한작지(Korean J. Crop Sci.), 58(3): 213~219(2013)
DOI : http://dx.doi.org/10.7740/kjcs.2013.58.3.213

# Nitrogen Use Efficiency of High Yielding Japonica Rice (*Oryza Sativa* L.) Influenced by Variable Nitrogen Applications

Shin-Gu Kang*†, Mian Sayeed Hassan*,***, Bon-Il Ku*, Wan-Gyu Sang*, Min-Kyu Choi*, Young-Doo Kim*, Hong-Kyu Park*, M. Khalequzzaman A. Chowdhury***, Bo-Kyeong Kim**, and Jeom-Ho Lee*

**Department of Rice and Winter Cereal Crop, NICS, RDA, Iksan 570-080, Korea*
***National Institute of Crop Science, RDA, Suwon 441-857, Korea*
****Bangladesh Agricultural Research Council (BARC), Farmgate Dhaka-1215, Bangladesh*

**ABSTRACT** A field study was conducted to understand nitrogen use efficiency of high yielding Japonica rice varieties under three levels of nitrogen fertilizer (90, 150 and 210 kg N $ha^{-1}$) in Iksan, Korea. Two high yielding rice varieties, Boramchan and Deuraechan, and an control variety, Dongjin2, were grown in fine silty paddy. Nitrogen use efficiencies (NUE) were 83.3, 56.3, and 41.2 in 90, 150, and 210 kg N $ha^{-1}$ fertilizer level, respectively. Total nitrogen uptake varied significantly among nitrogen levels and varieties. Variety Dongjin2 showed the highest nitrogen uptake efficiency (NUpE), while Boramchan and Deuraechan showed higher nitrogen utilization efficiency (NUtE). However, Nitrogen harvest index (NHI) was higher in Boramchan (0.58) than Deuraechan (0.57) and Dongjin2 (0.53). Rough rice yield showed linear relationship with total nitrogen uptake ($R^2$=0.72) within the range of nitrogen treatments. Boramchan produced significantly higher rough rice yield (8546 kg $ha^{-1}$) which mainly due to higher number of panicles per $m^2$ compared to Deuraechan (7714 kg $ha^{-1}$). Deuraechan showed higher number of spikelets per panicle, but showed lower yield due to lower number of panicle per $m^2$. Rice varieties showed different nitrogen uptake ability and NUE at different nitrogen level. Plant breeders and agronomist should take advantage of the significant variations and relationships among grain yield, NUpE, and NUE.

*Keywords* : rice, high yield, NUE, nitrogen uptake

**Nitrogen** is the most critical input that limits rice productivity (Mae, 1997). The required amount of nitrogen depends on soil type, variety, climate, method of application and type of fertilizer. However, supply of proper amount of nitrogen based on the physiological requirement is the key factor. Through proper nitrogen management, one kg of nitrogen accumulation can produce 50 kg of grain under irrigated conditions (Yoshida, 1981). However, acquisition of applied nitrogen by the rice crop is typically less than 40% in farmer's fields (Cassman *et al.,* 1993). Further increase of yield from the existing cultivars is possible by increasing nitrogen use efficiency (NUE).

For crops, NUE can be defined as grain yield per unit nitrogen supply (Moll *et al.,* 1982). NUE is understood by the combination of the nitrogen uptake efficiency (NUpE) and nitrogen utilization efficiency (NUtE). Nitrogen use efficiency (NUE) largely depends on nutrient balance, water availability, light intensity, disease pressures and cultivated variety. Nitrogen efficient genotype is considered in two different terms: the ability to convert high nitrogen input into yield comparatively better than other genotypes or the ability to realize an above average yield at suboptimal nitrogen level. Rice genotypes showed different nitrogen uptake, nitrogen translocation efficiency, and also NUE (Broadbent *et al.*, 1987; Cho and Koh, 2007, Singh *et al.*, 1998). In some researches, increasing NUpE is focused as the strategy to increase NUE with high grain yield (Cassman *et al.,* 1993; Rauna and and Johnson, 1999; Feng *et al.*, 2011).

Grain yield of rice is the final product of the combination of number of panicles per unit area, spikelet density, percentage of filled spikelets and grain weight. The primary yield determinant of yield in rice is the number of spikelets per unit land (Gravoid and Helms, 1992). For achieving higher yield in rice, the sink size

†Corresponding author: (Phone) +82-63-840-2168 (E-mail) sgkang82@korea.kr
<Received 3 January, 2012; Revised 24 May, 2013; Accepted 29 August, 2013>

should be increased by increasing panicle size or number or either. The cultivars having large panicles may the best option but the adequate numbers of panicles need to be maintained properly in terms of sink-source balance (Kim *et al.*, 1993). Therefore, this study has undertaken to evaluate the morpho-physiological response of high yielding Japonica rice varieties under variable nitrogen levels.

## MATERIALS & METHODS

Field experiment was conducted in a field at National Institute of Crops Science (NICS) in Iksan in 2011 to study variation in N use efficiency by mid-late maturing rice varieties. Major soil chemical properties of the experimental fields were pH 5.6-6.0, organic matter 26.8-29.7g $kg^{-1}$, total nitrogen 1.91-2.04 g $kg^{-1}$, available phosphorous ($P_2O_5$) 114-118 mg $kg^{-1}$, EC 0.6-07 $dSm^{-1}$. Exchangeable cations ($cmol^{+}$ $kg^{-1}$) were K 0.35-0.38, Ca 3.54-3.97, Mg 1.85-2.01, and Na 0.49-0.54.

The experiment was laid out in a split plot design with three replications, where nitrogen levels were in the main plot and rice varieties were in subplots. The subplot size was 28 m × 2.6 m. The nitrogen levels were 90, 150, and 210 kg N $ha^{-1}$ and three Japonica rice varieties were Boramchan, Deuraechan and Dongjin2, of which all mid-maturing but different in grain yield potential.

Experimental fields were plowed until well puddle and leveled properly. Nitrogen fertilizer was applied by split ratio of 50%, 30% and 20% at basal, tillering stage, and panicle initiation stage, respectively. As basal fertilizer, 100% phosphorus as $P_2O_5$ (45 kg $ha^{-1}$) and 70% potassium as $K_2O$ were also applied before transplanting. The remaining 30% $K_2O$ was applied as top dress at panicle initiation stage. The plots were transplanted 30-day-old seedlings by rice transplanter (3-4 seedlings per hill) with a spacing of 30 cm × 14 cm of 8 rows for each variety on 3 June, 2011. Weeds, insects and diseases were controlled with agrochemicals, and water was managed properly for optimum growth following standard cultivation protocol of NICS, RDA.

The seasonal changes in mean air temperature, precipitation, and sunshine hours during rice growing period were described in figure 1. The mean air temperature in the experimental year was similar to the previous 10-year average. However, rainfall in the experimental period recorded 1251 mm which was 350 mm higher than the 10-year average. Heading dates were delayed around 3 days due to heavy rainfall and reduced sunshine hours during

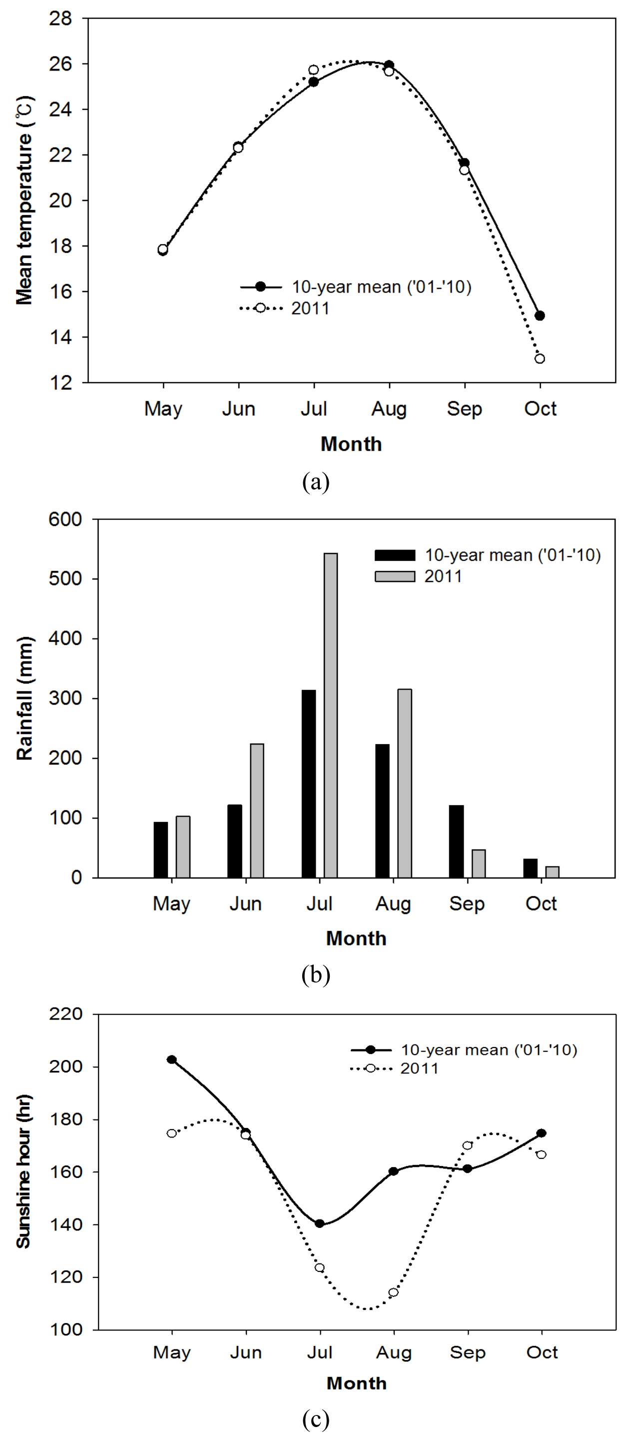


**Fig. 1.** Monthly mean air temperature, rainfall, and sunshine hour during the rice growing period in Iksan, 2011.

July and August. Under a little unfavorable weather condition, the three varieties in this experiment showed lower rough rice yield than the registered yield.

Gain yield was measured in 14% moisture contents and straw weight recorded as sun dry basis. Nitrogen contents (g $kg^{-1}$) were analyzed by Kjeldahl method using Kjeltec 2400 Analyzer. The terminology of nitrogen efficiency parameters was determined using the following equations (Gueye and Becker, 2011).

Nitrogen use efficiency (NUE) = Gw/Ns
Nitrogen uptake efficiency (NUpE) = Nt/Ns
Nitrogen utilization efficiency (NUtE) = Gw/Nt
Nitrogen harvest index (NHI) = Gn/Nt

Where, Gw is grain yield of rough rice at 14% moisture content, Ns is nitrogen supply, Nt is nitrogen content (total uptake) in plant, Gn is grain N uptake. All of the above quantities are expressed in kg $ha^{-1}$. Harvest index (HI) was derived variable represent the partitioning efficiency by the ratio of grain yield over total dry matter.

A combined analysis of variance for the single year data with two replications was carried out to evaluate the contribution of nitrogen level, variety, and nitrogen level × variety interaction. The interaction effects were presented where they were significant. Linear correlations were used to examine the relationship between grain yield and nitrogen uptake, NUtE, HI, and NHI were carried out. The differences between the treatments were determined using Duncan's multiple rage test procedures done by the SAS software (SAS Institute Inc., Cary, NC, USA).

## RESULTS & DISCUSSION

### Nitrogen content and uptake

Nitrogen content (g $kg^{-1}$) in grain and straw at maturity was examined to determine total nitrogen uptake and nitrogen use efficiency (NUE), uptake efficiency (NUpE), utilization efficiency (NUtE) and nitrogen harvest index (NHI). The status of grain and straw nitrogen (g $kg^{-1}$) showed consistent magnitude under optimum to high levels of nitrogen (Table 1). The mean across varieties nitrogen

**Table 1.** Effect of variable nitrogen levels on nitrogen contents of Japonica rice varieties.

| Nitrogen level/Variety | Nitrogen content (g $kg^{-1}$) | | Nitrogen uptake (kg $ha^{-1}$) | | Total N in plant (kg $ha^{-1}$) |
|---|---|---|---|---|---|
| | Grain | Straw | Grain | Straw | |
| Nitrogen level | | | | | |
| 90 kg $ha^{-1}$ | 9.6a | 7.1a | 72.2b | 59.1a | 131.3b |
| 150 kg $ha^{-1}$ | 9.8a | 7.5a | 82.6a | 64.4a | 147.0a |
| 210 kg $ha^{-1}$ | 9.9a | 7.6a | 86.0a | 65.8a | 151.8a |
| Variety | | | | | |
| Boramchan | 9.8a | 7.2a | 83.6a | 60.3b | 143.9a |
| Deuraechan | 9.8a | 7.3a | 75.8b | 58.1b | 133.9b |
| Dongjin2 | 9.7a | 7.7a | 81.4a | 70.8a | 152.2a |
| Source of variation | | | | | |
| Nitrogen level (A) | ns | ns | * | ns | * |
| Variety (B) | ns | ns | ** | ** | ** |
| A × B | ns | ns | ns | ns | ns |
| CV (%) | 2.8 | 6.6 | 3.6 | 6.1 | 4.2 |

* and **: Significant at 0.05 and 0.01 probability levels, respectively.
ns: Non-significant at 0.05 probability level.
Within a column, means followed by different letters are significantly different by Duncan's multiple range test.

content in grain and straw was not significantly different. Variety differences in nitrogen content were not observed. Nitrogen content ranged from 9.6 to 9.9 g $kg^{-1}$ in grain and 7.1 to 7.6 g $kg^{-1}$ in straw under variable nitrogen levels. Similarly, consistent amount of nitrogen uptake in grain and straw was accounted by the varieties. Nitrogen content in grain showed around 32% higher than in straw. Deuraechan showed the highest grain nitrogen content (9.8 g $kg^{-1}$) while Dongjin2 showed the highest nitrogen content in straw (7.7 g $kg^{-1}$). Both grain and straw nitrogen content at maturity were not significantly different.

Result revealed that total N uptake (kg $ha^{-1}$) showed significant variations by nitrogen levels and varieties (Table 1). Higher nitrogen levels accounted higher amount of nitrogen in grain which were ranged from 72.2 to 86.0 kg $ha^{-1}$. Boramchan (83.6 kg $ha^{-1}$) and Dongjin2 (81.4 kg $ha^{-1}$) accounted significantly higher nitrogen in grain than Deuraechan (75.8 kg $ha^{-1}$).

Nitrogen levels effect on total nitrogen uptake which varied both N levels and among varieties. Higher nitrogen levels (150 and 210 kg $ha^{-1}$) showed significantly higher total nitrogen uptake than practical level (90 kg $ha^{-1}$). Dongjin2 (152.3 kg $ha^{-1}$) and Boramchan (143.9 kg $ha^{-1}$) showed more nitrogen uptake than Deuraechan (133.9 kg $ha^{-1}$).

### Nitrogen use efficiency

The mean values of N-related parameters for the nitrogen levels and varieties are given in Table 2. Nitrogen uptake efficiency (NUpE) and nitrogen use efficiency (NUE) showed significant differences while harvest index (HI), nitrogen harvest index (NHI), and utilization efficiency (NUtE) didn't varied significantly by nitrogen fertilizer level. However, the mean values of N-related parameters for the variety across nitrogen levels were significantly different. NHI, NUpE, and NUE were significantly affected by nitrogen level × genotype interaction.

By nitrogen level, NUpE ranged from 0.72 to 1.46, while NUE ranged from 41.2 to 83.8. Higher nitrogen levels showed significantly lower nitrogen uptake and use efficiency. The result showed that the N uptake rate did not increase linearly with the nitrogen application amount. And high nitrogen input produced more grain yield but no

**Table 2.** Effect of variable nitrogen levels on physiological characters in variable nitrogen levels of Japonica rice varieties.

| Nitrogen level/ Variety | HI | NHI | NUpE | NUtE | NUE |
|---|---|---|---|---|---|
| Nitrogen level | | | | | |
| 90 kg $ha^{-1}$ | 0.48a | 0.55a | 1.46a | 57.5a | 83.8a |
| 150 kg $ha^{-1}$ | 0.50a | 0.56a | 0.98b | 57.6a | 56.3b |
| 210 kg $ha^{-1}$ | 0.50a | 0.57a | 0.72c | 57.2a | 41.2c |
| Variety | | | | | |
| Boramchan | 0.50a | 0.58a | 1.06b | 59.6a | 63.0a |
| Deuraechan | 0.49b | 0.57b | 0.98c | 57.7ab | 56.6b |
| Dongjin2 | 0.47c | 0.53c | 1.13a | 55.0b | 61.7ab |
| Source of variation | | | | | |
| Nitrogen level (A) | ns | ns | ** | ns | * |
| Variety (B) | * | ** | ** | ** | ** |
| A × B | ns | ** | * | ns | * |
| CV (%) | 3.1 | 2.5 | 3.4 | 3.5 | 3.0 |

HI: harvest index, NHI: nitrogen harvest index, NUpE: nitrogen uptake efficiency, NUtE : nitrogen utilization efficiency, and NUE : nitrogen use efficiency.
* and **: Significant at 0.05 and 0.01 probability levels, respectively.
ns: Non-significant at 0.05 probability level.
Within a column, means followed by different letters are significantly different by Duncan's multiple range test.

advantages in yield realization. Jiang *et al.* (2004) reported physiological nitrogen use efficiency (grain yield divided by total nitrogen uptake) ranged from 87 to 121 and from 88 to 119 (kg $kg^{-1}$) in two cultivation seasons under 0 to 157 kg $ha^{-1}$ nitrogen fertilizer level. Similarly, nitrogen uptake efficiency, utilization efficiency, and use efficiency at low nitrogen levels were 2.1, 46.9, and 95.7, while it was 0.7, 41.4 and 26.5 respectively at higher nitrogen level (Moll *et al.*, 1982).

Rice varieties showed significant variation in all the parameters of nitrogen efficiency and also harvest index. Averaged across nitrogen level, NUE value of Boramchan, Dongjin2, and Deuraechan were 63.0, 61.7, and 56.7, respectively. The high NUE of Boramchan could be attributed to the higher HI and NUtE. And the high NUtE is significantly correlated with grain yield (Samonte *et al.*, 2006). Although Dongjin2 showed the highest NUpE among the varieties, the lowest value of HI and NHI has effected on NUE. Similar variation in both nitrogen uptake and nitrogen use efficiency were also reported (Gueye and Becker, 2011; Oh *et al.*, 2006).

Deuraechan showed the lowest values in most of the N-related parameters. Because N-related parameters and grain yield of high yield rice varieties are easily affected by the weather conditions (Borrell *et al.*, 1998; Samonte *et al.*, 2001; Yoshida, 1981), additional experiment in other seasons would help for better evaluation of the performance of Deuraechan.

Significant nitrogen level × variety interaction effects on NHI, NUpE, and NUE seemed to be resulted from a different uptake ability of the variety at different nitrogen level and yield response of the varieties to nitrogen level.

### Yield and yield components

Rough rice yield and panicle number per $m^2$ were significantly affected by nitrogen level, variety, and nitrogen level × variety interaction. 1000-grain weight was affected by variety, and nitrogen level × variety interaction. While number of spikelets was significantly affected only by variety (Table 3).

Rough rice yield was increased as nitrogen level increasing, and it was ranged from 7537 to 8657 kg $ha^{-1}$. The higher yield in higher nitrogen levels was explained by the higher number of panicles per $m^2$. Boramchan

**Table 3.** Effect of nitrogen levels on yield and yield components of Japonica rice varieties.

| Nitrogen level/ Variety | No. of panicles ($m^{-2}$) | No. of spikelets ($panicle^{-1}$) | Ripened spikelets (%) | 1000-grain weight (g) | Rough rice yield (kg $ha^{-1}$) |
|---|---|---|---|---|---|
| Nitrogen level | | | | | |
| 90 kg $ha^{-1}$ | 286b | 140a | 91.3a | 28.1a | 7,537b |
| 150 kg $ha^{-1}$ | 302ab | 142a | 90.1a | 27.8a | 8,441a |
| 210 kg $ha^{-1}$ | 311a | 147a | 89.8a | 27.7a | 8,657a |
| Variety | | | | | |
| Boramchan | 338a | 128c | 91.1a | 27.7b | 8,546a |
| Deuraechan | 229b | 159a | 90.1a | 29.3a | 7,714b |
| Dongjin2 | 332a | 142b | 90.1a | 26.7c | 8,372a |
| Source of variation | | | | | |
| Nitrogen level (A) | * | ns | ns | ns | * |
| Variety (B) | ** | ** | ns | ** | ** |
| A × B | ns | ns | ns | ** | ns |
| CV (%) | 3.3 | 6.9 | 1.7 | 0.9 | 3.7 |

* and **: Significant at 0.05 and 0.01 probability levels, respectively.
ns: Non-significant at 0.05 probability level.
Within a column, means followed by different letters are significantly different by Duncan's multiple range test.

produced 7947, 8678 and 9012 kg per hectare of rough rice in the nitrogen level of 90, 150 and 210 kg N $ha^{-1}$, respectively. While, Deuraechan was from 6948 to 8147 kg $ha^{-1}$, and Donjin2 was from 7717 to 8812 kg $ha^{-1}$. Grain yields of Boramchan at 150 and 210 kg N $ha^{-1}$ fertilizer level were increased by 9.2% and 13.4%, respectively compared to 90 kg N $ha^{-1}$. Similarly, Deuraechan showed 16.0% and 17.3% increases, and Dongjin2 showed 11.3% and 14.2% increases in grain yield.

Rough rice yield of Deuraechan in this study was significantly lower than Boramchan and Dongjin2. Number of spikelets per panicle and 1000-grain weight of Deuraechan were the highest among the varieties, however, these characteristics did not compensate the yield loss due to lower number of panicle per $m^2$. So it could be thought that Deuraechan was affected by weather condition resulting in reduced tiller or panicle number which was a yield limiting factor in this experiment. Takada *et al.* (1984) reported that the number of spikelets per $m^2$ or sink size is the primary determinant of grain yield for cereal crops. However, number of panicle per $m^2$ has been understood for the most important yield component (Gravoid and Helms, 1992). Therefore, it is important to make balance between yield components especially panicle number for high grain yield in Deuraechan (Yoshida, 1981; Kim *et al.*, 1993).

Linear relationships were observed between total nitrogen uptake and grain yield (Fig. 2). As indicated by the coefficient of determination ($R^2$), 72% of the yield variance among the varieties under variable nitrogen levels could be explained by the differences in total nitrogen uptake at maturity. While each 90, 150 and 210 kg N $ha^{-1}$ fertilizer levels showed 0.43, 0.64 and 0.54 of $R^2$ values. Similar relationship between leaf nitrogen content and grain yield was reported by Koutroubas and Ntanos (2003). Sharma and Singh (1998) reported that total nitrogen uptake influenced grain yield by producing higher percentage of filled spikelets (around 90%) as a result of spikelet degeneration decreases linearly with increasing nitrogen content in leaf at anthesis.

Rice varieties responded well to higher levels of nitrogen but efficiency of nitrogen utilization comparatively better in lower levels (Cassman *et al.,* 1993). Boramchan and Dongjin2 produced significantly highest yield which were primarily supported by the number of panicles per $m^2$. But higher spikelets per panicle of Deuraechan could not compensate the yield due to lower number of panicle per unit area.

In this study, we examined nitrogen use efficiency of

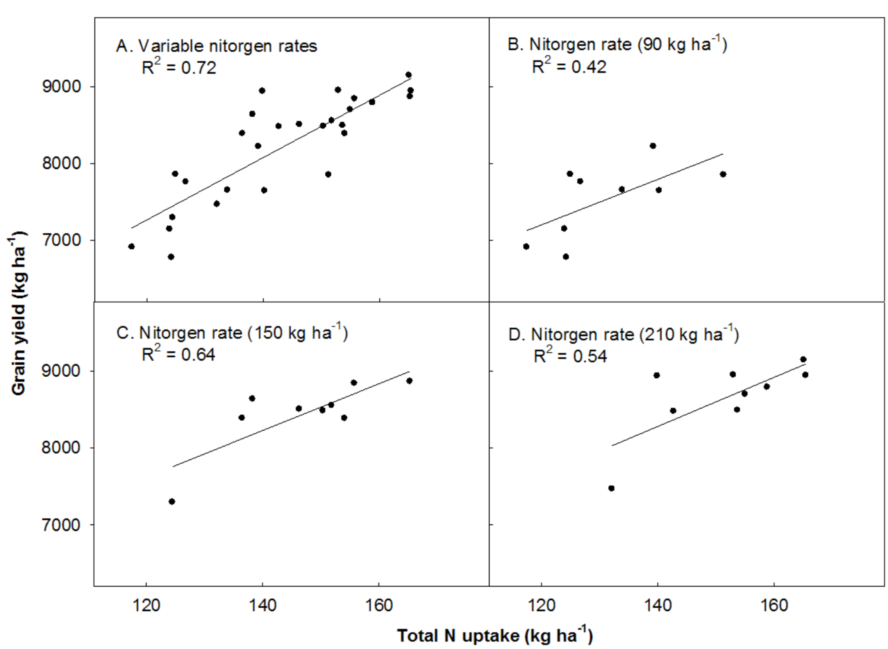


**Fig. 2.** Relationship between total N uptake and grain yield for the treatments of variable N fertilizer levels (A) and the nitrogen level of 90 kg $ha^{-1}$ (B), 150 kg $ha^{-1}$ (C), and 210 kg $ha^{-1}$ (D) with all three rice cultivars combined.

high yield Japonica rice varieties under variable nitrogen fertilizer level. There was significant variation in nitrogen uptake and NUE among genotypes. Plant breeders should take advantage of the significant variations and relationships among grain yield, NUpE, and NUE. The high yielding genotypes that are identified through a yield trial can be screened for high NUpE and NUE, so that the selected genotypes are both high yielder and efficient user of nitrogen. To provide practical information to farmers on nitrogen fertilization methods in cultivation of high yield Japonica varieties, further efforts are needed to find out practical nitrogen application methods for high nitrogen yielding varieties. The efforts may include analysis on the effects of ratio and timing of nitrogen top dressing on nitrogen uptake and utilization.

## REFERENCES

Borrell, A. K., A. L. Garside, S. Fukai, and D. J. Reid. 1998. Season, nitrogen level, and plant type affect nitrogen uptake and nitrogen use efficiency in rice. Aust. J. Agri. Res. 49(5) : 829-843.

Broadbent, F. E., S. K. De Datta, and E. V. Laueles. 1987. Measurement of nitrogen utilization efficiency in rice genotypes. Agron. J. 79 : 786-791.

Cassman, K. G., M. J. Kropff, J. Gaunt, and S. Peng. 1993. Nitrogen use efficiency of rice reconsidered: What are the key constraints? Plant Soil 155/156 : 359-362.

Cho, Y. I. and H. J. Kho. 2007. Physiological nitrogen use efficiency and agronomic characters of breeding lines in rice. Korean J. Breed. Sci. 39(1) : 33-38.

De Datta, S. K. and F. E. Broadbent. 1993. Development changes related to nitrogen use efficiency in rice. Field Crop Res. 34 : 47-56.

Feng, H., M. Yan, X. Fan, B. Li, Q. Shen, A. J. Miller, and G. Xu. 2011. Spatial expression and regulation of rice high-affinity nitrate transporters by nitrogen and carbon status. J. Exp. Bot. 62(7) : 2319-2332.

Gourley, C. J. P., D. L. Allan, and M. P. Russelle. 1993. Defining phosphorus efficiency in plant. In: Barrow, N.J. (Eds.). Plant nutrition from genetic engineering to field practice. Kluwer Academic Publishers. pp. 363-366.

Gravois, K. A. and R. S. Helms. 1992. Path analysis of rice yield and yield components as affected by seeding rate. Agron. J. 84 : 1-4.

Gueye, T. and H. Becker. 2011. Genetic variation in nitrogen efficiency among cultivars of irrigated rice in Senegal. J. Agric. Biotech. Sustainable Dev. 3(3) : 35-43.

Jiang, L., D. Tingbo, D. Jiang, W. Cao, X. Gan, and S. Wei. 2004. Characterising physiological N-use efficiency as influenced by nitrogen management in three rice cultivars. Field Crop Res. 88 : 239-250.

Kim, B. K., J. K. Ko, J. K. Lee, and H. T. Shin. 1993. Analysis of yield and its associated characters affected by planting density and fertilizer level in heavy-panicle Japonica rice. Korean J. Breed. 31(1) : 21-28.

Koutroubas, S. D. and D. A. Ntanos. 2003. Genotypic differences for grain yield and nitrogen utilization in Indica and Japonica rice under Mediterranean conditions. Field Crop Res. 83 : 251-260.

Lee, S. H., H. J. Lee, J. H. Jung, Y. C. Cho, J. H. Lee, and H. D. Kim. 2004. Variation of nitrogen use efficiency and its relationships with growth characteristics in rice cultivars. Korean J. Crop Sci. 49(2) : 89-93.

Mae, T. 1997. Physiological nitrogen efficiency in rice: Nitrogen utilization, photosynthesis, and yield potential. Plant Soil 196 : 201-210.

Moll, R. H., E. J. Kamprah, and W. A. Jackson, 1982. Analysis and interaction of factors which contribute to efficiency of nitrogen utilization. Agron. J. 74 : 562-564.

Oh, M. K., M. K. Kim, I. S. Choi, Y. C. Cho, Y. G. Kim, S. J. Yang, and Y. T. Lee. 2006. Variation of nitrogen use efficiency in rice genotypes. Korean J. Breed. 38(3) : 180-186.

Rauna, W. R. and V. Johnson. 1999. Improving nitrogen use efficiency for cereal production. Agron. J. 91 : 357-363.

Samonte, S. O. P. B., L. T. Wilson, A. M. McClung, and L. Tarpley. 2001. Seasonal dynamics of nonstructural carbohydrate partitioning in fifteen diverse rice (*Oryza sativa* L.) genotypes. Crop Sci. 41 : 902-909.

Samonte, S. O. P. B., L. T. Wilson, J. C. Medley, S. R. M. Pinson, A. M. McClung, and J. S. Lales. 2006. Nitrogen utilization efficiency: relationships with grain yield, grain protein, and yield-related traits in rice. Agron. J. 98 : 168-176.

SAS. 2008. SAS 9.2 for Windows. SAS Institute Inc., Cary, NC, USA.

Sharma, A. R. and D. P. Singh. 1999. Rice. In: D. L. Smith and C. In: D. L. Smith and C. Hamel (Eds.). Crop yield: Physiology and processes. SpringerVerlag, Berlin. pp. 109-168.

Singh, U., J. K. Ladha, E. G. Castillo, G. Punzalan, A. Tirol-Padre, and M. Duqueza. 1998. Genotypic variation in nitrogen use efficiency in medium and long duration rice. Field Crop Res. 58 : 35-53.

Yoshida, S. 1981. Fundamentals of rice crop science. International Rice Research Institute. Los Banos, Philippines. 269p.