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Nitrogen Uptake Dynamics and Dry Matter Production of Rice in Response to Nitrogen Fertilizer Application

Amina Khatun[1], M. K. A. Bhuiyan[2], A. B. M. Mostafizur[1], M. S. U. Bhuiya[3] and M. A. Saleque[4]

1. Rice Farming Systems Division, Bangladesh Rice Research Institute, Gazipur 1701, Bangladesh

2. Agronomy Division, Bangladesh Rice Research Institute, Gazipur 1701, Bangladesh

3. Department of Agronomy, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh

4. Co-ordinator for Advanced Studies & Research, Bangladesh Rice Research Institute, Gazipur 1701, Bangladesh

Abstract: Nitrogen is one of the most important nutrients in rice production but its uptake dynamics remained relatively unexplored. The present investigation evaluated uptake dynamics over the growing season at different levels of nitrogen fertilizer application. The experiment was conducted during Boro season (November-April) at Bangladesh Rice Research Institute experimental farm, Gazipur, Bangladesh. The experiment involved two modern rice varieties—BRRI dhan28 and BRRI dhan29 and six N rates: 0, 50, 100, 150, 200 and 250 $kg \cdot ha^{-1}$. The N uptake pattern was determined at every 15 days from transplanting to maturity. At 150 $kg \cdot N \cdot ha^{-1}$, initially N uptake was 0.1 $kg \cdot ha^{-1} \cdot day^{-1}$ which increased to 0.2 in BRRI dhan28 and 0.4 in BRRI dhan29, respectively. During 30 to 45 DAT, per day N uptake was 2.0 $kg \cdot ha^{-1}$ in BRRI dhan28 and 2.2 in BRRI dhan29 which increased to the peak at 2.4 and 2.8 $kg \cdot ha^{-1} \cdot day^{-1}$ in BRRI dhan28 and BRRI dhan29, respectively, during 45 to 60 DAT. The grain yield showed a stronger correlation with N uptake during 45 to 60 DAT in both the varieties. The highest N uptake contributed to the highest dry matter production in both the varieties.

Key words: Rice, nitrogen rates, nitrogen uptake, dry matter production, grain yield.

1. Introduction

Rice (*Oryza sativa* L.) is the staple food for nearly half of the world's population and most of them live in developing countries. The crop occupies one-third of the world's total area planted to cereals and provides 35-40% of the calories consumed by 2.7 billion people [1]. About 90% of rice is produced and consumed in Asia. It is the main food for about 140 million people of Bangladesh. Enhancement of rice production and sustainability is important features of grain production to benefit the world's approximate 3 billion people who depend on rice for their livelihood and as their basic food [2]. In this context, there is no alternative other than yield increase per unit area. It is possible either by using improved technologies or developing management practices.

Nitrogen is one of the most yield-limiting nutrients in rice production around the world [3], especially in tropical Asian soils and almost every farmer has to apply the costly N fertilizer to get a desirable yield of rice [4]. Judicious and proper use of fertilizers can markedly increase the yield and improve the quality of rice [5]. However, both excess and insufficient supplies of nitrogen are harmful to the rice crop and may decrease grain yield. An adequate nitrogen supply can increase as much as 60% rice production over control [6].

Current recommendations of split applications of N fertilizer with fixed rates at specific growth stages for large rice growing areas assume the requirement of rice for N fertilizer that is constant across large areas and years. The requirement of rice for N fertilizer can, however, vary greatly from location to location, season to season, and year to year because of high variability among fields, seasons, and years in N-supplying capacity of soil [7, 8].

Lowland rice yields in central Brazil on Varzea soil

Corresponding author: Amina Khatun, senior scientific officer, research field: farming systems research.

were significantly higher at 200 kg·N·ha^{-1} than at 100 kg·N·ha^{-1} [9]. Timely and split application of N may improve a crop's response to N, especially at high rates. Split application of N also allows for more efficient use of N throughout the growing season as it provides specific amounts of nutrients to the crop during peak periods of growth and may reduce leaching of nitrate-N in the soil [10].

The application of N fertilizer increased plant total N uptake, and it ranged from 62-92 kg·ha^{-1} for 10 rice genotypes in Bangladesh [4]. Among macronutrients, nitrogen uptake is the highest with the exception of potassium [1]. Nitrogen uptake increased with the advancement of the age of the crop up to the flowering growth stage and decreased thereafter [1].

Dry matter as well as grain yield depends on N accumulation in rice plant but up to a certain limit. After that limit there is no more increase in dry matter or grain yield. At harvest, more N was accumulated in grains than in dry matter. In general, dry matter accumulation increased at slow rate up to 30 days after transplanting and thereafter increased at faster rate up to harvest. The higher dry mass of nitrogen treated plants could be connected with the positive effect of nitrogen in some important physiological processes [5].

Under these circumstances, the present research works were designed with an attempt to attain the objectives: (i) to determine the nitrogen uptake dynamics at days after transplanting, (ii) to estimate daily N uptake by rice plant and (iii) to determine dry matter production pattern under variable nitrogen management practices.

2. Materials and Methods

The field experiment was conducted at the experimental farm of the Bangladesh Rice Research Institute, Gazipur, Bangladesh, during Boro season of 2011-12, located 23°59' N latitude, 90°24' E longitude with an elevation of 8.4 m from the sea level. The site has a subtropical climate, which is strongly influenced by the southwestern monsoon. It belongs to Agro-Ecological Zone (AEZ) number 25 known as Madhupur Tract. The soil of the experimental field was Chhiata clay loam, a member of the fine, hyperthermic Vertic Endoaquept [4]. Two rice varieties BRRI dhan28 (growth duration 145 days) and BRRI dhan29 (growth duration 160 days) were grown in the experimental field under fully irrigated conditions. These two varieties were transplanted in first week of January with 45 day-old seedlings and harvested in May. Two/three rice seedlings were transplanted maintaining 20 × 20 cm spacing. The experiment was conducted in a randomized complete block design (RCBD) with four replications. Unit plot size was 5 × 4 m. All plots were surrounded by soil levees 30 cm high to avoid N contamination between plots. After transplanting the seedlings, intercultural operations like weeding, irrigation and control of pest were done as and when necessary for better growth and development of rice plants. The experiment consisted of six N rates: 0, 50, 100, 150, 200 and 250 kg·ha^{-1} for BRRI dhan28 and BRRI dhan29 rice. Nitrogen was top dressed as urea in three equal splits: 20, 35 and 50 days after transplanting (DAT) for BRRI dhan28 and 20, 35 and 55 DAT for BRRI dhan29. Phosphorus, K, S and Zn were applied as triple super phosphate, muriate of potash, gypsum and zinc sulphate, respectively, during final land preparation as per soil test basis (STB). Dry matter weight of rice plant was determined at every 15 days from transplanting to maturity. Nitrogen was determined from the collected plant samples and total N concentration was determined by micro Kjeldahl method [11]. Total N uptake was determined by the following formulae:

$$\text{Nitrogen uptake by grain (kg ha}^{-1}) = \frac{\%\text{ N in grain} \times \text{Grain yield (kg ha}^{-1})}{100}$$

$$\text{Nitrogen uptake by straw (kg ha}^{-1}) = \frac{\%\ \text{N in straw} \times \text{straw yield (kg ha}^{-1})}{100}$$

Analysis of variance (ANOVA) of the measured parameters was performed and the treatment means were compared using Least Significant Difference (LSD) at the 5% level of probability (Gomez and Gomez 1984). The significance test of the regression analysis was done following Ref. [12].

3. Results and Discussions

3.1 Nitrogen Uptake at Different Growth Stages

Nitrogen uptake pattern in BRRI dhan28 and BRRI dhan29 at different growth stages under different N rates is presented in Fig. 1. Irrespective of treatments, N uptake by rice plant at the early growth stages (15 and 30 DAT) had very low, started to increase from 45 DAT and showed a peak at 75 DAT in both the varieties. Under control N treatment, varietal difference in N uptake demonstrated insignificance at all growth stages except 15 and 90 DAT. At 15 and 90 DAT, BRRI dhan29 had significantly higher amount of nitrogen accumulation ($p < 0.01$ and $p < 0.04$, respectively) compared to BRRI dhan28. With the application of 50 kg·N·ha^{-1}, no significant difference in N uptake was observed in BRRI dhan28 and BRRI dhan29 at all growth stages except 90 DAT ($p < 0.02$). Under all N treatment, N uptake was significantly lower at 90 DAT in BRRI dhan28 compared to BRRI dhan29. It might have related to N translocation to grains at harvest. At 100 kg·N·ha^{-1}, BRRI dhan29 demonstrated significantly higher N uptake at 45, 60 and 90 DAT ($p \leq 0.05$) compared to BRRI dhan28. At 150 kg·ha^{-1} N treatment, no significant difference in N uptake was observed in both the varieties except 90 DAT. At 200 kg·ha^{-1}, N uptake in BRRI dhan29 was significantly higher at 30, 75 and 90 DAT compared to BRRI dhan28. But with the application of 250 kg·ha^{-1}, N uptake at all the growth stages except 90 DAT showed insignificant difference in both the varieties (Fig. 1). Nitrogen uptake increased with the progression of the crop growth up to the flowering stage and decreased thereafter [1].

3.2 Daily Nitrogen Uptake at Different Dates after Transplanting Influenced by Nitrogen Rates

The pattern of N uptake on daily basis at different growth stages under different N rates is presented in Fig. 2. Daily N uptake varied widely with growth stage and different N rates at a given growth stage. In N control treatments, the daily N uptake (DNUP) increased with the increase of crop age and highest N uptake was achieved at 75 DAT in both the tested varieties. Varietal difference in DNUP was not significant at any growth stages with control N treatments. At 50 kg·N·ha^{-1}, DNUP increased with the advance of growth stage and highest uptake was achieved at 45 DAT both in BRRI dhan28 and BRRI dhan29 (Fig. 2). After this stage, DNUP showed decreasing pattern up to 60 DAT and then increased at 75 DAT in BRRI dhan29. BRRI dhan28 showed similar trend at 60 and 75 DAT. At 100 kg·N·ha^{-1}, DNUP increased with the increase of crop age and at 45 DAT, BRRI dhan29 achieved significantly higher N uptake compared to BRRI dhan28. At 60 DAT, BRRI dhan28 achieved significantly higher N uptake compared to BRRI dhan29. But at 75 DAT, varietal difference in DNUP showed insignificant and BRRI dhan28 and BRRI dhan29 had similar DNUP with this N rate. Higher DNUP achieved at 60 DAT with the rate of 150 kg·N·ha^{-1} in both the varieties and decreased thereafter. At 75 DAT, the decreasing trend of BRRI dhan29 was higher compared to BRRI dhan28 (Fig. 2). But varietal difference in DNUP was not significant at all growth stages with this N rate.

With the rate of 200 kg·N·ha^{-1}, highest DNUP was obtained from 60 DAT in BRRI dhan28. But in BRRI dhan29, highest DNUP was observed at 75 DAT which was statistically similar to 45 DAT. At 75 DAT,

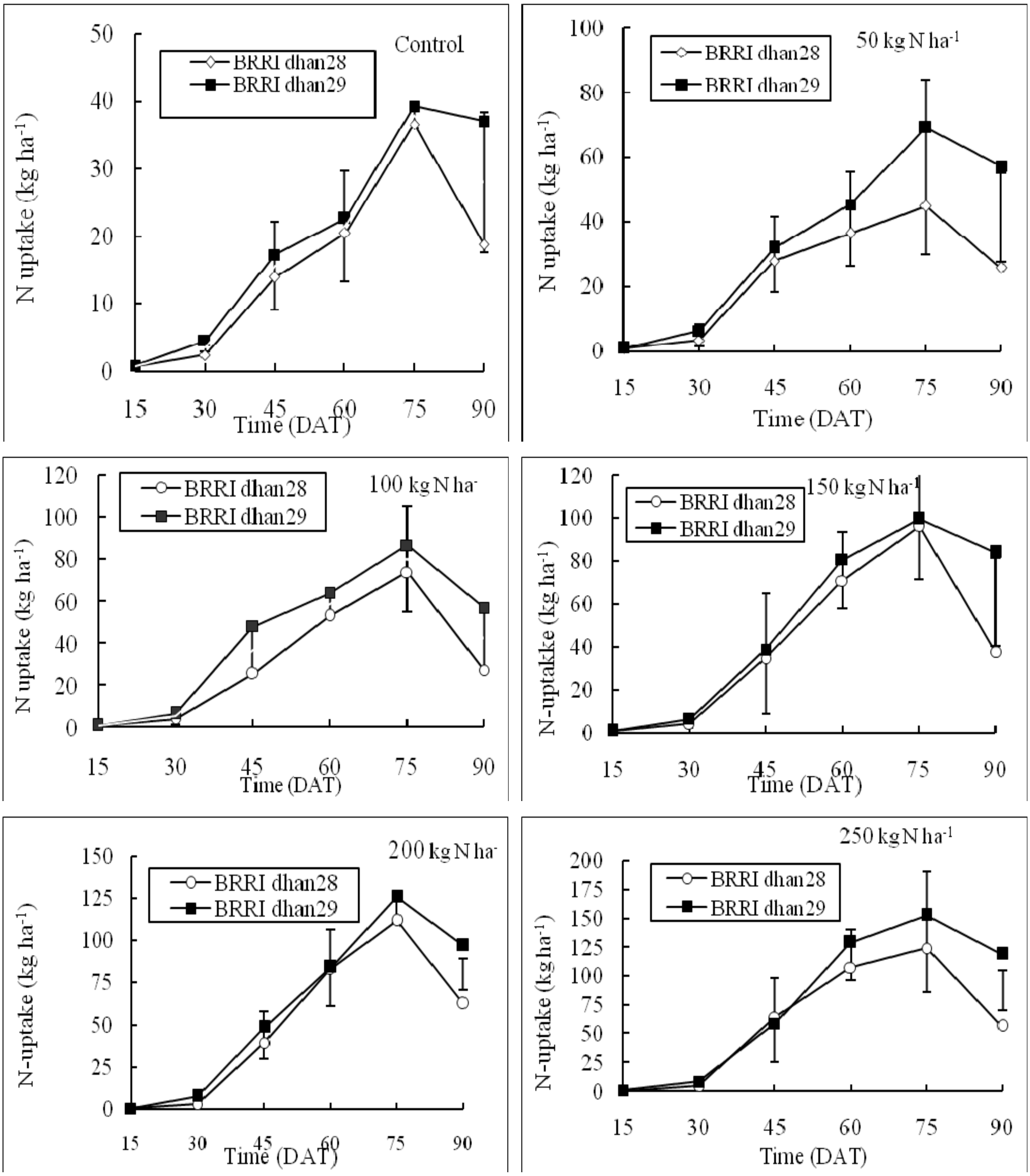

Fig. 1 Nitrogen uptake at different dates after transplanting influenced by nitrogen management in BRRI dhan28 and BRRI dhan29.

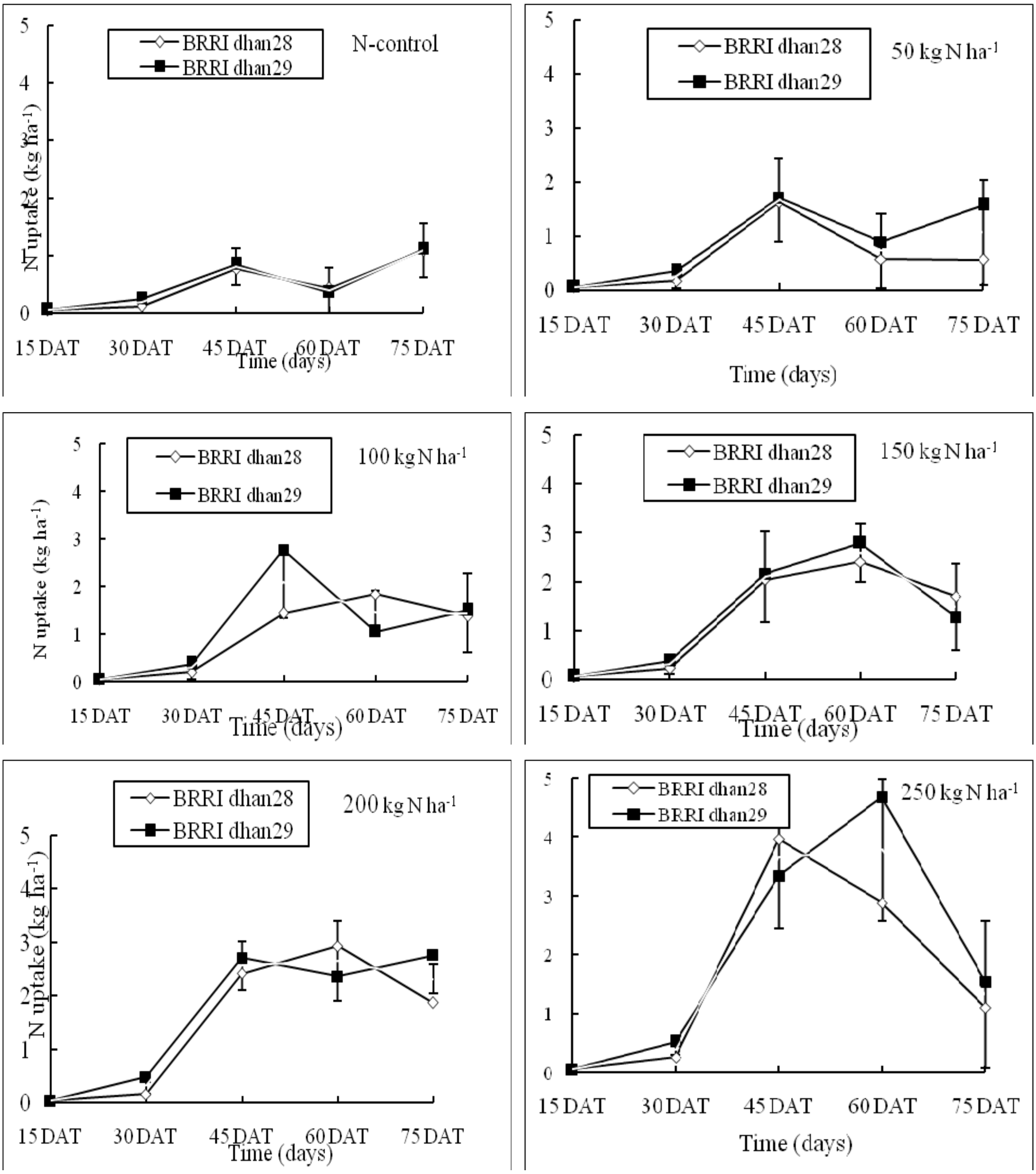

Fig. 2 Daily nitrogen uptake at different dates after transplanting influenced by nitrogen management in BRRI dhan28 and BRRI dhan29.

varietal difference in DNUP was significant and BRRI dhan29 showed significantly higher DNUP compared to BRRI dhan28 with this N rate. With the rate of 250 kg·N·ha^{-1}, BRRI dhan28 achieved highest DNUP at 45 DAT and then showed decreasing trend. BRRI dhan29 achieved the highest at 60 DAT and decreased thereafter. The decreasing pattern was higher in BRRI dhan29 in comparison to BRRI dhan28 but there was no significant varietal difference in DNUP at all growth stages (Fig. 2). Lower daily N uptake at the early growth stages compared to the PI stage dictate the strategy of N management. As compared to the present recommendation of three equal split application of N, a modified split would give better efficiency of N fertilizer. Since the daily requirement of N at 45 to 60 DAT was several higher than at 15 to 30 DAT, the first and second splits should apply less N than at PI.

3.3 Dry Matter Yield at Different N Rates

At 15 DAT, the increase in dry matter with the increase of N rates explained poor quadratic relationship both in BRRI dhan28 and BRRI dhan29 (R^2 = 0.24 for BRRI dhan28 and R^2 = 0.31 for BRRI dhan29) (Fig. 3). At 30 DAT, the increase in dry matter with the increase in N rates showed poor quadratic relationship in BRRI dhan28 (R^2 = 0.38), but this trend demonstrated strong relationship in BRRI dhan29 (R^2 = 0.86) (Fig. 3). At this growth stage, BRRI dhan29 produced significantly higher dry matter compared to BRRI dhan28. At 45 DAT, regression analysis showed quadratic increases in dry matter production with the increase of N rates ($p <$ 0.01) in both the varieties (Fig. 3). BRRI dhan29 demonstrated higher dry matter production ($p < 0.05$) compared to BRRI dhan28 at this growth stage. At 60 and 75 DAT, a significant quadratic increase ($p \leq 0.01$) in dry matter production was observed with the increase of N rates in both the varieties (Fig. 3). The dry matter production increased significantly ($p < 0.01$) with the increase of N rates and BRRI dhan29 produced significantly higher ($p < 0.01$) dry matter compared to BRRI dhan28 (Fig. 3). At this growth stage, regression equation showed significant quadratic increases in dry matter production both in BRRI dhan28 and BRRI dhan29 (R^2 = 0.93 for BRRI dhan28 and R^2 = 0.99 for BRRI dhan29). It means that the equation can explain 93% of the relationship in BRRI dhan28 and 99% of the relationship in BRRI dhan29. Dry matter yield increased with the advancement of plant age up to flowering stage and then decreased [1]. Dry matter loss from the vegetative tissues during the interval from flowering to maturity suggested active translocation of assimilates to the panicles [10]. The decrease in dry matter shortly before maturity can also be partially explained by the senescence of the lower leaves [13].

3.4 Relationship between N Uptake and Dry Matter Production

A relation between N uptake and dry matter production was determined at different growth stages (Fig. 4). At 15 DAT, poor linear relationship was observed between N uptake and dry matter production both in BRRI dhan28 and BRRI dhan29 (R^2 = 0.50 for BRRI dhan28 and R^2 = 0.71 for BRRI dhan29). The equation ($Y = 12.79x + 9.47$ for BRRI dhan28 and $Y = 16.67x + 9.60$ for BRRI dhan29) can be explained 71% of the relationship in BRRI dhan28 and 50% of the relationship in BRRI dhan29. At 30 DAT, the dry matter increased linearly with the increase in N uptake in BRRI dhan28 and BRRI dhan29 (R^2 = 0.84 and 0.93 for BRRI dhan28 for BRRI dhan29, respectively). In BRRI dhan28, the highest N uptake (4.8 $kg \cdot ha^{-1}$) contributed to the highest dry matter production (72 $kg \cdot ha^{-1}$) and in BRRI dhan29, the highest N uptake (8.8 $kg \cdot ha^{-1}$) contributed to the highest dry matter production (151 $kg \cdot ha^{-1}$). At 45 DAT, quadratic equation explained the relationship between dry matter production and N uptake both in BRRI dhan28 and BRRI dhan29 (R^2 = 0.98 for BRRI dhan28 and R^2 = 0.92 for BRRI dhan29). The highest N uptake corresponded to the highest dry matter production in BRRI dhan28 and in BRRI dhan29 but the rate of dry matter increase per unit of the N uptake increase diminished at this point, especially at 45 DAT. At 60 DAT, dry matter production increased linearly with the increase in N uptake in both the varieties (R^2 = 0.91 for BRRI dhan28 and R^2 = 0.98 for BRRI dhan29). It means that N uptake explained about the change in dry matter production by 91% in BRRI dhan28 and 98% in BRRI dhan29 at 60 DAT (Fig. 4). At this growth stage, the highest N uptake of 108 $kg \cdot ha^{-1}$ with a corresponding dry matter of 3,088 $kg \cdot ha^{-1}$

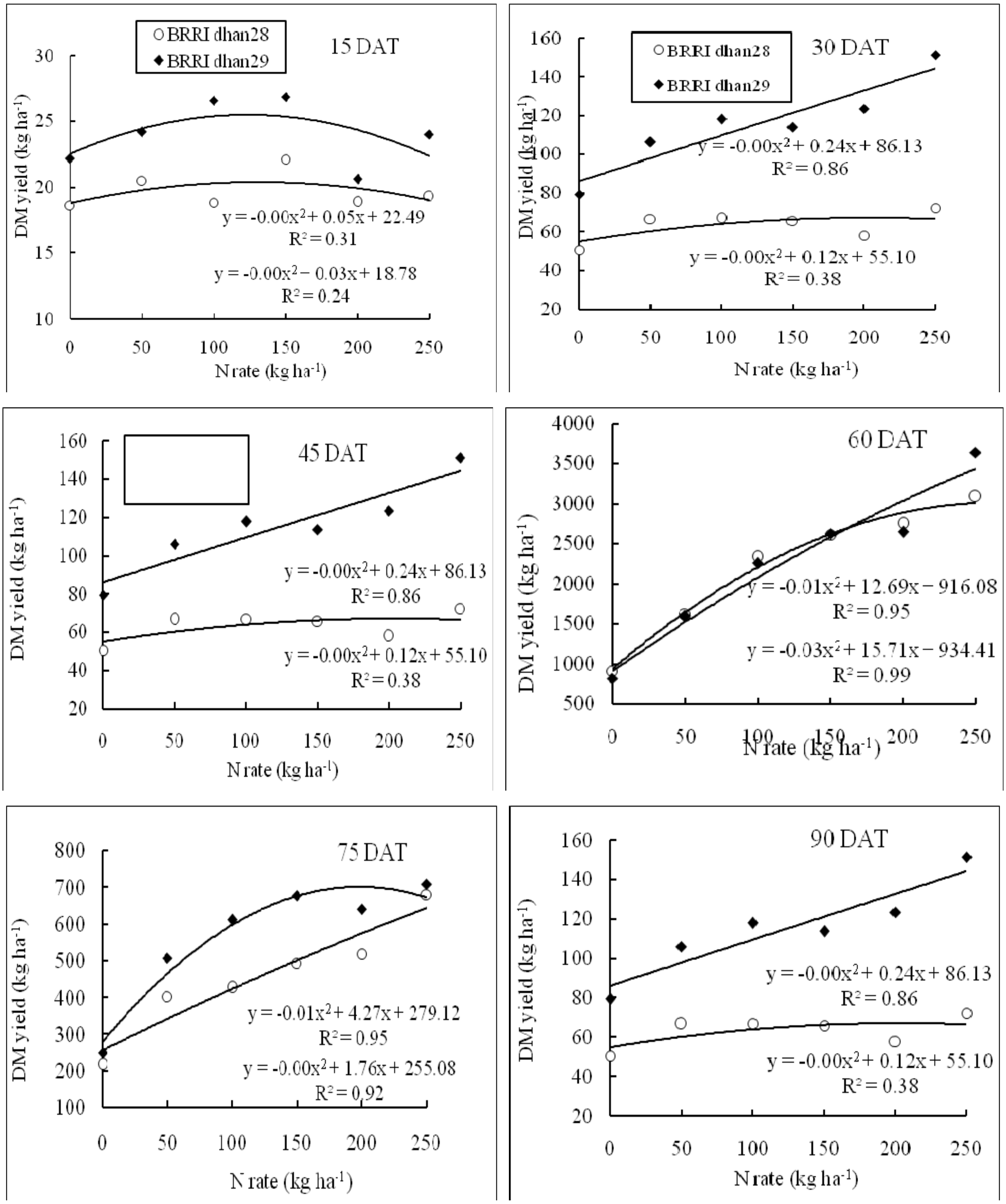

Fig. 3 Relationship of dry matter production with different rates of nitrogen fertilizer application at different growth stages.

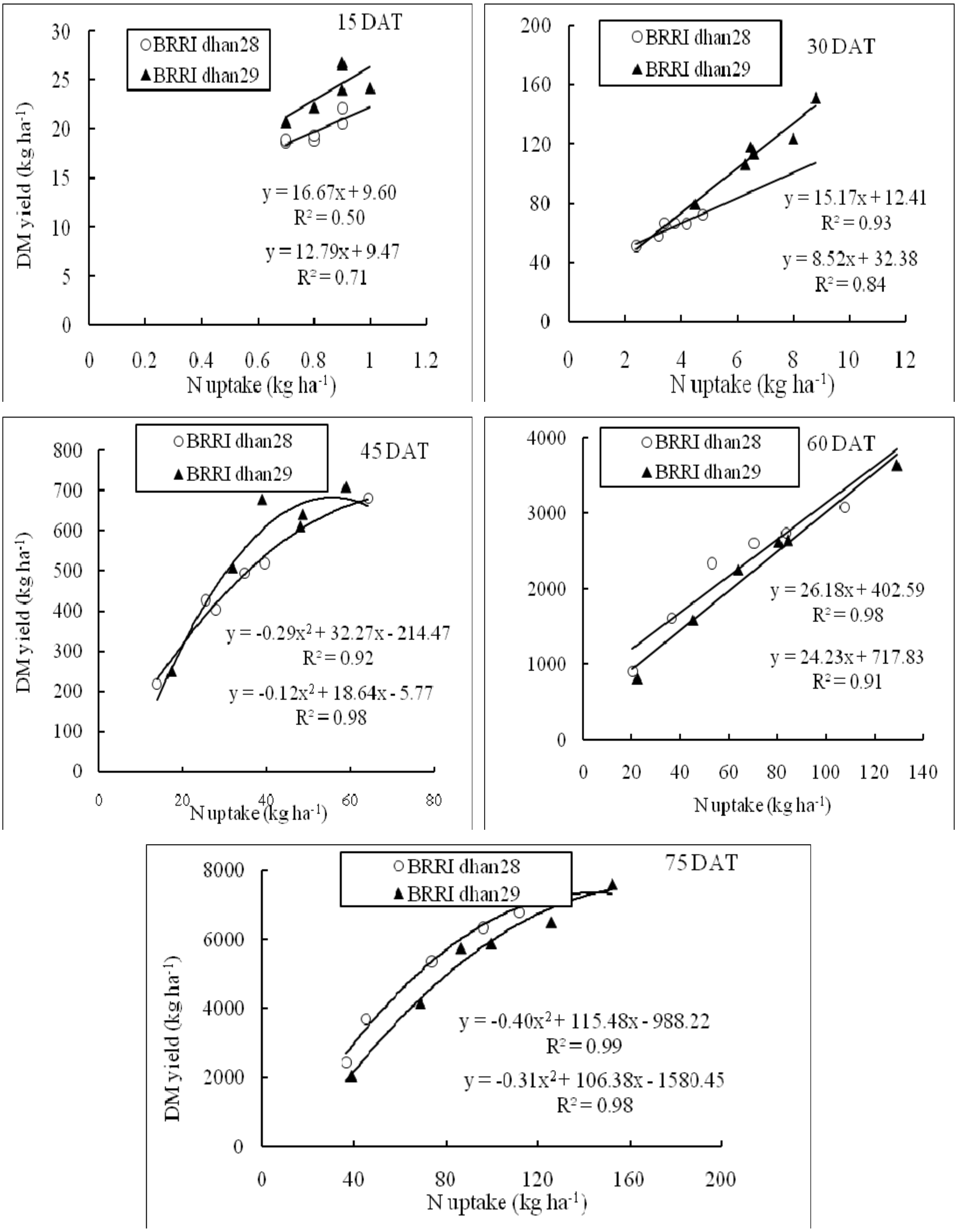

Fig. 4 Relationship between N uptake and dry matter production under different N rates in two rice varieties.

in BRRI dhan28 and 129 kg·ha^{-1} N uptake and 3,640 kg·ha^{-1} dry matter production in BRRI dhan29 were observed. Unlike 60 DAT, the relationship between N uptake and dry matter was quadratic (R^2 = 0.98 for BRRI dhan28 and R^2 = 0.99 for BRRI dhan29). At this growth stage BRRI dhan28 and BRRI dhan29 showed the highest N uptake of 124 and 153 kg·ha^{-1} with a corresponding dry matter yield of 7,306 and 7,611 kg·ha^{-1}, respectively. The increase in N uptake has strong relation in dry matter production [14]. Based on regression equation, accumulation of 72 kg·N·ha^{-1} produced 9,449 kg·ha^{-1} of dry matter in flooded rice cultivar Metica 1 [1].

3.5 Grain Yield

Nitrogen (N) and variety (V) demonstrated significant interaction effect on the grain yield (p < 0.05). Grain yield increased with N fertilization and showed significant (p < 0.01) quadratic response both in BRRI dhan28 and BRRI dhan29 rice (Fig. 5). The quadratic regression equation (Y = 2899.6 + 31.92x – 011x^2, R^2 = 0.98 for BRRI dhan29 and Y = 2081.4 + 23.25x – 0.07x^2, R^2 = 0.99 for BRRI dhan28) explained 98% of yield variation in BRRI dhan28 and 95% in BRRI dhan29 by nitrogen application. Varietal effect showed highly significant (p < 0.01) and BRRI dhan29 achieved significantly greater yield compared to BRRI dhan28 (Fig. 5). BRRI dhan28 and BRRI dhan29 gave 2,486 and 2,908 kg·ha^{-1} grain yield in the control plots, respectively, which increased to 4,130 and 4,534 kg·ha^{-1}, respectively, with 50 kg·N·ha^{-1}. Increasing N dose to 100 kg·ha^{-1}, BRRI dhan28 increased yield to 4,864 kg·ha^{-1}, while BRRI dhan29 gave 5,186 kg·ha^{-1}. Difference in yield between BRRI dhan28 and BRRI dhan29 was larger at 100 and 150 kg·N·ha^{-1} compared to other doses. Differentiating the quadratic equation of yield response with respect to applied N doses, the maximum N rate appeared as 164 kg·ha^{-1} both for BRRI dhan28 and BRRI dhan29. However, the economic optimum dose appeared as 156 and 158 kg·ha^{-1} for BRRI dhan28 and BRRI dhan29, respectively. Maximum grain yield of 20 lowland rice genotypes was obtained at 150-200 kg·N·ha^{-1} at IRRI in Philippines [15]. The N fertilization significantly increased grain yield and shoot dry weight. The variation in grain yield with nitrogen fertilization varied from 66 to 93% depending on genotypes [16]. About 90 kg·ha^{-1} as the optimum dose of nitrogen for rice in Iran, however, the yield level of his test variety, shirodi, was below 2 t·ha^{-1}. Variation of optimum N doses for rice depends on many abiotic and biotic factors; therefore, it has

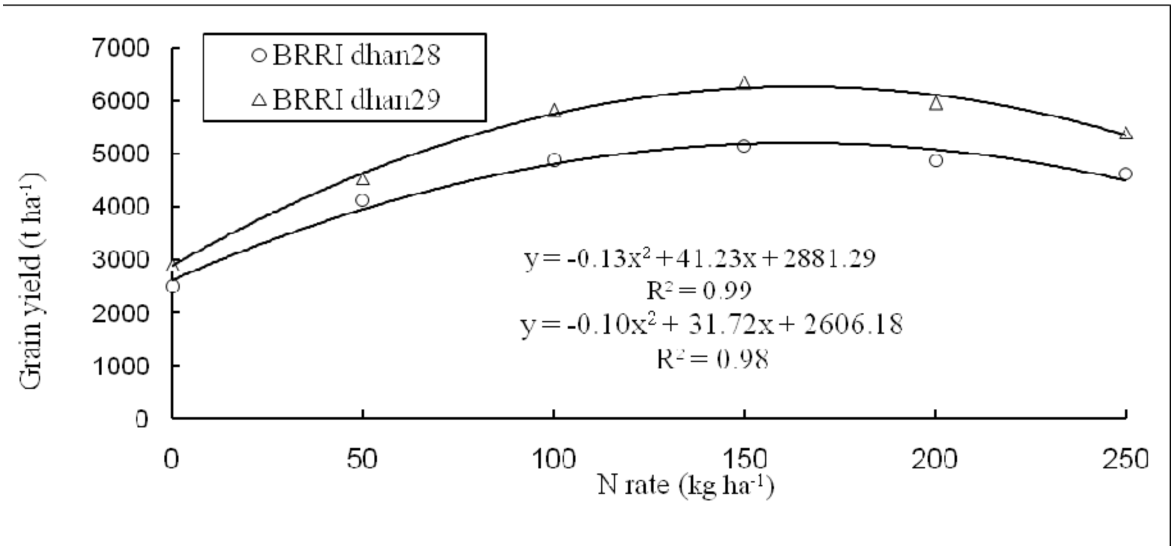

Fig. 5 Grain yield of two rice varieties at different rates of nitrogen application.

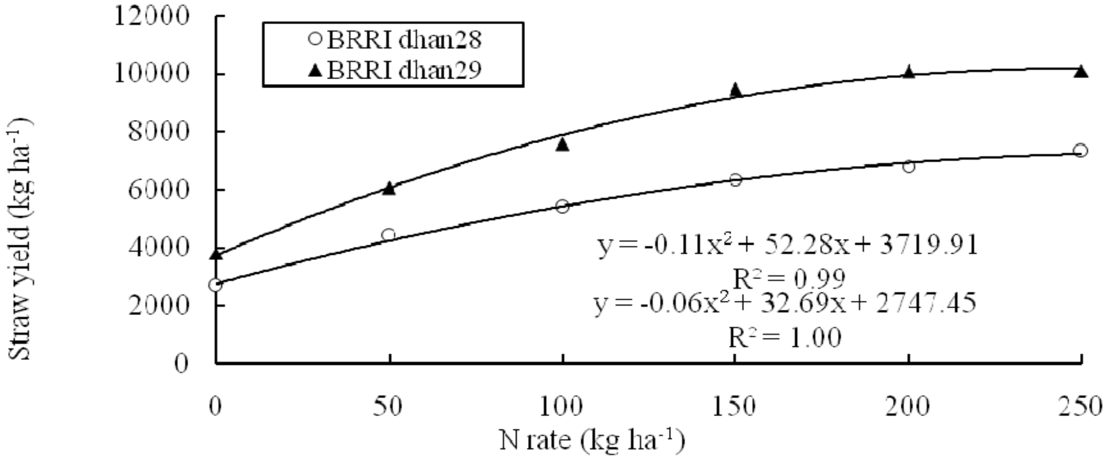

Fig. 6 Straw yield of two rice varieties at different rates of nitrogen application.

limited use in a particular geographical and ecological conditions [17]. About 120 kg·N·ha^{-1} as an optimum dose for a yield level of 7.45 and 6.80 t·ha^{-1} in two consecutive years was observed for direct wet season rice in Indo-Gangetic plain of Ludhiana, India [18].

3.6 Straw Yield

The interaction of nitrogen (N) and variety (V) demonstrated significant ($p < 0.05$) effect on straw yield. Nitrogen treatment significantly ($p < 0.01$) affected the straw yield production. The straw yield increased with the increase of N fertilization and showed quadratic response both in BRRI dhan28 and BRRI dhan29 rice (Fig. 6). The quadratic regression equation ($Y = -0.06x^2 + 32.69x + 2747.45$ for BRRI dhan28 and $Y = -0.11x^2 + 52.28x + 3719.91$ for BRRI dhan29) can explain 100% of the relationship for BRRI dhan28 and 99% of the relationship in BRRI dhan29. The highest straw yield was obtained with the rate of 250 kg·N·ha^{-1} in both the varieties. Varietal effect showed highly significant ($p < 0.01$) and BRRI dhan29 achieved significantly greater straw yield compared to BRRI dhan28 (Fig. 6). Highly significant positive correlation was found between shoot dry weight and grain yield of eight lowland rice genotypes [19]. Similarly, shoot dry weight is an important plant component for determining grain yield in field crops [20]. Quadratic relationship was observed between shoot dry weight and grain yield in rice [1, 16]. Differences in shoot and grain yield of lowland rice genotypes was also reported [2, 19].

4. Conclusions

The daily requirement of N at 45 to 60 DAT was much higher than at 15 to 30 DAT. Nitrogen uptake increased with the increase of N rates both in BRRI dhan28 and BRRI dhan29 from initiation of tillering stage (15 DAT) up to flowering stage (75 DAT). At all N treatments, dry matter production increased with the advancement of plant age and the highest N uptake contributed to the highest dry matter production in both the varieties. The current N management recommendation of three equal splits needs a thorough attention for its modification. The N uptake pattern in both the varieties suggests applying relatively lower proportion of nitrogen at the early growth stages and a larger quantity at the panicle initiation stage.

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