Fate of Nitrogen in Paddy Fields and Nitrogen Absorption by Rice Plants

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Introduction and general patterns

As compared to the remarkable progress in basic researches on both N physiology of rice plants and biochemistry of N in paddy fields, studies on the N relationships between soil and plant have lagged significantly. It is probably because of the complexity of the factors governing the rice growth and yields, and a wide variation in the properties of paddy fields.

As described later, recently intensive field studies using stable isotope ^{15}N, however, have provided a considerable amount of important information concerning the soil-plant relationships or agronomy of N for rice plants. For example, based on the investigations carried out by Shoji and Wada and their associates,[1-6,10-14,16-22] Shoji and Mae[15] showed a comprehensive model for the relationships between the behavior of soil ammonium N and N uptake by rice plants throughout the growing season in northeastern Japan as given in Fig. 1.

Soil ammonium N tends to decrease after transplanting and largely disappears at the time of the maximum number of tillers, or at the end of June to the beginning of July in northeastern Japan. It is usually negligibly small in amount after the time of the maximum number of tillers, but when N is topdressed (Fig. 1-a).

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Soil ammonium N consists mainly of basal N (applied by basal dressing) at the transplanting time. However, the ratio of ammonium N from basal N to total ammonium N decreases with the lapse of time, showing that ammonium N from basal N is diluted with ammonium N from soil organic N.[12]

Takahashi et al.[17] successfully adopted the accumulated effective thermal index (AETI) to relate both the behavior of soil ammonium N and N absorption by rice plants to thermal factors. The AETI was first proposed by Hanyu and Uchijima[7] to show the relationships between the heading time of rice plants and thermal factors. Both total and basal ammonium N decrease exponentially after transplanting and largely disappear at an AETI of about 400 (Fig. 1-b).

The rate of N absorption by rice plants increases after transplanting and shows a maximum at the maximum tiller number stage. Another maximum is mostly observed soon after N topdressing or at the young panicle formation stage (Fig. 1-c).

The amount of N per unit area absorbed by rice plants is shown by an exponential equation of AETI for the early growth stage and by a linear one for the middle and late growth stages (Fig. 1-d). Since soil ammonium N is present in a certain amount at the early growth stage, the exponential part nearly indicates the rate of tillering. In contrast, the linear equation strongly suggests the rate of mineralization of soil organic N at the middle and late growth stages. The slope of this equation can be used to estimate the nitrogen fertility of paddy soil. The crossing point of the 2 equations is almost coincident with the maximum

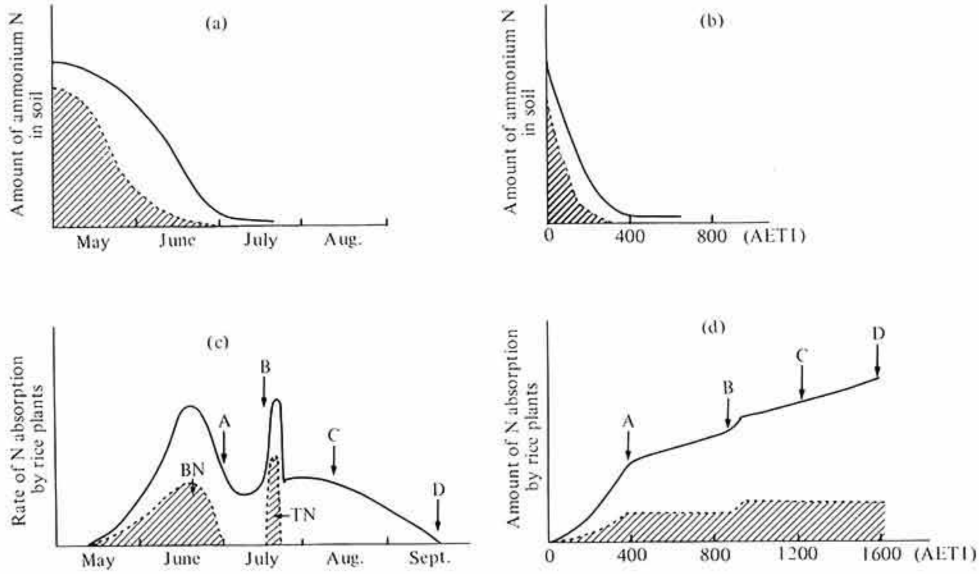

Fig. 1. A model for the behavior of ammonium N in paddy soil and N absorption by rice plants (Shoji and Mae, 1984)
(a) and (b): Behavior of soil ammonium N from basal N and soil organic N
(c): Rate of N absorption by rice plants from different sources
(d): Amount of N absorbed by rice plants

BN = Basal nitrogen, TN = Topdressed nitrogen,
A = Date of maximum number of tillers,
B = Young panicle initiation stage,
C = Heading stage, D = Maturity stage,
AETI = Accumulated effective thermal index by Hanyu and Uchijima.

: N from fertilizers
: N from soil organic N

tiller number stage. Therefore, it is quite likely that the time of the maximum number of tillers is not determined by the growth process itself but mostly by N nutrition of rice plants.[1]

Basal nitrogen

The fate of basal N is influenced by various factors such as absorption by plants, fixation by both biological and non-biological processes, leaching, nitrification-denitrification, ammonia volatilization, etc. However, the general patterns for the fate of basal N and N absorption by rice plants are schematically shown in Fig. 1. These patterns were recognized for widely differed paddy soils by Ando et al.[1] and Shoji and Nogi.[14]

As given in Fig. 2, soil ammonium N in all the soils largely disappeared at the maximum tiller number stage and was found in a small or trace amount after this stage. As already mentioned, the absorption of basal N by rice plants was almost completed at the maximum tiller number stage. This indicates that the mineralization of immobilized basal N at the middle and late growth stages is not significant in all the paddy soils.

The amount of N absorption by rice plants was also shown by exponential equations of AETI for the early growth stage and by linear ones for the middle and late growth stages. The slopes of linear equations showed the N supply to rice plants through the mineralization of soil organic N. The crossing point of 2 equations or the maximum

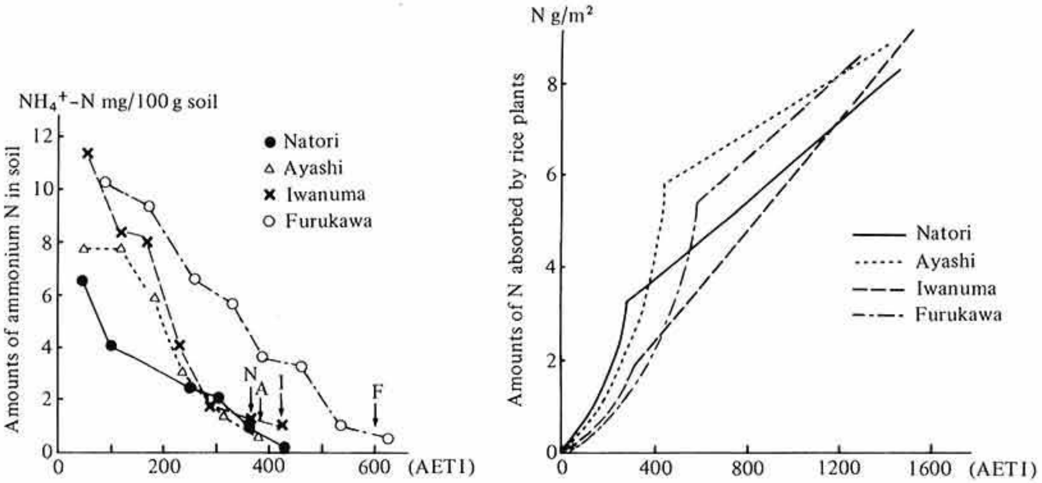

Fig. 2. Behavior of soil ammonium N and N absorption by rice plants in widely differed paddy soils (Ando et al. 1978)

Arrows: Date of maximum number of tillers

Soil types

Natori (N):	Gray Brown Lowland Soil
Ayashi (A):	Wet Andosol
Iwamura (I):	Peat Soil
Furukawa (F):	Strong Gley Soil

tiller number stage was observed at about 400 of AETI in all the soils except the Strong Gley Lowland soil in which rice roots were seriously damaged by toxic substances from late May to middle June.

Recently Shoji and Mae[15] reviewed many field studies on the recovery of basal ^{15}N in rice plants which were carried out under various climatic and soil conditions in northeastern Japan. They showed that the plant recovery varied from 40 to 20% with the mean value of about 30% in most cases.

The overall recovery of basal N is highly variable reflecting the different soil conditions and agronomic practices.[3,11-14] For example, a field study made by Ando et al.[3] in Fukushima Prefecture (Table 1) indicated that 44 to 29% of basal N remained in the Ap horizons at the harvesting time. Application of rice straw increased the amount of basal N remaining in the Ap horizons. The unaccounted portion of basal N varied from 51 to 24% of the basal N and was the greatest in the fine-textured Strong Gley soil which has high CEC due to smectite and very low percolation. Such N loss can be mainly attributable to nitrification-denitrification followed by leaching. Loss of basal N due to ammonia volatilization is not serious in northeastern Japan.

The transplanting time influences conspicuously the fate of basal N and N absorption of rice plants.[13,16] Though soil ammonium N in all the early, conventional and late transplanting plots tends to decrease after transplanting, the later the transplanting time, the more rapid the decrease of soil ammonium N. It is mainly because of the more rapid growth of rice plants in the late transplanting. The percentage of basal N in total soil ammonium N is also related to the transplanting time reflecting mainly the loss of ammonium N from basal N and mineralization of soil organic N. Therefore, the earlier the transplanting time, the smaller the percentage of soil ammonium N derived from basal N when compared on the same days.

Absorption of basal N by rice plants is finished by the time when most of the soil ammonium N disappears. However, the amounts of N absorbed by plants before the heading time and the recoveries of basal N in plants are nearly the same in all the early, conventional and late transplanting

Table 1. Fate of basal N (ammonium sulfate) in different paddy soils

Soil	Location*	Plot**	Percentage of basal N at rice harvest time		
			Rice	Soil (plowed layer)	Unaccounted
Gray Lowland (Fine-textured, gray brown type)	Koriyama	Standard	31	35	34
		Rice straw	32	44	24
Gley Lowland (Fine-textured, strong gley type)	Soma	Standard	20	29	51
		Rice straw	17	34	49
Gray Lowland (Medium-textured, grayish brown type)	Aizu	Standard	30	37	33

(Ando, Shoji & Takeda, 1980)

* Location in Fukushima Prefecture
** Fertilizers applied:
Basal fertilizer: N-P_2O_5-K_2O = 6-10-10 kg/10 a for all the plots
Organic materials: 1,000 kg/10 a of rice straw compost for standard plots
250 kg/10 a of rice straw for rice straw plots
Cultivar of rice: Toyonishiki

plots of the same field. Since the number of days from the transplanting to the commencement of ear-primodia formation is significantly smaller in the late-transplanted plot than in the other plots, the rate of N absorption by rice plants is greater in the former plot.

In order to develop an ideal plant type of rice by which light utilization efficiency of plants can be improved and lodging be minimized in the paddy field, it is necessary to restrict the N supply to rice plants at the necknode initiation stage.[8] Therefore, heavy application of basal N in the late-transplanted plot is unfavorable to develop an ideal plant type.

Levels of basal N vary widely with environmental factors, target yields and cultivation practices. Leaf color or N content of rice plants responds to the levels of basal N even at the middle growth stage. Therefore, it has often been considered that rice plants can absorb basal N not only at the early growth stage but also the middle growth stage in the paddy field with heavy dosage of basal N. The ^{15}N study by Ando and Shoji[2] and Wada et al.,[22] however, indicates that translocated N which was absorbed by rice plants at the early growth stage significantly contributes to the rice growth at the middle and late growth stages and that the degree of this contribution corresponds to the levels of basal N.

As for the behavior of soil ammonium N, its amount at the early growth stage reflects the levels of basal N as shown in Fig. 3. However, it is noticeable that the soil ammonium N disappears at the same time or at the maximum tiller number stage irrespective of the amounts of basal N. Therefore, that stage is also considered to be the time when rice roots develop wholly and densely enough to absorb most of the soil ammonium N in the plowed layer. Observation of root system supports this consideration.

Absorption of basal N by rice plants is also completed at the maximum tiller number stage, by that time soil ammonium N largely disappears.

Topdressed nitrogen

Topdressing of N can change drastically N absorption by rice plants from that in the early stage to that in the late growth stage and is one of useful cultivation practices to increase rice yields. Therefore, there are a variety of methods and time to topdress N.

Fate of topdressed N in paddy soils and N absorption by rice plants were studied in detail

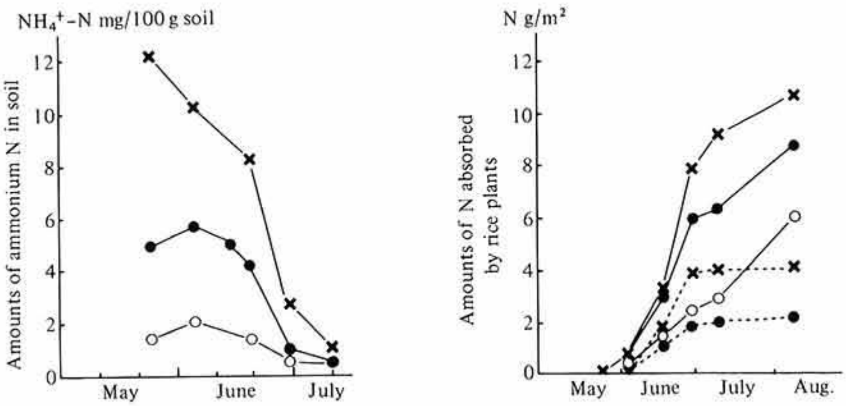

Fig. 3. Behavior of soil ammonium N and N absorption by rice plants in a paddy field with different levels of basal N (Shoji et al. 1974)
× : High basal N (15 kg N/10 a)
● : Standard basal N (7 kg N/10 a)
○ : No basal N
—: Total N
······: N from basal N

using the ^{15}N tracer method by Wada et al.,[21] Takahashi,[17] and Ando et al..[4] Based on the field studies, Takahashi[17] demonstrated the patterns for the absorption by rice plants of N topdressed at various growth stages as given in Fig. 4.

It is clear that N topdressing remarkably influences the N absorption by rice plants at any stages. However, as shown in Table 2, the duration of absorption and recovery by plants of topdressed N are considerably different with different application time. The earlier the time of topdressing made during the vegetative growth stage, the longer the duration of existence of soil ammonium N derived from topdressed N in the plowed layer. This fact is almost coincident with the duration of absorption of topdressed N by rice plants.[21]

Plant recovery of topdressed N also differed with different application time. The greatest recovery is obtained for the topdressing at the middle growth stage as seen in Table 2. Shoji and Mae[15] examined many field studies on the recovery of such topdressed N in northeastern Japan and obtained the average value of 55% with SD of 14.29.

Fate of topdressed N at the middle growth stage was studied carefully by Ando et al.[4] as shown in Fig. 5. A proportion of topdressed N

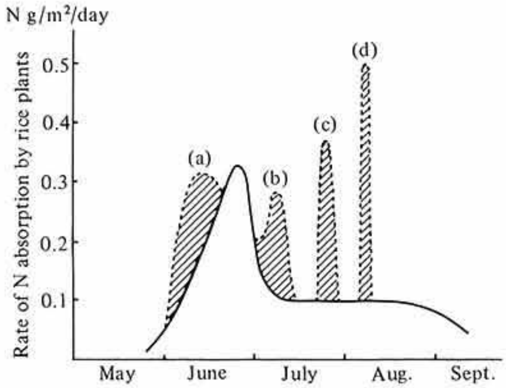

Fig. 4. Rate of absorption of topdressed N by rice plants at various growth stages (Takahashi, 1975)
Time of N topdressing
(a): Early tillering stage
(b): Necknode initiation stage
(c): Just before reduction division stage
(d): Heading stage
▨ : N from topdressed N
□ : N from both basal N and soil organic N

Table 2. Recovery of top-dressed N in plants

Time of application	N recovery in plants (%)	Duration of N absorption by rice plants (days)
7 days after transplanting*1	11	50
14 days after transplanting*1	15	40
30 days after transplanting*2	24	—
40 days after transplanting*2	37	—
Necknode initiation*3	50	10
Young panicle formation to booting*3,4,5,6	44–68	4–7

*1 Tanaka, N. & Yoshida, A.: *Tohoku Agri. Res.* **33**, 53-54 (1983)
*2 Shiga Pref. Exp. Sta.: Annual Reports (1981)
*3 Wada, G. et al.: *Proc. Crop Sci. Soc. Jpn.*, **40**, 287-293 (1971)
*4 Yamamuro, S.: *Jpn. J. Soil Sci. & Plant Nutr.*, **56**, 10-14 (1985)
*5 Yamamuro, S.: *Jpn. J. Soil Sci. & Plant Nutr.*, **56**, 15-20 (1985)
*6 Ando, H. et al.: *Jpn. J. Soil Sci. & Plant Nutr.*, **56**, 53-55 (1985)

disappeared in the submerged water and the exchangeable ammonium N in soil reached the maximum amount one day after the N topdressing. Almost all the exchangeable ammonium N was observed in the uppermost layer (0–1 cm) of the Ap horizon. The absorption of topdressed N by the rice plant was largely finished by the 7th day after the top dressing and the plant recovery was determind to be about 50%. The decrease of exchangeable ammonium N almost synchronized with the absorption of topdressed N by rice plants. Overall recovery of topdressed N was found to be about 75% 2 days after the placement, indicating that about 25% of topdressed N was lost within 2 days. About 25% of the topdressed N was fixed in the 0–4 cm layer of the Ap horizon.

N topdressing by surface placement is most common in Japan. N topdressing by deep placement has, however, been popular in Aomori Prefecture, northeastern Japan. According to Shimada,[9] the deep-placed N was absorbed by rice plants for the long interval from early July to late August and the plant recovery amounted to about 80%.

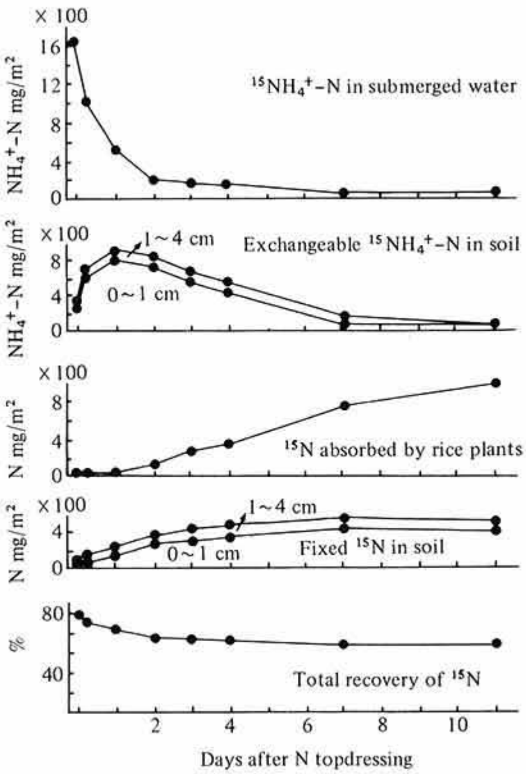

Fig. 5. The fate of topdressed N applied at the panicle formation stage (Ando et al. 1985)
The amount of topdressed N: 2 g/m²

Soil organic nitrogen

It has commonly been considered that remarkable increase in rice production per unit area in Japan after the World War II is attributable in large measure to the heavy dosage of N in commercial forms. However, field studies using ^{15}N on the N relationships between soil and plant have definitely indicated that a half or more than a half of total N absorbed by rice plants is N mineralized from soil organic N.[15] Therefore, accurate prediction of mineralization of soil organic N or ammonification in the paddy soil and absorption of mineralized N by rice plants is of great importance for high-yielding rice cultivation.

The mineralization of soil organic N is primarily controlled by the soil temperature as shown by Yoshino and Dei,[23] and Ando et al.[6] As for the kinds of soil organic N, absorption of mineralized N by rice plants shown in Fig. 1-c strongly suggests that there are 2 kinds: rapidly and slowly decomposable forms. The former is absorbed by rice plants at the early growth stage and the latter is largely absorbed by rice plants at the middle and late growth stages.

Recently Ando and Shoji[6] made a kinetic study on soil N mineralization and immobilization of paddy soils applying the Michaelis-Menten's

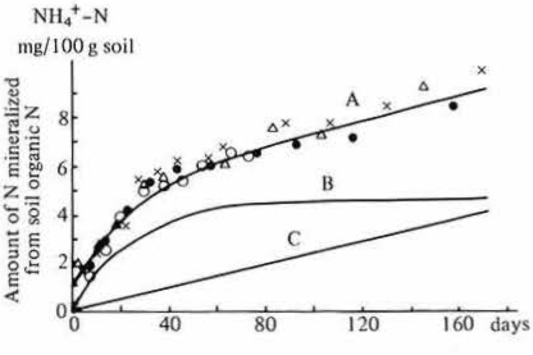

Fig. 6. Application of Michaelis-Menten's equation to the mineralization of soil organic N in a paddy field (Ando et al. 1986)

(1) Date of beginning of ammonification in the field
○ : May 10, × : May 20
● : May 31, △ : June 10

(2) The X axis indicates the days equivalent to duration of incubation at 18°C

(3) A : Total ammonium N mineralized from soil organic N and is expressed by
$Y = 4.56\,(1 - \exp(-0.048t)) + 297.08\,(1 - \exp(-8 \times 10^{-5}t)) + 0.60$
B: Rapidly mineralizable N
C: Slowly mineralizable N

equation. As given in Fig. 6, they obtained the exponential equation for mineralization of soil organic N consisting of 2 exponential equations for rapidly and slowly mineralizable forms as described above. They also insisted that the rate of mineralization of soil organic N is mainly controlled by the soil temperature.

Furthermore, Ando and Shoji[5] studied the relationship between the amount of mineralized N absorbed by rice plants at the middle growth stage and the amount of mineralized N predicted by their equation and obtained a close linear correlation for this relationship.

As described so far, recent field studies using stable isotope ^{15}N have provided useful information on the absorption processes of N from fertilizer and soil organic N by rice plants and the behavior of these N sources in the soil. Nowadays these accumulations of basic information are highly expected to be used for the accurate soil-plant modeling and prediction and control of N transformation in the soil and plant growth.

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(Received for publication, December 20, 1985)