# Effects of different types of fertilizers and methods on dry matter production, yield and nitrogen use efficiency of rice cultivars under field conditions

**Ryo Yabe[a)], Nguyen Quang Co[b,c)], Trinh Thi Sen[a,c)] and Kuniyuki Saitoh[b)]**

*(Course of Applied Plant Science)*

**To examine the effects of different types of fertilizers and application methods on dry matter production, yield, nitrogen accumulation and use efficiency in rice cultivars, we used two rice cultivars (Nipponbare and Takanari) and five fertilizer methods, i.e. Control (0N), Conventional method, Deep fertilizer method, Standard fertilizer method and High fertilizer method in 2009. Dry matter production was more markedly increased with nitrogen fertilizer application than in control, and it was higher with deep fertilizer application in Takanari and standard fertilizer application in Nipponbare, respectively. The differences in dry matter production resulted from CGR and mean LAI in rice cultivars. Greater dry matter production was accompanied with the nitrogen accumulation at harvesting. Rice cultivars accumulated the largest amount of nitrogen at deep fertilizer application. Higher fertilizer application increased the number of panicle and total spikelets m$^{-2}$. The higher grain yield in Takanari resulted from the larger sink capacity. The grain yield of rice cultivars tended to be higher with deep fertilizer application due to the increase in sink capacity. Both deep fertilizer application and basal application of slow-release fertilizer increased the recovery efficiency and partial factor productivity of applied N, however, using slow-release fertilizer is recommended in terms of labor saving and lower cost.**

**Key words :** Conventional method, deep fertilizer method, nitrogen use efficiency, rice (*Oryza sativa* L.), slow-release fertilizer

## Introduction

Rice is the staple food of more than a half the population in the world[7,8]. Rice production accounts for 27% of total cereal production in the world, and 90% of rice production takes place in Asian countries[2,12].

Nitrogen (N) is necessary for rice growth and development and it is the most yield-limiting nutrient in lowland rice production all around the world[3]. Nitrogen uptake is affected by various factors such as type of fertilizers, soil and weather conditions[20], etc. Nitrogen is involved in all the metabolic processes in plants, and about 75% of leaf N is associated with chloroplast, which are essential for dry matter production during photosynthesis[11]. Nitrogen requirement in rice is higher than that of other nutrients. High nitrogen availability to the plant has been associated with increase in plant height, high chlorophyll content, and leads to increased productivity[1]. Moreover, nitrogen plays an important role in increasing leaf area and photosynthetic rate which consequently affects dry matter production and yields of rice plants.

In the efforts to improve rice yields, researchers have applied many methods such as using high yielding varieties, applying more nitrogen fertilizers and timely scheduling of topdressing[4,6,14]. However, heavy nitrogen application not only increases labor and costs of production but also pollutes the air and water quality[17]. Therefore, cultivation techniques have been applied such as fertilizer applications that help rice plant absorb nutrients at different growth stages and produce higher dry matter production, grain yield is still needing to improve.

Deep layer fertilizer application, known as deep fertilizer application was used in the previous century. Wada[18] and Wang[19] reported that deep layer application increased the number of spikelets m$^{-2}$, thus increasing rice grain yield (10—13%) compared with conventional fertilizer method. However, deep layer fertilizer application increased the costs of labor than conventional method. Recently, use of slow-release fertilizer has been

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*a) Graduate school of Natural Science and Technology, Okayama University.*
*b) Graduate school of Environmental and Life Science, Okayama University.*
*c) Faculty of Agronomy, Hue University of Agriculture and Forestry, Hue University, Vietnam.*

adopted before transplanting. This method is effective in supplying nutrients in a timely manner, and reduces nitrogen losses. Slow-release fertilizer application can be advantageous in rice production since plants efficiently absorb available nitrogen leading to high dry matter production and grain yield. However, the amount of nitrogen uptake and accumulation by rice plants is not clearly understood, especially in some newly developed high-yielding cultivars. The objective of this study is to classify the uptake and use efficiency of nitrogen fertilizer based on dry matter production, grain yield, nitrogen accumulation and use efficiency with different fertilizer application methods.

## Materials and Methods

### 1 . *Plant materials and cultivation*

In this study, we selected two rice cultivars, "Nipponbare", widely grown in Japan, and "Takanari", one of the high yielding rice cultivars. The two rice cultivars were grown in a submerged paddy field.

The experiment was conducted in the experimental farm at the Field Science Center, Faculty of Agriculture, Okayama University, Japan (34° 41'N, 133° 55'N) in 2009. Two rice cultivars and five fertilizer methods were arranged in a randomized complete block design. Three fertilizer methods were used, namely ; Control (0N) ; Conventional method ; Deep fertilizer method for "Nipponbare" and "Takanari", and another two methods, Standard fertilizer method and High fertilizer method for "Nipponbare". The timing and amount of nitrogen fertilizer application are presented in Table 1.

In the conventional method, chemical fertilizer (Rin-ka-an 44, N : $P_2O_5$ : $K_2O$=14 : 17 : 13) was mixed and incorporated into the soil at 4 g $m^{-2}$ as basal dressing, every 2 gN were applied at 45 DBH (days before heading), 20 DBH and 5 DAH (days after heading), respectively. In the deep fertilizer method, the same amount of fertilizer was applied with conventional method as a basal dressing and 6 g $m^{-2}$ of paste fertilizer (Neo paste 1, N : $P_2O_5$ : $K_2O$=12 : 12 : 12) was injected in the middle of 4 hills at the depth of 15 ㎝ by soil injector at 30 DBH. In the standard and high fertilizer methods using slow release fertilizer (100D-80, N : $P_2O_5$ : $K_2O$=14 : 14 : 14) was applied as basal dressing at the rate of 8 and 16 gN $m^{-2}$, respectively.

Seeds of rice were sown on 11 May and transplanted on 10 June, 2009 at a density of 22.2 hills $m^{-2}$ (30× 15 ㎝), with three plants per hill. Pests and diseases were intensively controlled to avoid yield loss.

### 2 . *Growth analysis and nitrogen use efficiencies*

The plants were sampled every two weeks after transplanting to determine dry weight and leaf area. Sixteen hills were sampled and eight hills with average numbers of stem were selected at each stage. Plants were separated into leaves, stems and panicles. Leaf area was measured with leaf area meter (AAM-9 ; Hayashi Denko Co., Tokyo, Japan) after separation. All plant samples were dried in a ventilated oven at 80℃ until constant weight. The crop growth rates (CRG), net assimilation rates (NAR) and mean leaf area index (LAI) were calculated.

At the maturity stage, 20 hills for each replication were harvested manually for yield determinations. Yield was determined by brown rice weight. Fully ripened grains were selected by sieving through 1.8 ㎜ and 1.6 ㎜ mesh for Nipponbare and Takanari, respectively. Thousand grain weights was measured by using brown grains with 14.5% moisture.

At each stage, the plant parts from two hills were each ground into powder by vibrating mill (Heiko, Co. Ltd) and the nitrogen concentration from each plant parts was analyzed by CN-Corder (MT-700, Yanaco Industry). Total nitrogen accumulation was calculated by multipling the above-ground dry weight by nitrogen concentration.

On the basis of these measurements, nitrogen use

Table 1 Timing and amount of nitrogen fertilizer application for rice cultivation

| Nitrogen application methods | Basal dressing (N g $m^{-2}$) | Top dressing | | | | Total dressing ( g $m^{-2}$) |
|---|---|---|---|---|---|---|
| | | 45 DBH | 30 DBH | 20 DBH | 5 DAH | |
| Control (0N) | 0 | 0 | 0 | 0 | 0 | 0 |
| Conventional method | 4 | 2 | 0 | 2 | 2 | 10 |
| Deep fertilizer method | 4 | 0 | 6 | 0 | 0 | 10 |
| Standard fertilizer method | 8 | 0 | 0 | 0 | 0 | 8 |
| High fertilizer method | 16 | 0 | 0 | 0 | 0 | 16 |

(DBH : Days before heading ; DAH : Days after heading) efficiency (NUE) indices were calculated by the following formulas ;

N use efficiency for biomass ($BE_N$) = BY/AN

Recovery efficiency of applied N ($RE_N$) = ($AN-AN_O$)/APN

Nitrogen use efficiency for yield ($YE_N$) = GY/AN

Partial factor productivity of applied N ($PFP_N$) = GY/APN

Where BY ; Biomass yield ($g\,m^{-2}$), GY ; Grain yield ($g\,m^{-2}$), AN ; Accumulated N ($g\,m^{-2}$), $AN_O$ ; Accumulated N without fertilizer ($g\,m^{-2}$), APN ; Applied N ($g\,m^{-2}$)

## Results and Discussion

### 1. *Dry matter production*

The effects of different nitrogen application methods on dry weight were significant for all growth and development stages, except for the young seedling in Nipponbare and Takanari (Table 2). Nitrogen fertilizer increased the number of tillers and top dry weight at full heading stage (76 DAT). At full heading stage, Takanari produced a significantly larger amount of dry matter at deep fertilizer method (1359 $g\,m^{-2}$) than that of the other methods. However, with more nitrogen fertilizer application in Nipponbare, plant dry weight also increased but there was no significant difference among fertilizer methods.

At harvesting stage, plant dry weight with deep fertilizer method showed the largest amount of dry weight in Takanari (1891 $g\,m^{-2}$), and was consistently higher than other methods, followed by standard fertilizer method in Nipponbare (1750 $g\,m^{-2}$). Without nitrogen application, Nipponbare produced the least biomass (1243 $g\,m^{-2}$), lower than Takanari (1410 $g\,m^{-2}$).

### 2. *Growth parameter*

To identify the factors affecting the differences in dry matter production, we compared CGR, NAR and mean LAI among fertilizer methods (Fig. 1). CGR increased after 20 DAT (days after transplanting) and it differed according to fertilizer method. In Takanari, CGR tended to be higher in deep fertilizer, especially 62–76 DAT and 76–90 DAT. During these periods, CGR was 26.8 and 29.7 $g\,m^{-2}\,day^{-1}$, respectively. The same result was observed in Nipponbare. After heading, CGR decreased in both cultivars and fertilizer methods. The CGR after heading was consistently higher in standard and high fertilizer methods, especially at late ripening stage. Higher CGR after heading were responsible for the larger dry matter production.

NAR tended to be lower after transplanting and it differed by fertilizer method. NAR decreased with applied nitrogen fertilizer. However, it tended to be higher in standard and high fertilizer methods at the late ripening period.

Higher nitrogen application increased the number of stems with larger leaf area in both rice cultivars. The mean LAI increased after transplanting and it was largest at 76 DAT in both cultivars. In Takanari, deep fertilizer application method indicated the largest mean LAI (7.87 $m^2\,m^{-2}$), whereas high fertilizer application (using slow release fertilizer) showed the largest mean LAI (8.29 $m^2\,m^{-2}$) in Nipponbare. After heading, mean LAI decreased in all fertilizer application methods. At late ripening stage, deep fertilizer application method also showed the highest mean LAI values among the fertilizer applications in both cultivars.

### 3. *Yield and yield components*

Nitrogen fertilizer application methods had significant

Table 2 Dry matter production at different fertilizer application methods in rice cultivars

| Cultivars | Methods | Days after transplanting (DAT) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 20 | 34 | 48 | 62 | 76* | 90 | 104** |
| Nipponbare | 0N | 4.2 a | 58 b | 172 c | 437 e | 704 d | 984 b | 1162 d | 1244 c |
| | Conventional method | 4.2 a | 64 ab | 297 b | 539 d | 805 c | 1109 a | 1380 c | 1486 b |
| | Deep fertilizer method | 4.2 a | 64 ab | 275 b | 504 c | 860 bc | 1168 a | 1482 b | 1640 a |
| | Standard fertilizer method | 4.2 a | 68 a | 287 b | 605 b | 923 ab | 1169 a | 1539 a | 1750 a |
| | High fertilizer method | 4.2 a | 72 a | 349 a | 692 a | 959 a | 1158 a | 1414 c | 1669 a |
| Takanari | 0N | 3.7 a | 59 b | 218 b | 445 c | 692 b | 991 c | 1217 c | 1411 b |
| | Conventional method | 3.7 a | 60 a | 335 a | 629 a | 905 a | 1166 b | 1458 b | 1635 ab |
| | Deep fertilizer method | 3.7 a | 60 a | 306 a | 566 b | 942 a | 1359 a | 1703 a | 1891 a |

Means followed by the same letters are not significantly different at the 0.05 level by Tukey's test.
Unit : $g\,m^{-2}$. *, ** : heading and maturity stages, respectively.

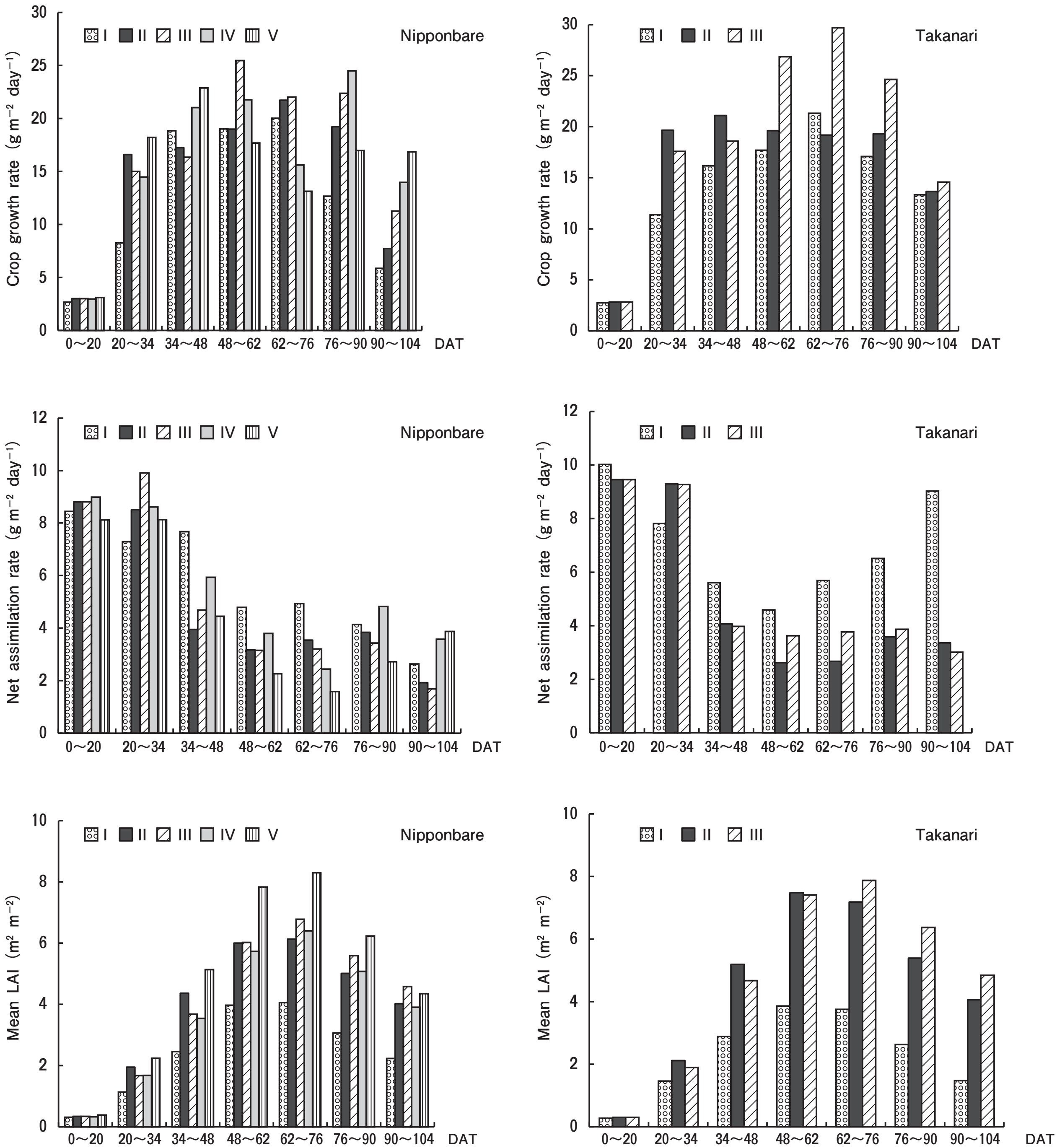


**Fig. 1 Changes in CGR, NAR and mean LAI from DAT from transplanting to harvesting under different fertilizer methods in two rice cultivars. (I ; 0N, II ; Conventional method, III ; Deep fertilizer method, IV ; Standard fertilizer method, V ; High fertilizer method).**

effects on grain yield, but the differences by fertilizer method were not significant.

Grain yields without nitrogen application were 451 g $m^{-2}$ and 706 g $m^{-2}$ in Nipponbare and Takanari, respectively. The more nitrogen fertilizer is applied to rice, the more the grain yield increases. The grain yield of Takanari with deep fertilizer application method exceeded 863 g $m^{-2}$ with the highest sink capacity (945 g $m^{-2}$), followed by conventional fertilizer application method (with grain yield 800 g $m^{-2}$ and sink 854 g $m^{-2}$, respectively). The same tendency was observed in Nipponbare. Grain yield increased with

Table 3 Yield and yield components of rice cultivars under different fertilizer application methods

| Cultivars | Fertilizer methods | No. of panicles (panicle $m^{-2}$) | No. of spikelets ($panicle^{-1}$) | No. of spikelets ($10^3$ $m^{-2}$) | % of ripened grains (%) | 1000 grains weight (g) | Sink capacity (g $m^{-2}$) | Grain yield (g $m^{-2}$) |
|---|---|---|---|---|---|---|---|---|
| Nipponbare | 0N | 257 b | 85 a | 21.9 b | 92.4 a | 22.3 a | 488 b | 451 b |
| | Conventional method | 368 a | 82 a | 30.2 a | 93.2 a | 22.4 a | 676 a | 630 a |
| | Deep fertilizer method | 347 a | 93 a | 32.1 a | 91.1 a | 22.0 ab | 707 a | 644 a |
| | Standard fertilizer method | 337 a | 86 a | 29.1 a | 91.5 a | 21.9 ab | 638 a | 590 a |
| | High fertilizer method | 388 a | 84 a | 32.6 a | 91.0 a | 21.4 b | 699 a | 656 a |
| Takanari | 0N | 249 a | 149 a | 37.2 b | 92.5 ab | 20.5 b | 763 b | 706 b |
| | Conventional method | 283 a | 146 a | 40.9 ab | 93.7 a | 20.9 ab | 854 ab | 800 a |
| | Deep fertilizer method | 299 a | 151 a | 45.0 a | 91.4 b | 21.0 a | 946 a | 863 a |

Means followed by the same letters are not significantly different at the 0.05 level by Tukey's test.

Table 4 Nitrogen accumulation in rice cultivars under different nitrogen fertilizer application methods

| Cultivars | Methods | Days after transplanting (DAT) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 20 | 34 | 48 | 62 | 76* | 90 | 104** |
| Nipponbare | 0N | 0.14 a | 1.6 c | 2.6 d | 5.8 e | 6.6 d | 7.4 d | 7.5 e | 8.0 d |
| | Conventional method | 0.14 a | 2.1 b | 6.8 b | 8.3 d | 11.2 c | 10.5 c | 12.9 d | 16.1 c |
| | Deep fertilizer method | 0.14 a | 2.1 b | 5.7 cc | 9.2 c | 12.6 b | 16.0 a | 19.2 a | 24.0 a |
| | Standard fertilizer method | 0.14 a | 2.2 b | 6.2 bc | 9.9 b | 11.5 bc | 11.7 b | 15.2 c | 15.8 c |
| | High fertilizer method | 0.14 a | 2.7 a | 9.4 a | 14.0 a | 15.8 a | 15.4 a | 17.3 b | 18.7 b |
| Takanari | 0N | 0.08 a | 1.6 b | 3.6 b | 5.0 b | 6.1 c | 7.1 c | 8.0 c | 10.8 b |
| | Conventional method | 0.08 a | 1.9 a | 6.8 a | 10.6 a | 11.8 b | 12.0 b | 14.2 b | 14.9 a |
| | Deep fertilizer method | 0.08 a | 1.9 a | 6.5 a | 10.7 a | 16.4 a | 18.6 a | 19.5 a | 18.22 a |

Means followed by the same letters are not significantly different at the 0.05 level by Tukey's test.
Unit : g $m^{-2}$. *, ** : heading and maturity stages, respectively.

more nitrogen fertilizer applied. Grain yield in high nitrogen fertilizer application (using slow release fertilizer) exceeded 656 g $m^{-2}$, a little higher than deep fertilizer application method (644 g $m^{-2}$), due to the increased number of panicles. Higher grain yield and sink capacity in deep fertilizer method resulted from the larger number of spikelets per panicle and total spikelets $m^{-2}$ in both rice cultivars.

**4. *Nitrogen accumulation***

Table 4 shows the accumulated nitrogen in rice cultivars with different fertilizer methods. The accumulated nitrogen varied among rice cultivars and fertilizer methods. Before heading stage, the amount of accumulated nitrogen tended to be larger in Takanari than Nipponbare. Deep fertilizer application method showed the largest amount of accumulated nitrogen in Takanari 16.4 g $m^{-2}$, followed by high fertilizer application method using slow release fertilizer in Nipponbare (15.8 g $m^{-2}$). In Nipponbare, the amount of nitrogen accumulated was significantly larger with deep fertilizer application than the other fertilization methods, followed by high fertilizer application method (18.7 g $m^{-2}$). In Takanari, deep fertilizer application method also accumulated the larger amount of nitrogen (18.2 g $m^{-2}$) than conventional method (14.9 g $m^{-2}$), but the difference was not significant. Without nitrogen fertilizer application, accumulated nitrogen was higher in Takanari (10.8 g $m^{-2}$) than that in Nipponbare (8.0 g $m^{-2}$).

**5 . *Nitrogen use efficiency and some relative parameters***

Nitrogen use efficiency and some relative parameters with different fertilizer application methods are presented in Table 5.

$BE_N$ was varied among fertilizer and application methods and it tended to be lower with more nitrogen fertilizer application. $BE_N$ varied from 104.0 to 134.9 g $g^{-1}$ and 84.0 to 155.1 g $g^{-1}$ in Takanari and Nipponbare, respectively. Standard fertilizer application method using slow-release fertilizer had higher biomass nitrogen use efficiency (108.9 g $g^{-1}$) than other fertilizer methods in Nipponbare.

$RE_N$ reflected the capability of nitrogen accumulation from fertilizer application. In both rice cultivars, deep fertilizer application method showed higher values than in other fertilizer methods, 159.5% and 75.7% in Nipponbare and Takanari, respectively. $RE_N$ also decreased in high fertilizer method compared to standard fertilizer method using slow-release fertilizer (97.3%).

$YE_N$ varied among fertilizer methods. In both rice cultivars, $YE_N$ were highest with no nitrogen application, followed by the conventional method, and lowest in deep fertilizer method. $YE_N$ was higher in Takanari than in Nipponbare at each fertilizer application method.

$PFP_N$ was defined as the ratio of grain yield with nitrogen application, and it reflected the marginal effect of nitrogen absorbed by rice plant from N fertilizer. In both cultivars, $PFP_N$ was higher in standard fertilizer application method (73.7 g $g^{-1}$) than the other methods in Nipponbare. Meanwhile, $PFP_N$ was highest in standard fertilizer method than the other fertilizer methods in Nipponbare.

**6 . *Relationship between sink capacity, grain yield and accumulated N***

Sink capacity had a significant relationship with grain

Table 5 Nitrogen use efficiency and some relative parameters

| Cultivars | Methods | Grain yield (g $m^{-2}$) | N accumulation (g $m^{-2}$) | $BE_N$ (g $g^{-1}$) | $RE_N$ (%) | $YE_N$ (g $g^{-1}$) | $PFP_N$ (g $g^{-1}$) |
|---|---|---|---|---|---|---|---|
| Nipponbare | 0N | 451 | 8.0 | 155.1 | — | 56.3 | — |
| | Conventional method | 630 | 16.1 | 92.2 | 81.0 | 39.1 | 63.0 |
| | Deep fertilizer method | 644 | 24.0 | 77.1 | 159.5 | 26.9 | 64.4 |
| | Standard fertilizer method | 590 | 15.8 | 108.9 | 97.3 | 37.3 | 73.7 |
| | High fertilizer method | 656 | 18.7 | 84.0 | 66.4 | 35.2 | 41.0 |
| Takanari | 0N | 706 | 10.8 | 134.9 | — | 65.6 | — |
| | Conventional method | 800 | 14.9 | 109.9 | 41.2 | 53.7 | 80.0 |
| | Deep fertilizer method | 863 | 18.2 | 104.0 | 75.7 | 47.1 | 86.3 |

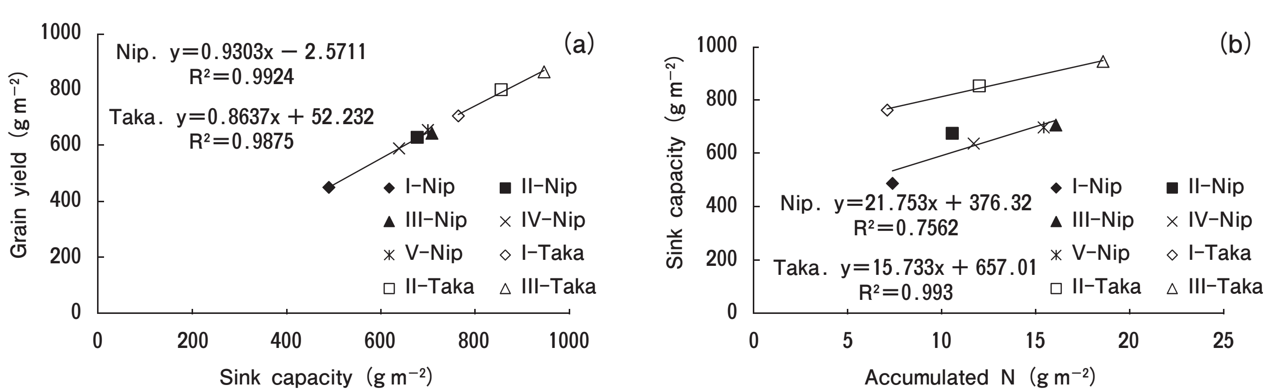


Fig. 2 Relationships between sink capacity and grain yield (a), accumulated N at heading stage and sink capacity (b) in Nipponbare and Takanari with different fertilizer methods. (I ; 0N, II ; Conventional method, III ; Deep fertilizer method, IV ; Standard fertilizer method, V ; High fertilizer method).

yield (Fig. 2a). Higher sink capacity contributed to higher grain yield in Nipponbare and Takanari. In both cultivars, deep fertilizer application method had larger sink capacity than the other fertilizer methods. Close relation was found between accumulated N at heading and sink capacity but the sink capacity with the same level of accumulated N in Takanari was larger than that in Nipponbare (Fig. 2b). Sink capacity of Takanari was larger than that in Nipponbare with each fertilizer method. The more nitrogen accumulated, the higher the sink capacity produced. Especially with deep fertilizer application method in Takanari, the largest nitrogen accumulation contributed to the higher sink capacity.

## Discussion

In recent years, rice grain yield has increased markedly due to the improvement of rice cultivars and cultivation methods. In this study, we compared the effects of different fertilizer application methods on dry matter production, N accumulation and yield in rice cultivars. With more nitrogen fertilizer application, the rice plant can absorb and produce more dry matter, resulting in higher grain yield[4,9,20]. Previously, it was reported that nitrogen fertilizer plays an important role in increases dry mater and rice yield[13,14,17], because it increases the photosynthetic rate and thus dry matter especially at the heading and ripening stages[5,13]. In this study, plant dry weight increased with different nitrogen fertilizer applications (Table 2). Plant dry weight showed higher values in deep fertilizer, standard fertilizer and high fertilizer application methods than both conventional method and control (0N). Takanari produced the highest dry matter production (1891 g $m^{-2}$) among rice cultivars and fertilizer methods. However, in Nipponbare, the highest plant dry weight was obtained with standard fertilizer method, followed by deep fertilizer method (Table 2). Thus, deep fertilizer application method is effective to obtain a high dry matter production in rice cultivars, and methods using slow-release fertilizer might have the potential to get higher dry matter production in rice cultivars.

With differing nitrogen fertilizer dose and timing of application, CGR and mean LAI tended to be higher with high nitrogen fertilizer applied[10,17]. In the present study, CGR and mean LAI showed the highest values during 62–76 DAT. Deep fertilizer method had a higher CGR at this stage, 29.7 g $m^{-2}$ $d^{-1}$ and 25.5 g $m^{-2}$ $d^{-1}$ in Takanari and Nipponbare, respectively (Fig 1). Similarly, the mean LAI in all fertilizer methods tended to be significantly higher than control, especially with deep fertilizer method and high fertilizer method (slow-release fertilizer), and CGR and mean LAI showed the maximum at the heading and flowering stages. Plants with higher CGR and mean LAI during this stage might be related with higher grain yield at harvest.

Rice plant can absorb and accumulate more nitrogen under high nitrogen applied condition. Accumulated N was remarkably affected by nitrogen fertilizer application and cultivation method[4,10,15]. The present study showed that nitrogen uptake and accumulation increased consistently from transplanting to harvesting time. At the same time, nitrogen accumulated was lowest in control (0N) and higher in the other methods, especially with deep fertilizer methods (24.0 g $m^{-2}$) in Nipponbare. This means that plants can uptake and use more nitrogen when the fertilizer applied deep and near to the root systems. This method is easy for rice plant uptake nitrogen fertilizer and produces higher sink capacity (Fig. 2b). Using slow-release fertilizer, plants can uptake and accumulate more nitrogen compared with other methods, especially in Nipponbare (Table 4).

Grain yield of rice is the product of different yield components. The panicle density is the most important component in determining grain yield[2,3]. Okumura[15] reported that deep fertilizer application increased the number of spikelets $m^{-2}$ and number of spikelets per panicle, which leads to increasing yield. Wada[18] and Wang[19] also concluded with the same result, but confirmed that grain yield increased 10% to 13% compared with conventional methods. In this study, the number of panicles increased with different fertilizer application methods. The number of panicles ranged from 249 to 388 which was significantly higher than in the control (0N). High fertilizer application method produced higher number of panicles than other methods in Nipponbare. On the other hand, the number of spikelets $m^{-2}$ significantly increased with fertilizer application method. Deep fertilizer application showed the highest number of spikelets (45,000) in Takanari, and high fertilizer application method produced the highest number of spikelets (32,000) in Nipponbare. Higher yield components contributed to higher sink capacity, and higher grain yield is determined by higher sink capacity (Fig. 2a). It indicated that larger sink capacity is one of the factors that determine grain yield.

$YE_N$ decreased more among the other fertilizer application methods than in the control (0N). These results are similar with the other studies reported for japonica cultivars[2,16]. $YE_N$ tended to be higher in Takanari than in Nipponbare. This was due to the higher amount of accumulated N resulting in larger sink capacity relative to accumulated N, and then increased the yield in Takanari. Both deep fertilizer application and basal application of slow release fertilizer increased the recovery efficiency and partial factor productivity of applied N. Using slow release fertilizer is recommended in terms of labor saving and lower cost.

## Conclusion

Nitrogen fertilizer application methods were able to significantly increase dry matter production, panicle $m^{-2}$, total spikelet $m^{-2}$, grain yield, and nitrogen accumulation at harvesting time. Deep fertilizer application is a good way for rice cultivar uptake of more nitrogen fertilizer. However, using slow-release fertilizer might be suitable for modern rice cultivation because of labor saving and lower cost. Higher grain yield can be explained by higher dry matter production, higher nitrogen accumulated at harvesting and larger sink capacity.

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# 水稲品種の乾物生産，収量と窒素利用効率に及ぼす肥料と施肥法の影響

矢部　　亮[a)]・グエン クアン コ[b,c)]・トリン ティ セン[a,c)]・齊藤　邦行[b)]
（応用植物科学コース）

水稲の乾物生産，収量，窒素利用効率に及ぼす肥料と施肥法の影響を試験するため，水稲品種日本晴とタカナリを供試し，対照区（無施肥），慣行施肥区（分割追肥），深層追肥区，標準緩効性肥料基肥施肥区，倍量緩効性肥料基肥施肥区の5試験区を用いて栽培を行った．窒素施肥とともに，乾物生産が増大し，最終乾物重はタカナリでは深層追肥区，日本晴では標準緩効性肥料基肥施肥区で最も高くなった．乾物重の相違には個体群成長速度と葉面積指数が主として影響していた．収穫期の乾物重が大きいほど，窒素蓄積が多くなった．窒素蓄積量は両品種ともに深層追肥区で多くなった．施肥量の増加は穂数と㎡当たり穎花数を増加させた．タカナリの収量が高いことには，シンク容量が大きいことが関係した．両品種ともに慣行施肥区に比べ深層追肥区の収量が高くなったが，これにはシンク容量の拡大が関係していた．深層追肥区，標準緩効性肥料基肥施肥区ともに慣行施肥区に比べ窒素回収効率，部分要因生産性ともに向上したが，省力・低コストの観点からは施肥効率の高い緩効性肥料の利用が推奨された．

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a）岡山大学自然科学研究科
b）岡山大学環境生命科学研究科
c）フエ大学農学部