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Improving Yield and Nutrient Uptake Potentials of *Japonica* and *Indica* Rice Varieties with Nitrogen Fertilization

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Abstract: The most important problem in achieving high yields in rice is how to increase the nitrogen (N) absorption at each growth stage without reducing the percentage of ripened grains. Proper amount and timing of application could reduce N losses and increase fertilizer use efficiency while cost of production is also reduced and yield is increased. In order to avoid losses and to use soil-and fertilizer-nitrogen efficiently, it is necessary to develop better ways of predicting the optimum amount of N needed by the rice plants. A field experiment was conducted to determine the effect of different levels of N on N uptake, yield components and dry matter yield of *japonica* (*Hatsuboshi*) and *indica* (*IR-13*) rice varieties. Results showed an increasing trend in the N uptake, rice yield, panicle number, tiller number and dry matter production, with increasing the amount of applied N fertilizer. The yield (brown rice) of the two varieties (*Hatsuboshi,* 3.2-6.5 tons ha^{-1}; *IR-13*, 2.6-6.4 tons ha^{-1}) did not differ significantly (p=0.05). However, the agronomic efficiency (AEN) of *IR-13* was significantly higher than *Hatsuboshi.* There was a 30 kg ha^{-1} increase in the yield of brown rice and about 1.4% increase in the total N uptake for every additional kilogram of applied N ha^{-1}. Higher correlations (p=0.001) were found between the yield (r = 0.96; r = 0.99), number of panicles (r = 0.98; r = 0.96) and number of tillers (r = 0.96; r = 0.97) and N uptake (r = 0.97; r = 0.95) of *japonica* and *indica* rice varieties and applied N, respectively. The increase in yield (ton ha^{-1}) of *japonica* (y = 1.07x + 2.5) and *indica* (y = 1.24x + 1.5) could be attributed to the increase in N uptake with increasing N application and mineralized soil N after flooding. However, best timing and amount of N application should be determined to reduce N losses and increase soil and fertilizer N efficiency while cost of production is also reduced but yield was increased.

Key words: Nitrogen uptake · Yield · *Japonica* · *Indica* · Soil nitrogen · Nitrogen fertilizer

INTRODUCTION

Agriculture remains as the key sector for the economic development of most developing countries in Southeast Asia where rice is the most important and dominant agricultural crop. This is primarily because rice is the staple food of over 80% of the country's population, while 70% of it depends on rice cultivation and marketing for their livelihood. Being the staple food, rice is the main source of carbohydrates and protein. It is critically important for ensuring food security, alleviating poverty and conserving the vital natural resources that the world's present and future generations will be entirely dependent upon for their survival and well-being [1].

Many factors influence the growth and yield of rice. One of the most important factors is N fertilization. Nitrogen management is essential in growing rice. It is the most commonly used nutrient that produces significant effects on crop growth. Moreover, it is used in the biggest quantity among all fertilizers; yet, it is subject to great losses through leaching, surface runoff, ammonia volatilization, nitrification-denitrification and seepage, which result to low N recovery efficiency in lowland rice [2]. About 75% of leaf N is associated with chloroplasts, which are important in dry matter production through photosynthesis [3]. Hence, application of N enhances both photosynthetic activity and total above ground dry matter production. Nitrogen is required by rice plants

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during the vegetative stage to promote growth and tillering, which determines the potential number of panicles [4]. It also plays an important role in the formation and death of tillers as well as differentiation and degeneration of spikelets. Among the various functions of N are spikelet production during the early panicle formation stage and carbohydrate accumulation in culms and leaf sheaths during pre-heading stage and in grain during grain-filling stage through photosynthesis. During the late panicle formation stage, N contributes to sink size by decreasing the number of degenerated spikelets and increasing hull size [4]. There are different sources and forms of N utilizable by rice plants. The major sources are chemical fertilizers and soil N through mineralization from organic matter.

The most important problem in achieving high yields is how to increase the N absorption at each growth stage without reducing the percentage of ripened grains. In order to avoid losses and to use soil-and fertilizer-nitrogen efficiently, it is necessary to develop better ways of predicting the optimum amount of N needed by the rice plants. To develop efficient N management protocols, it is crucial to recognize cultivar differences and the critical stages of crop growth in which fertilization is essential to avoid potential yield loss [5]. Proper amount and timing of application could reduce N losses and increase fertilizer use efficiency while cost of production is also reduced and yield is increased. However, N needs and uptake patterns of rice vary among varieties and ecosystems. Thus, this study was conducted with the following objectives: (1) to evaluate the effect of varying levels and split application of N on the growth and yield of rice; (2) to determine the relationship of N uptake to yield, yield component and dry matter production of rice; and (3) to determine the N uptake patterns of *japonica* and *indica* rice varieties applied with different levels of N fertilizer.

MATERIALS AND METHODS

Experimental Design: The experiment was conducted at the E-1 field of Tsukuba International Center (TBIC), Ibaraki, Japan and laid out in split plot design with three replications per treatment combination. The main-plot was rice variety (V1-*Hatsuboshi japonica*; V2-*IR-13, Indica*) and N levels (0, 60, 90 and 120 kg ha^{-1}) as our sub-plots. Half of the required N levels were applied at planting while the remaining half was top-dressed (25 days before heading, DBH).

Seedling Establishment and Cultural Management: Hatsuboshi seeds previously disinfected with Helcite were sown on April 15 and IR-13 on April 16, 1997. Basal fertilizer was applied before puddling and transplanting (one seedling $hill^{-1}$ at 30 x 15 spacing-22.2 hills per m^2) was completed at 28 days after sowing (DAS). The experimental plot size was 3.9 m x 2.7 m (10.53 m^2). Potassium and phosphorus fertilizers were also applied following the standard recommendation of Ibaraki prefecture (110 K_2O and 100 kg P_2O_5 ha^{-1}, respectively). Irrigation water was maintained at about 3 cm depth until heading time and herbicide was also applied once to control weeds. Variety *IR-13* was harvested at 116 days after transplanting (DAT) while *Hatsuboshi* was at 122 DAT.

Soil and Plant Sampling: Soil samples were collected (0-13 and 13-30 cm depth) just before plowing. The soils were air-dried, pulverized and sieved through 2-mm mesh. Destructive sampling of plants was done before topdressing (25 days DBH) and at maturity, by collecting randomly three representative plant samples from each plot. The samples were oven-dried at 80°C for 48 hours. The total above ground dry matter weight was determined. Oven-dried samples were then cut and ground using the vibrating mill for soil N analysis.

Soil and Plant Analyses: For the determination of soil available N, 16 g of ground sample (oven-dry weight basis) was incubated in culture tube at 30°C under anaerobic condition. The mineralizable N from the soil was measured from 0 to 4 weeks after incubation by extraction with 2 N potassium chloride solutions. The amount of ammonium N from the extract was determined by steam-distillation and titration method while the total N and total carbon content of plant samples were analyzed using the N-C analyzer (Sumigraph NC-90A).

Agronomic Character Observation: Five representative hills at random from each plot were marked for observation of growth characters. Two weeks after transplanting, the leaf age was determined. The number of tillers per hill was likewise counted and the plant heights were recorded. The observation was done weekly until heading stage (77 DAT for *IR-13* and 82 DAT for *Hatsuboshi*). Before harvesting, five hills from each treatment were sampled for yield components analyses. Filled grains were separated by using salt solution with specific gravity of 1.06 for *japonica* variety and water (specific gravity = 1.0) for *indica* variety. The number of filled and unfilled grains was counted to calculate ripening ratio. The number of panicles per square meter, number of spikelets per panicle, panicle length and weight of 1000 grains were likewise determined. Twenty-eight hills were harvested from the center of each plot. After drying and threshing, the paddy rice and straw were weighed for the grain-straw ratio. The yield of brown rice was determined at 14% moisture content. Agronomic efficiency (AEN) was determined for both varieties.

RESULTS AND DISCUSSION

Number of Tillers and Panicles: Data on the number of tillers per hill are presented in Table 1. Results showed that *Hatsuboshi* had the highest number of tillers (18.8) when applied with 120 kg N ha^{-1} but without N fertilization, it had only 5.7 tillers. Furthermore, no significant difference was noticed when applied with 60 (13.5 tillers) and 90 kg N ha^{-1} (15.2 tillers). However, the number of tillers produced by *IR-13* (12.2-15.7) did not differ significantly with the application of 60 to 120 kg N ha^{-1}. Results of experiments conducted by several researchers show that the higher the application of N, the faster the growth rate and the more number of tillers. Other studies showed that application of high N fertilizer resulted in an increase of growth rate and number of tillers. The effects of applied N fertilizers in the number of tillers for *japonica* and *indica* rice varieties can be best described by equations 1 and 2, respectively. This is probably because the absorption of N is higher in *indica* variety than that of *japonica* at the early growth stage.

$$y = 4.1x + 3.1; R^2 = 0.92^{**} \quad (1)$$

$$y = 2.4x + 6.4; R^2 = 0.95^{**} \quad (2)$$

where y = number of tillers and x = rates of nitrogen application (kg ha^{-1}).

There was an increase of about 2.1 and 1.5 panicles m^{-2} for *Hatsuboshi* and *IR-13*, respectively, when N applied was increased by one kg ha^{-1} (Fig. 1). On the other hand, *Hatsuboshi* gave significantly higher number of panicles m^{-2} than *IR-13*. The relationships of the number of panicles and applied N for *japonica* (equation 3) and *indica* (equation 4) are shown below.

$$y = 82.5x + 140; R^2 = 0.97^{**} \quad (3)$$

$$y = 60.0x + 122; R^2 = 0.95^{**} \quad (4)$$

where y = number of panicles and x = rates of nitrogen application (kg ha^{-1}).

Table 1: Effect of applying different levels of nitrogen fertilizer on the number of tillers of *japonica* and *indica* rice varieties at 41 days after transplanting

Nitrogen levels (kg ha^{-1})	Rice variety *Hatsuboshi (japonica)*	IR-13 *(indica)*
0	5.7c[§]	8.2b
60	13.5b	12.2a
90	15.2b	14.1a
120	18.8a	15.7a
Regression model	y = 4.1x + 3.1; R^2 = 0.92**	y = 2.4x + 6.4; R^2 = 0.95**

[§]Means followed by common letter(s) are not significantly different from each other at p=0.05

Table 2: Effect of applying different levels of nitrogen fertilizer on brown rice yield (ton ha^{-1}) and agronomic efficiency (AEN, kg grain kg^{-1} applied N) of *japonica* and *indica* rice varieties

Nitrogen levels (kg ha^{-1})	Rice variety Hatsuboshi (japonica)	AEN	IR-13 (indica)	AEN
0	3.2d[§]	0.0	2.6d	0.0
60	5.1c	31.7	4.2c	23.7
90	5.9b	30.0	5.2b	28.9
120	6.5a	27.5	6.4a	31.7
Regression model	y = 1.07x + 2.5; R^2 = 0.93**		y = 1.24x + 1.5; R^2 = 0.99**	

[§]Means followed by common letter(s) are not significantly different from each other at p=0.05, The values of AEN (yellow color) need to recalculation

For every kilogram increase in the N uptake of the plant, there was an increase of 1.4% in number of panicles per square meter and 1.1-2.4% in number of tillers per hill. At 25 days before heading, the brown rice yield, number of panicles m^{-2} and number of tillers per hill were highly correlated to the amount of N absorbed. De Datta [6] reported that the N absorbed by the rice plant from tillering to panicle initiation tends to increase the number of tillers and panicles. Therefore, split N application with one dose at transplanting and another at panicle initiation (PI) is best for obtaining high yields in relation to yield components. This is in conformity with the findings of Wada *et al*. [7]. They reported that higher N absorption was observed with large basal N fertilization thus, producing higher yield and yield components.

Grain and dry matter yield: The grain yield of *japonica* (y = 1.07x + 2.5) and *indica* (y = 1.24x + 1.5) rice varieties (Table 2) was greatly affected (p=0.001) by the application

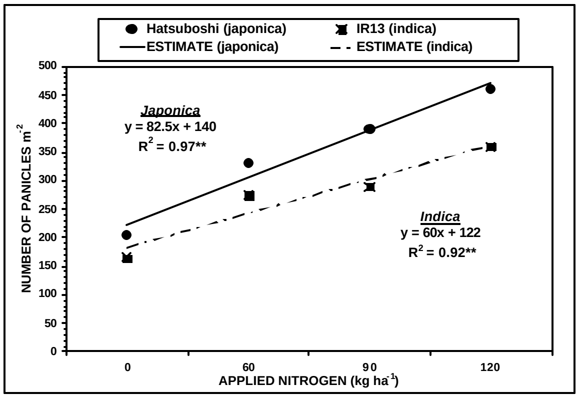

Fig. 1: Effect of different levels of N fertilization on the number of panicles of japonica and indica rice varieties

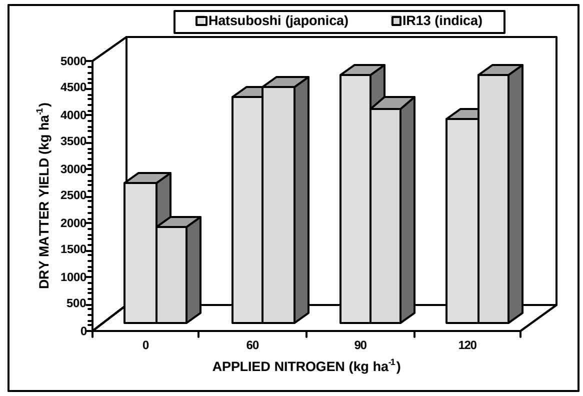

Fig. 2: Dry matter yield of japonica and indica rice varieties as affected by different levels of N fertilization

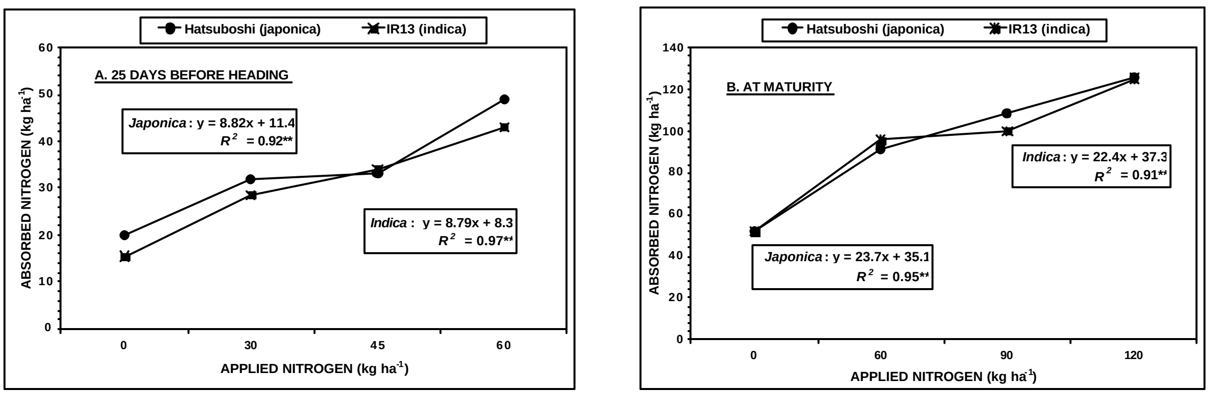

Fig. 3: Comparison of N absorption capacities of japonica and indica rice varieties at different growth stages

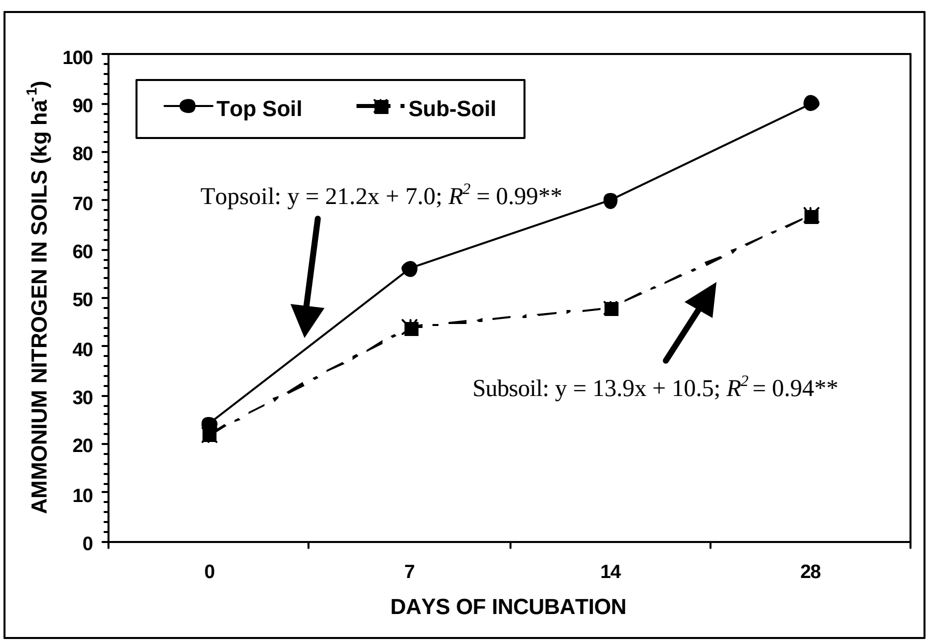

Fig. 4: Mineralizable N from topsoil and subsoil as affected by time of incubation

of the different levels of N fertilizer, but there was no significant difference (p=0.05) between *Hatsuboshi* (3.2-6.5 tons ha^{-1}) and *IR-13* (2.6-6.4 tons ha^{-1}). However, the agronomic efficiency (AEN, kg grain per kg N applied) of *IR-13* was significantly higher than *Hatsuboshi* (Table 2). When averaged over N rates, *Hatsuboshi* yielded 29.7 kg grain kg^{-1} applied N. Conversely, *IR-13* yielded 91.8 kg grain kg^{-1} applied N. With increasing in applied N of one kilogram, there was a 30 kg increase in yield per hectare which is about 0.92% and 1.2% for *Hatsuboshi* and *IR-13*, respectively (Table 2). The increase in yield could be attributed to the increase in N uptake of the rice plant at different growth stages. The experiment conducted by Wada *et al.* [7] recognizes the same phenomenon. It is important to know the N absorption pattern of rice varieties grown under different cultural conditions. Furthermore, it has been found that top-dressing at the time of heading increases the percentage of ripened grains and results in higher yields [8].

Increasing of N application from 60 to 120 kg ha^{-1} did not give significant effect on the weight of 1000 grains and ripening ratio for both varieties (data not presented). The ripening ratio of *Hatsuboshi* ranged from 83.35 to 89.06% and *IR-13* has 80.44 to 93.49% while the weight of 1000 grains was from 20.1 to 21.9g and 20.3 to 21.5g for *Hatsuboshi* and *IR-13*, respectively.

The total dry matter production of *Hatsuboshi* was significantly higher than *IR-13* at the early growth stage (Fig. 2). An increasing trend in the dry matter weight of both varieties was observed with increasing N applied. However, at maturity, higher dry matter was produced by *IR-13* when 60 and 120 kg N ha^{-1} were applied while *Hatsuboshi* had higher with 0 and 90 kg N ha^{-1}. Basal N application plays an important role in dry matter production of rice. In the study conducted by Islam *et al* [9], reported that the dry matter production of tall *indica* is considerably higher than the semi-dwarf *indica* at panicle initiation stage but at maturity, it is not significantly different (p=0.05).

Nitrogen Uptake and Grain Yield: The growth duration, native soil fertility and cultural practices affect N absorption pattern, which in turn affects the amount of N in plants leading to profound effect on N use efficiency [10]. As shown in Fig. 3, the total N uptake or the amount of N absorbed by *Hatsuboshi* (19.8-48.8 kg ha^{-1}) at 25 DBH increased with increasing N application. The percentage of fertilizer-derived N ranged from 38 to 59% (Fig. 4). The same trend was observed for *IR-13* (15.5-45.9 kg ha^{-1}) with 46 to 64%. Nakanishi *et al.* [11] has reported the same findings. When ammonium sulfate is top-dressed at the panicle initiation stage, 40-60% of the fertilizer is recovered by plants. As a result, the yield and sink size obtained were higher. According to Wada and Sta. Cruz [12], the low absorption ability at the early growth stage is compensated by higher basal N application and narrow spacing in short-duration varieties. Rice varieties responded differently to N application [10] and differed in their ability to extract soil and fertilizer N [13]. During maturity, N uptake of *Hatsuboshi* was 52-126 kg ha^{-1} while *IR-13* has 52-125 kg ha^{-1}. Results showed that, at 25 DBH, IR-13 was more responsive to N application but *Hatsuboshi* was observed to have higher N uptake at maturity. To increase the efficiency of soil and fertilizer N, it is important to use nutrient-efficient varieties [13].

The amount of N absorbed by *japonica* and *indica* rice varieties, both at the early and late growth stages had high correlations with applied N (Fig. 3). The amount of absorbed N at 25 DBH and at maturity by *japonica* and *indica* were significantly affected by N fertilization and can be best described by the relationships given in equations 5-6 (at early stage) and 7-8 (at maturity), respectively. Equations 5-8 are given below.

$$y = 8.82x + 11.4; R^2 = 0.92^{**} \quad (5)$$

$$y = 8.79x + 8.3; R^2 = 0.97^{**} \quad (6)$$

$$y = 23.7x + 35.1; R^2 = 0.95^{**} \quad (7)$$

$$y = 22.4x + 37.3; R^2 = 0.95^{**} \quad (8)$$

where y = amount of N adsorbed (kg ha^{-1}) and x = rates of nitrogen application (kg ha^{-1}).

The amount of N derived from the fertilizer ranged from 43 to 59% for *Hatsuboshi* and 45 to 58% for *IR-13*. It was observed that the percentage of soil-derived N at 25 DBH was higher in *Hatsuboshi* (41-62%) than in *IR-13* (36-54%) but at maturity, no significant difference was found for both varieties. This conforms to previous findings that at maturity, the amount of fertilizer-derived N are similar among the test varieties and that a larger amount of fertilizer N is accumulated with increased N application [9]. It is emphasized in PhilRice Technoguide [14] that the efficiency of fertilizer use is greatly improved if N fertilizer is properly mixed with the soil upon application. The recovery of N fertilizer applied to the rice crop would range from 30 to 40%. However, with improved cultural practices, such recovery can increase up to 65% [6].

CONCLUSION

The N uptake of *japonica* and *indica* rice varieties increased with increasing in levels of applied N. At the early growth stage, *IR-13* was more responsive to N fertilization while *Hatsuboshi* was more responsive to N fertilization at the later stage until maturity. The yield and yield components were positively correlated to the amount of N applied. Topdressing of N significantly increased the yield of brown rice, weight of 1000 grains, dry matter production and panicle number. It also enhanced the tillering ability of the rice plant. Hence, such increase in the yield and other agronomic characters could be attributed to the increase in N uptake from the soil and from the applied fertilizer, regardless of the type or variety of rice. However, several factors such as climatic condition, ecosystem and other environmental factors should be taken into consideration. Further investigation on the optimum N requirement of the rice plant is necessary. Moreover, more detailed studies on the best timing (split application) of N as well as the kind or type of N source, should be done. To get an accurate and precise data on soil and fertilizer-derived N, labeled N would be necessary. Information on the seasonal N uptake patterns and partitioning within the crop is valuable in assessing the amount of, timing and method of N fertilization to prevent the occurrence of N deficiencies or over fertilization [6, 15].

Mineralization of soil organic N is a key process for the supply of N to tropical wetland rice. Estimation of soil N availability based on mineralization is an important step toward developing N fertilizer recommendations for intensively cropped wetland soils. The mineralization process could be influenced by many factors including temperature and chemical properties of the soil. Flooding induces significant changes in the chemical and microbiological environment of the soil and it is assumed that these changes may affect the mineralization process of soil organic N. It increases the amount and rate of soil N mineralization. Rice grown in flooded soil absorbs larger quantity of soil N than that grown in non-flooded soil [16]. Our results have shown that the amount of mineralized N increased with time (Fig. 4). The topsoil and subsoil can supply as much as 91 and 56 kg N ha^{-1}, respectively, from 0 to 4 weeks after flooding. The soil (upper 13 cm plow depth) has a total N content of 0.091%.

REFERENCES

1. Rothschild, G.H.L., 1997. Main issues for sustainable agricultural development in Asia. In Sustainable Agricultural Development Compatible with Environmental Conservation in Asia. The 4th JIRCAS International Symposium, Tsukuba, Japan, 7.
2. Craswell, E.T. and P.L.G. Vlek, 1979. Fate of fertilizer N applied to wetland rice. In: Nitrogen and rice, Symposium Proceedings. International Rice Research Institute, Manila, Philippines, pp: 19.
3. Dalling, M.J., 1985. The physiological basis of nitrogen redistribution during filling in cereals. In: Harper, J.E. *et al.* (Ed.). Exploitation of physiological and genetic variability to enhance crop productivity. Am. Soc. Plant Physiologists, Rockville, MD, pp: 55-71.
4. Mae, T., 1997. Physiological nitrogen efficiency in rice: Nitrogen utilization, photosynthesis and yield potential. Plant Soil, 196: 201-210.
5. Senanayake, N., R.E.L. Naylor, S.K. De Datta and W.J. Thompson, 1994. Variation in development of contrasting rice cultivars. J. Agric. Sci., 123: 35-39.
6. De Datta, S.K., 1981. Principles and Practices of Rice Production. John Wiley & Sons, New York, pp: 375.
7. Wada, G., S. Shoji and T. Mae, 1986. Relationship between nitrogen absorption and growth and yield of rice plants. JARQ, 20 (2): 135-145.
8. Matsushima, S., 1984. Theory of yield determination and its application. Crop Science in Rice. Nippon Sangyo Saiken Gijutsu Kyokai. Tokyo, Japan, pp: 241.
9. Islam, N., S. Inaga, N. Chishaki and T. Horiguchi, 1996. Effect of nitrogen top-dressing on dry matter and nitrogen distribution in *indica* rice. Japan J. Trop. Agric., 40 (2): 89-92.
10. Sta. Cruz, P.C. and G. Wada, 1994. Genetic variation in nitrogen uptake by rice and the effects of management and soil fertility. In: Kirk, G.J.D. (Ed.). Rice roots, nutrient and water use. International Rice Research Institute, Manila, Philippines, pp: 29-40.
11. Nakanishi, M., N. Tanaka and H. Ando, 1990. Effect of coated urea topdressing on growth and yield of rice plant. Japan J. Crop Sci., 59 (2): 265-269.
12. Wada, G. and Sta. P.C. Cruz, 1990. Nitrogen response of rice varieties with reference to nitrogen absorption at early growth stage. Japan J. Crop Sci., 59 (3): 54-57.

13. Swain, D.K., B.C. Bhaskar, P. Krishnan, K.S. Rao, S.K. Nayak and R.N. Dash, 2006. Variation in yield, N uptake and N use efficiency of medium and late duration rice varieties. J. Agric. Sci., 144: 69-83.
14. Philippine Rice Research Institute (PhilRice), 1993. Rice Production Technoguide, Illustrated English Edition, pp: 43-46.
15. Saito, M., 1991. Soil management for the conservation of soil nitrogen. Ext. Bull. 341. Food and Fertilizer Technology Center, Taiwan.
16. Ono, S., 1991. Effects of liming on the promotion of mineralization of soil organic nitrogen. Soil Sci. Plant Nutr., 37 (3): 427-433.