Correlation of the Amount of Nitrogen Accumulated in the Aboveground Biomass at Panicle Initiation and Nitrogen Content of Soil with the Nitrogen Uptake by Lowland Rice during the Period from Panicle Initiation to Heading

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Abstract: To estimate the site-specific optimal amount of nitrogen (N) to be applied as top-dressing (N top-dressing) at panicle initiation, we examined the effects of the amount of N accumulated in the aboveground biomass at the panicle initiation stage (N_i), the total N content of soil and the amount of mineralizable soil N (N_m) on the amount of soil N taken up by the plants during the period from panicle initiation to heading (N_s) and the recovery ratio of applied chemical N during this period (J). We analyzed the data obtained in paddy fields with a similar soil type and weather condition in the growth period from 1999 to 2001. The growth of rice plants was regulated by the amounts of N applied before transplanting and at panicle initiation. The relative N uptake rate during the period from panicle initiation to heading (RNR) in the plots without N top-dressing was explained about 89% by multiple regression of N_i, the total N of soil and N_m. N_s in the plots with N top-dressing that was estimated using RNR showed a significantly negative partial correlation with N_i, the total N of soil and N_m. N_s in the plots with N top-dressing showed a significantly negative partial correlation with N_i, but a significantly positive partial correlation with N_m. These results suggest that the fertilizer N should be applied considering the contribution of N_i, the total N content of soil and N_m to N_s and J to fit the site-specific N demand of rice.

Key words: Nitrogen uptake, Oryza sativa L., Precision agriculture, Recovery ratio, Soil nitrogen, Topdressing.

Nitrogen (N) is commonly applied as top-dressing at the panicle initiation stage to increase rice grain yield. N accumulated in the aboveground biomass at this stage is efficiently used to increase spikelet number. Another effect of N top-dressing is to activate photosynthesis during ripening. However, N fertilizer applied by the farmer may not always fit the N demand of rice in the tropics (Cassman et al., 1993).

The amount of chemical N to be applied as top-dressing at the panicle initiation stage (N_c) is theoretically shown as follows (Miyama, 1988);

\[ N_c = \frac{(N_{op} - N_i - N_s)}{J} \]  

(1)

Where, J is the recovery ratio of chemical N top-dressing during the period from panicle initiation to heading; N_op is the optimum amount of N to be accumulated in aboveground biomass at the heading stage; N_i is the amount of N accumulated in the aboveground biomass at the panicle initiation stage; N_s is the amount of N taken up by the plants from soil during the period from panicle initiation to heading.

N_op is estimated from the relationship between the amount of N accumulated in the aboveground biomass at heading (N_2) and spikelet number or grain yield. N_s and J are estimated from the amount of N in the plants without N top-dressing or by the 15N technique. N_s and J calculated by the 15N technique were lower than those estimated from the values in the plants without N top-dressing (Yoshino and Dei, 1978). Practically, N_i in the paddy field has been estimated by the farmer using a leaf color chart (Kato et al., 1987). More recently, the remote sensing techniques for estimating N_i have been developed (Inoue, 1997; Inoue, 2003).

In the large paddy field made by merging small paddy fields together and in the large-scale farm management due to the decreasing number of farmers, the spatial variability of the rice yield and the soil properties within and among fields are great enough to justify the cost of expense equipment for site-specific fertilizer management (Cassman, 1999). An agricultural system with site-specific fertilizer management, i.e., precision agricul-
ture, can help to solve such problems. If the spatial variability of the yield can be corrected, the yield would be increased with a lower environmental impact. Therefore, the spatial variability of soil properties and crop yield especially in upland fields has been evaluated in USA, Europe, Australia and Japan (Campbell, 1978; Burgess and Webster, 1980; Vitera et al., 1981; Cassel et al., 1988; Finke and Goense, 1993; Bhatti et al., 1998; Nakamoto et al., 2002).

Cassman (1999), Yanai et al. (2000) and Yanai et al. (2001) indicated the need for site-specific soil management and possibility of precision agriculture even in small-scale farm management in an almost flat paddy field. Site-specific N application in paddy fields, i.e., N top-dressing at the panicle initiation stage, would be determined by the above-mentioned equation 1. In farmer's paddy fields, Ns and J should be determined based on soil types, crop management and weather condition in growth period (Miyama, 1988; Miyama and Okabe, 1979). In the field, Ni, J and Ns vary with the rate of basal N application, planting spacing, fertilizer types, improving soil fertility (Wada et al., 1989), and deep placement of fertilizer (Shimada, 1970; Marumoto et al., 1979). The soil chemical characteristics influenced the amount of N accumulated in the above-ground biomass at the middle and late growth stages in paddy fields (Wada et al., 1989). The soil and rice growth properties also influenced J in the paddy fields, as well as crop management practice and weather condition during the growth period (Maeda, 1983; Yoshino and Dei, 1978). However, the relationship between the agronomical factors, i.e., the spatial variability of soil physicochemical property or rice growth property, and Ns or J has not been considered. Limited information is available on the effect of the soil properties and rice growth properties on Ns and J. Therefore, the amount of chemical fertilizer N topdressing has been often decided not only by the variability of Ns and J but also by the variability of Ni in the fields. The objective of this study was to clarify the effect of the soil and rice growth properties on Ns and J for establishing the site-specific fertilizer management in paddy rice production.

### Table 1. Characteristics of experimental plots and weather condition during the growth period at the experimental farm of Kyoto Univ. in 1999-2001.

| Year  | Plot size (m) | Total carbon in soil (%) | Total nitrogen in soil (%) | Mineralizable soil nitrogen (mg 100 g⁻¹) | Average temperature °C |
|-------|---------------|--------------------------|---------------------------|------------------------------------------|------------------------|
| 1999  | 5.0 x 6.0     | 2.22±0.33                | 0.19±0.025                | 2.44±0.93                                | 24.95±3.67             |
| 2000  | 12.5 x 5.0    | 2.08±0.36                | 0.17±0.028                | 6.86±1.33                                | 24.63±4.34             |
| 2001  | 4.5 x 4.5     | 1.97±0.35                | 0.18±0.037                | 10.26±0.83                               | 25.03±4.03             |

Mean±S.D.

Means followed by the same letter are not significantly different at the 5% level based on Duncan’s Multiple Range Test.

### Table 2. Crop management in each field experiment at the experimental farm of Kyoto Univ. in 1999-2001.

| Year | Seeding date | Transplanting date | Transplanting spacing cm | N input basal g m⁻² | N input top dressing g m⁻² |
|------|--------------|-------------------|--------------------------|---------------------|---------------------------|
| 1999 | 5 May        | 7 June            | 33 x 22                  | 0.3                 | 0.6                       |
| 2000 | 10 May       | 9 June            | 33 x 22                  | 0.6                 | 0.6                       |
| 2001 | 11 May       | 11 June           | 33 x 22                  | 0.6                 | 0.6                       |

### Materials and Methods

1. **Cultivation and treatments**

Japonica rice ( cv. Minamihikari) was grown under an irrigated condition in 1999–2001 at the experimental farm of Kyoto University located in Takatsuki, Osaka Prefecture (135°36', 34°51'N, 9 m above sea level). The soil of the farm is classified as Coarse Textured and Gray Lowland soil (Yanai et al., 2000). Total C content of soil, total N content of soil, Nm and average temperature in growing period are shown in Table 1. Seeding date, transplanting date and spacing, and N level are shown in Table 2.

In all years, pregerminated seeds were sown on seedling trays to produce uniform seedlings. Thirty- to 33-day-old seedlings were transplanted at 3 seedlings per hill. Plot size ranged from 20 to 62 m². The experiments were laid out in a randomized block design with two replications. All plots received 10-g P m⁻² and 10-g K m⁻² before transplanting as basal application. N in the form of ammonium sulphate (21% N) was applied before transplanting as basal application and at panicle initiation at three levels (0, 3, 6 g N m⁻²).

2. **Measurement of dry matter and N and C contents of soil**

Plants from 12 hills were sampled at panicle initiation and heading stages from each plot. Dry matter was determined after oven drying at 70°C to constant weight, and N concentration was analyzed by the Kjeldahl method.

Each soil sample was collected as a composite of 5 sub-samples taken from the surface soil (0 to 15 cm deep).
All soil samples were air-dried and ground to pass through a 2-mm sieve before analysis. Total N and total C content were analyzed by using the trace mass spectrophotometer (Tracer MAT, Thermo Quest Co. Ltd., Tokyo). Nm was determined as the difference between the amount of N extractable with 2 M KCl solution before and after incubation at 30°C for 4 weeks under waterlogged conditions. In the analysis, the concentration of NH₄⁺ was determined by the indophenol blue method.

3. N uptake analysis

N uptake is theoretically shown as follows.

\[
N_{\text{uptake}} = N_2 - N_1 = N_1 \left( e^{RNR \times (t_2 - t_1)} - 1 \right)
\]

Where \( t_1 \) and \( t_2 \) are the date of panicle initiation and heading, respectively. RNR is the relative N-uptake rate from \( t_1 \) to \( t_2 \). J is shown as follows.

\[
J = \frac{N\text{ uptake} - N_0}{N_c}
\]

Where \( N_c \) is the amount of chemical N to be applied as top-dressing at \( t_1 \).

Results and Discussion

1. Soil properties of experimental plots and N uptake by rice plants

The total G and N contents of soil were not statistically different among different years. Nm was about 2.4, 6.9 and 10.3 mg 100 g⁻¹ in 1999, 2000 and 2001. The water content of soil and the amount of rice straw plowed into the soil during wintertime influenced the amount of N released from soil at following springtime. Such a difference in the amount of solubilized soil N (equal to Nm) among different years was caused by the difference in the soil management in previous wintertime (Table 1).

\( N_1 \), in 1999 was not statistically different from that in 2000 or 2001, respectively. \( N_2 \) and the amount of N accumulated during the period from panicle initiation to heading (\( N_2 - N_1 \)) were greater in 1999 than in other years. Such a difference was caused by the difference in the duration between \( t_1 \) and \( t_2 \) (Table 3).

Table 3. The amount of nitrogen (N) accumulated in aboveground biomass at panicle initiation (\( N_1 \)) and heading (\( N_2 \)), N uptake by rice plants and duration between panicle initiation and heading in the field at the experimental farm of Kyoto Univ. in 1999-2001.

| Year | Accumulated N (g m⁻²) N uptake Duration |
|------|--------------------------------------|-------------------------------|
| 1999 | 4.96a±1.03 12.31a±2.30 7.35a±1.97 38 |
| 2000 | 5.48b±0.95 8.38b±1.80 3.84b±2.23 28 |
| 2001 | 5.69a±1.06 9.55b±2.48 3.86b±2.17 28 |

Mean±S.D.

Means followed by the same letter are not significantly different at the 5% level based on Duncan’s Multiple Range Test.

2. Relationship between \( N_s \) and agronomic properties

In the plots without N top-dressing, Nm and \( N_1 \) significantly correlated with \( N_s \), but the amount of N applied as basal-dressing and the total N content of soil did not (Table 4). The correlation of \( N_s \) with \( N_1 \) and Nm was negative.

Wada et al. (1989) showed that during the period from panicle initiation to the late stage of spikelet initiation, the paddy rice absorbed less N if more N was accumulated at panicle initiation. The rooting zone of paddy rice at panicle initiation in the paddy field with a low N supply is larger in depth and width than that in the field with a high level of N supply (Kawata et al., 1977). The amount of N mineralized from soil organic compounds and that applied as basal-dressing determines the early growth rate of rice. In this study, \( N_1 \) correlated with Nm and the amount of N applied as basal-dressing (\( r=0.464, P<0.05 \) and \( r=0.562, P<0.01 \), respectively). The amount of N accumulated in the aboveground biomass increases as the size of the rooting zone increases (Akita et al., 1989). These facts implied that \( N_1 \) is a negative indicator of the ability of the root system to take up N during panicle initiation to heading.

The amount of N taken up from soil at the middle stage in rice has been reported to be closely correlated with the amount of slowly mineralizable organic N which closely correlated with the total N content of soil (Ando et al., 1978; Ando and Shinjo, 1986; Yamamoto et al., 1993). In the plots without N top-dressing, however, the total N content of soil varied only slightly and did not significantly correlate with \( N_s \).

The amount of N applied as basal-dressing did not correlate with \( N_s \), because most of the N applied as basal-dressing was taken up before panicle initiation (Wada et al., 1971).

In the plots with N top-dressing, the standard deviations of \( N_1 \) and Nm were 1.12 and 3.27, respectively. This suggested that the variation of \( N_s \) was high enough to be predicted individually for the plots with N top-dressing.

Table 4. Correlation coefficient of the amount of N taken up during the period from panicle initiation to heading (\( N_s \)) with the total N content of soil, the amount of mineralizable soil N (Nm), \( N_1 \) and the amount of N applied as basal dressing in the plots without N top-dressing.

| Parameter | Correlation coefficient |
|-----------|------------------------|
| \( N_s \) and Total N content of soil | 0.387 NS |
| Nm | -0.745 ** |
| \( N_1 \) | -0.557 ** |
| Amount of N applied as basal dressing | -0.197 NG |
Table 5. Correlation coefficient and partial correlation coefficient of relative N uptake rate (RNR) during the period from panicle initiation to heading with the total N content of soil, Nm, N1, and the amount of N applied as basal dressing in the plots without N top-dressing.

| Parameter                      | Correlation coefficient | Partial correlation coefficient |
|--------------------------------|-------------------------|--------------------------------|
| RNR and Total N content of soil | 0.402 NS                 | 0.462 *                        |
| Nm                             | -0.739 **                | -0.767 **                      |
| N1                             | -0.839 **                | -0.776 **                      |
| Amount of N applied as basal dressing | -0.381 NS             | 0.182 NS                       |

Table 6. The estimated Ns and the estimated J.

| Amount of N applied as top-dressing (g m⁻²) | Ns (g m⁻²) | J (g⁻¹) |
|---------------------------------------------|------------|---------|
| 0                                           | 2.78a±0.85 | -       |
| 3                                           | 3.15a±0.78 | 0.58a±0.23 |
| 6                                           | 2.75a±0.70 | 0.67a±0.25 |

Mean ± S.D.
Means followed by the same letter are not significantly different at 5% level based on Duncan’s Multiple Range Test.

3. Relationship between RNR and agronomical properties
In order to estimate Ns using equation 2 in each plot with N top-dressing, we examined the relationship between RNR and agronomical properties (total soil N, Nm, and N basal-dressed) in the plots without N top-dressing (Table 5). Nm and N1 significantly correlated with RNR, but the amount of N applied as basal-dressing and total N content of soil did not. Nm, the total N content of soil and N1, significantly correlated (partial correlation) with RNR, but the amount of N applied as basal-dressing did not. Since the correlation of N uptake ability of root system with N1, and Nm was negative in the plots without N top-dressing, the simple and partial correlation of RNR with Nm and N1, also became negative in the plots without N top-dressing.

In the plots without N top-dressing, the simple correlation of RNR with Nm and N1, was significant at the 1% level. The standard deviation of the total N content of soil in the plots without N top-dressing was 0.033, which was too small for the total N content of soil to show a significant simple correlation with RNR. The total N content of soil showed significant partial correlation with RNR at the 5% level, because both the factors, Nm and N1, have been excluded. Since the amount of N absorbed from soil during the period from panicle initiation to heading closely correlated with the total N content of soil (as mentioned above), the partial correlation of RNR with the total N content of soil was positive.

4. Multiple regression analysis
To further elucidate the effect of the agronomical properties on RNR in the plots without N top-dressing, we regressed Nm, the total N content of soil and N1, along with their interaction effects using forward step-wise multiple regression to model the RNR. The resulting equation was

\[ RNR = -0.00081 \times (Nm) + 0.03259 \times (\text{Total N content of soil}) - 0.00333 \times (N1) + 0.00321 \]

\( R^2 = 0.886. \)

Both the coefficients of Nm and N1 were significant at \( p < 0.01 \). The coefficient of the total N content of soil was significant at \( p < 0.05 \).

Ns in the plots without N top-dressing was estimated using equation 2 and 5, and the relationship between estimated and measured values of Ns is shown in Fig. 1 \( (R^2=0.765). \) This result suggests that Ns and J in the plots with N top-dressing can be calculated by substituting RNR estimated using equation 5 for equation 2 and 4. The calculation result is shown in Table 6. Ns calculated using equation 2 and 5 in the plots with N top-dressing did not statistically differ from Ns in the plots without N top-dressing. J calculated using equation 4 was not different among the plots with different N top-
Table 7. Correlation coefficient and partial correlation coefficient of $N_s$ with the total $N$ content of soil, $N_m$, $N_j$, and the amount of $N$ applied as basal-dressing and top-dressing in the plots with $N$ top-dressing.

| Parameter                              | Correlation coefficient | Partial correlation coefficient |
|----------------------------------------|-------------------------|--------------------------------|
| $N_s$ and Total $N$ content of soil    | 0.236 NS                 | 0.575 **                       |
| $N_m$                                  | -0.966 **               | -0.982 **                      |
| $N_j$                                  | -0.280 NS               | -0.604 **                      |
| Amount of $N$ applied as basal dressing| -0.168 NS               | 0.035 NS                       |
| Amount of $N$ applied as top dressing  | -0.260 NS               | -0.295 NS                      |

Table 8. Correlation coefficient and partial correlation coefficient of $J$ with the total $N$ content of soil, $N_m$, $N_i$, and the amount of $N$ applied as basal-dressing and top-dressing in the plots with $N$ top-dressing.

| Parameter                              | Correlation coefficient | Partial correlation coefficient |
|----------------------------------------|-------------------------|--------------------------------|
| $J$ and Total $N$ content of soil      | -0.140 NS               | 0.066 NS                       |
| $N_m$                                  | 0.550 **                | 0.618 **                       |
| $N_i$                                  | -0.311 NS               | -0.446 *                       |
| Amount of $N$ applied as basal dressing| -0.145 NS               | 0.123 NS                       |
| Amount of $N$ applied as top dressing  | 0.295 NS                | 0.188 NS                       |

5. Contribution of $N_1$ and $N$ content of soil to $N_s$ and $J$

The correlation of $N_m$, total $N$ content of soil or $N_i$ with $N_s$ and $J$ was analyzed to examine the contribution of these factors to $N_s$ and $J$ in the plots with $N$ top-dressing (Table 7, 8).

Only the mineralizable soil $N$ significantly correlated with $N_s$. $N_m$, the total $N$ content of soil and $N_1$ showed a significant partial correlation with $N_s$, but the amount of $N$ applied as basal-dressing and top-dressing did not. The standard deviations of the total $N$ content of soil and $N_1$, in the plots with $N$ top-dressing were 0.027 and 1.120, respectively, which were too small to show a significant simple correlation with $N_s$. $N_s$ showed a significant partial correlation with the total $N$ content of soil and $N_1$ at the 1% level because the effect of $N_m$ has been excluded. The simple and partial correlation of $N_s$ with $N_j$ and $N_m$ was negative in the plots without $N$ top-dressing.

Only $N_m$ significantly correlated with $J$. $N_m$ and $N_i$ showed a significant partial correlation with $N_s$, but the total $N$ content of soil and the amount of $N$ applied as basal-dressing and top-dressing did not. The standard deviations of $N_1$ in the plots with $N$ top-dressing were 1.120, which was too small to show a significant simple correlation with $J$. $J$ showed a significant partial correlation with the $N_1$ at the 5% level because the effect of $N_m$ has been excluded.

The correlation of $N_s$ with $N_m$ was negative as mentioned above but the correlation of $J$ with $N_m$ was positive. The $N$ top-dressed on the surface of the paddy field penetrates into the soil of 5 cm deep (Wada et al., 1971). The top-dressed $N$ might have been absorbed mainly by the superficial roots of paddy rice. Application of rice straw or farmyard manure to the paddy field accelerates the development of superficial roots of rice (Kawata and Sejima, 1976). $N_m$ is expected to be larger in the plots with a larger amount of rice straw or farmyard manure plowed into the soil. Thus, the correlation of $J$ with $N_m$ was positive as the result.

6. Conclusion

The soil physicochemical property and rice growth have been reported to influence $J$ and $N_s$ in the paddy fields (Wada et al., 1989; Maeda 1983; Yoshino and Dei, 1978). In our study, the total $N$ content of soil and $N_m$ were used as indicators of the physicochemical property of soil. $N_1$ was used as an indicator of rice growth because it was the critical parameter for deciding the amount of chemical $N$ to be top-dressed at this stage. $N_1$ is a negative indicator of the $N$ uptake activity of the root system.

We quantified the contribution of $N_1$ and $N$ properties of soil to $N_s$ and $J$ in the plots with $N$ applied as top-dressing. $N_i$ affects $N_s$ and $J$ in the paddy fields with the same soil type and weather condition in the growth period. In such paddy fields, crop management generally influences the spatial variability of $N_i$ (Shimada, 1976; Marumoto et al., 1979; Wada et al., 1989). The farmer has been managing the paddy fields
by site-specific N application as topdressing at panicle initiation. In these practices, the amount of fertilizer N might not be fit for the N demand of rice, since the amount is determined assuming that Ns and J are the same in all fields. If the contribution of N1, total N content of soil and Nm to Ns and J is taken into account, the fertilizer N may fit the N demand of rice.

Ns and J were scarcely affected by the total N content of soil. The amount of N taken up by rice plants at the middle and late growth stages has been reported to closely correlate with the amount of slowly mineralizable organic N in soil (Ando and Shinjo, 1986). In our study, the amount of slowly mineralizable soil organic N varied only slightly among plots. The effect of the slowly mineralizable soil organic N on the N sand J must be examined in paddy fields with different crop management practices and in a large paddy field made by merging small paddy fields together.

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