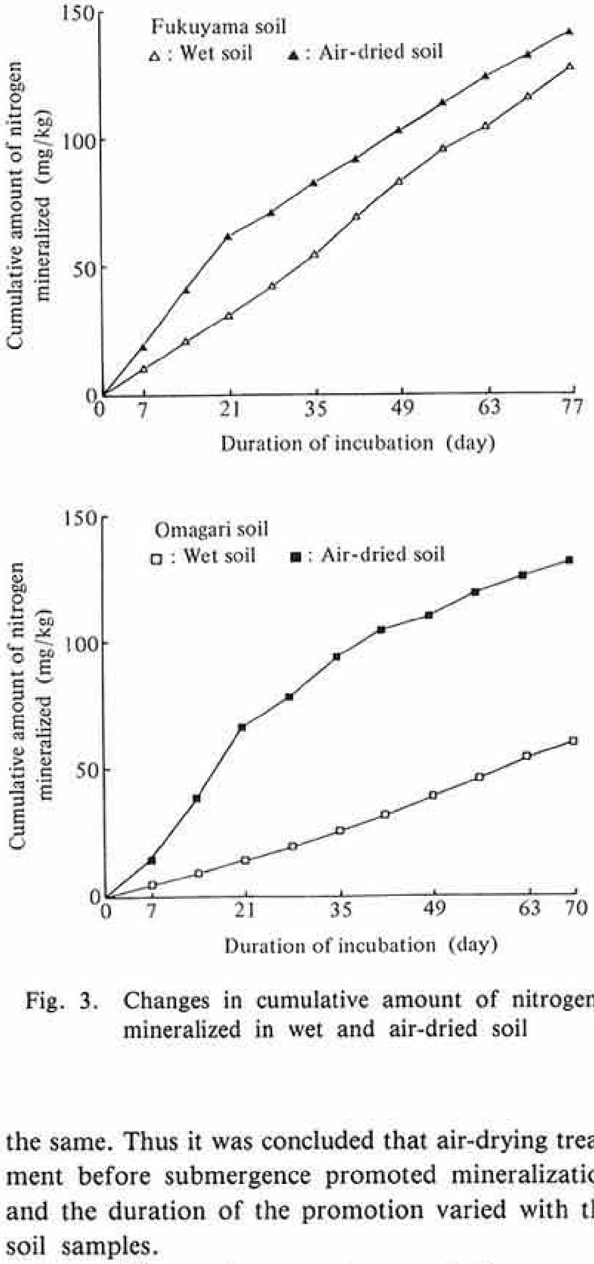

Fig. 3. Changes in cumulative amount of nitrogen mineralized in wet and air-dried soil

the same. Thus it was concluded that air-drying treatment before submergence promoted mineralization and the duration of the promotion varied with the soil samples.

The difference between the cumulative amount of nitrogen mineralized in the air-dried and the wet soils during the mineralization promoting period was 31 and 73 mg/kg in the Fukuyama and Omagari soils, respectively. It appears that in the Omagari soil the effect of the air-drying treatment was much more pronounced than in the Fukuyama soil from the point of view of NH_4^+-N, while the effect on the promotion of mineralization in fact was not appreciably different.

The air-drying effect is considered to indicate the total amount of available nitrogen or the amount of available nitrogen in soil. Mineralization occurred even during the period when the amount of NH_4^+-N decreased. The total amount of available nitrogen cannot be evaluated under a given incubation. As mentioned above, the increase in the amount of nitrogen mineralized in air-dried soil was higher in the Omagari soil. However the cumulative amount of nitrogen mineralized in the wet Fukuyama soil was approximately 2 times larger than that in the wet Omagari soil (Fig. 3). Thus the results obtained in air-dried soil do not correspond to the total amount of available nitrogen and/or the index of available nitrogen in soil.

References

1) Bartholomew, W. V. (1965): Mineralization and immobilization of nitrogen in the decomposition of plant and animal residues. *In* Soil nitrogen. eds. Bartholomew, W. V. & Clark, F. E., Am. Soc. Agron., Madison, 285-306.
2) Jansson, S. L. & Persson, J. (1982): Mineralization and immobilization of soil nitrogen. *In* Nitrogen in agricultural soils. ed. Stevenson, F. J., Am. Soc. Agron., Madison, 229-252.
3) Savant, N. K. & De Datta, S. K. (1982): Nitrogen transformation in wetland rice soils. *Adv. Agron.*, **35**, 241-302.
4) Sparling, G. P. & Ross, D. J. (1988): Microbial contributions to the increased nitrogen mineralization after air-drying of soil. *Plant Soil*, **105**, 163-167.
5) Sugihara, S., Konno, T. & Ishii, K. (1986): Kinetics of mineralization of organic nitrogen in soil. *Bull. Natl. Inst. Agro-Environ. Sci.*, **1**, 127-166 [In Japanese with English summary].
6) Takahashi, S. & Yamamuro, S. (1992): Relationship between mineralization of soil organic nitrogen and soil temperature under submerged soil conditions. *Jpn. J. Soil Sci. Plant Nutr.*, **63**, 463-465 [In Japanese].
7) Takahashi, S. & Yamamuro, S. (1994): Effect of air-drying before flooding on nitrogen mineralization. *Jpn. J. Soil Sci. Plant Nutr.*, **65**, 165-170 [In Japanese with English summary].
8) Toriyama, K., Sekiya, S. & Miyamori, Y. (1988): Quantification of effect of air-drying of paddy soil before submergence on amount of nitrogen mineralization. *Jpn. J. Soil Sci. Plant Nutr.*, **59**, 531-537 [In Japanese with English summary].
9) Yamamuro, S. (1981): The accurate determination of nitrogen-15 with an emission spectrometer. *Soil Sci. Plant Nutr.*, **27**, 405-419.
10) Yamamuro, S. (1988): A theoretical approach to the fate of nitrogen in paddy field by using an NH_4-^{15}N tracer technique. *Jpn. J. Soil Sci. Plant Nutr.*, **59**, 538-548 [In Japanese with English summary].
11) Yamamuro, S. (1988): Behavior of soil nitrogen in a paddy field and the incubation soil and a rapid estimate of the rate of absorption by rice plant. *Jpn. J. Soil Sci. Plant Nutr.*, **59**, 549-556 [In Japanese with English summary].
12) Yoshino, T. & Dei, Y. (1977): Prediction of nitrogen release in paddy soils by means of the concept of

effective temperature. *J. Cent. Agric. Exp.*, **25**, 1 - 62 [In Japanese with English summary].

13) Yanagisawa, M. & Takahashi, J. (1964): Studies on the factors related the productivity of paddy soils in Japan with special reference to the nutrition of the rice plants. *Bull. Natl. Inst. Agric. Sci.*, **B14**, 41 - 171 [In Japanese with English summary].

(Received for publication, Sept. 9, 1994)