ORIGINAL RESEARCH

Research on Crop Ecophysiology
Vol. 10/2, Issue 1 (2015), Pages: 1-16

Nitrogen Fertilizer Optimization and Its Response to the Growth and Yield of Lowland Rice

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Received: 7 July 2014 Accepted: 25 November 2014

ABSTRACT

Lowland rice (*Oryza sativa* L.) in South Asia is under stress, as nitrogen removals by crops are higher than their replenishment through fertilizers. Limited information is available on optimizing nitrogen dose in lowland rice to turn out higher yield. The present investigation aimed to optimize nitrogen fertilization and it's response to the growth and yield of lowland rice. We evaluated two modern rice varieties (BRRI dhan28 and BRRI dhan29) under six nitrogen rates ranging from 0 to 250 kg ha^{-1} during the dry season. Positive response of nitrogen fertilization was observed in tiller and dry matter production from the early growing stage in both varieties. Tillering increased progressively with the advancement of growth stage and reached at the peak within 60 days after transplanting (DAT) in all cases. BRRI dhan28 and BRRI dhan29 achieved the highest dry matter at 75 and 90 DAT with 250 kg N ha^{-1}. The relationship between N application and N uptake by plants became quite evident at 30 DAT and beyond. N uptake started to increase from 45 DAT and showed a peak at 75 DAT in both the varieties. Nitrogen application significantly increased the grain yield of both varieties. The highest yield of 5.15 and 6.34 Mg ha^{-1} was obtained with 150 kg N ha^{-1} in BRRI dhan28 and BRRI dhan29, respectively. However, the nitrogen dose was optimized at 156 and 158 kg ha^{-1} for BRRI dhan28 and BRRI dhan29, respectively.

Keywords: *Oryza sativa* L., N rates, Dry matter production, N uptake, Tillering pattern, Yield

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food for nearly half of the world's population, most of whom 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 (Fageria and Baligar, 2001). By the year 2025, it is estimated that it will be necessary to produce about 60% more rice than what is currently produced to meet the food needs of a growing world population (Fageria *et al.*, 2003). 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 (Fageria *et al.*, 2008), especially in tropical Asian soils and almost every farmer has to apply the costly N fertilizer to get a desirable yield of rice (Saleque *et al.*, 2004). Judicious and proper use of fertilizers can markedly increase the yield and improve the quality of rice (Chaturvedi, 2005). Given the importance of nitrogen fertilization on the yield in grain, it is necessary to know what the best dose is for each variety as well as its influence on yield components and other agronomic parameters (Chaturvedi, 2005). However, both excess and insufficient supply of nitrogen is harmful to the rice crop and may decrease grain yield.

Most soils of Bangladesh require N fertilizer application to achieve high yield. Saleque *et al*. (2004) reported modern rice varieties need chemical N fertilizer application to produce a pretty yield and estimated 78 to 113 kg N ha^{-1} for 10 rice genotypes in Bangladesh. Fageria *et al*. (2008) reported 136 kg N ha^{-1} as the optimum dose for MV rice in South America. However, optimum N dose for rice crop is not often mentioned. 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 is constant across large areas and years.

Selection of the most appropriate rate of N fertilizer is one of the management practices that can affect both economic viability of crop production and impact of agriculture on the environment. Traditionally, the optimum rate of N fertilizer has been the rate that results in maximal economic yield (Jongkaewattana *et al*., 1993). Further, proper timing in combination with adequate rate of N application is crucial to minimize N losses and improve N use efficiency (Datta and Buresh, 1989). Insufficient nitrogen supply is an important constraint to productivity of lowland rice and there is limited information available on optimum timing of N application for lowland rice (Fageria and Baligar, 1999).

Fageria and Baligar (2005) reported that shoot dry weight is an important plant component for determining grain yield in field crops. Fageria and Baligar (2001) and Fageria *et al*. (2004) also reported quadratic relationship between shoot dry weight and grain yield in rice. Saleque *et al*. (2004) reported 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. Among macronutrients, nitrogen uptake is the highest with the exception of potassium (Fageria and Baligar, 2001). 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. Under these circumstances, the present research work was designed with an attempt to determine the optimum dose of nitrogen and its response to the growth and yield of lowland rice.

MATERIALS AND METHODS

An experiment was conducted during *Boro* season (November-April) at the experimental farm of the Bangladesh Rice Research Institute (BRRI), Gazipur, Bangladesh, located at $23^0 59'$ N latitude, $90^0 24'$E longitude and altitude of 16 feet. It belongs to Agro-Ecological Zone (AEZ) number 28 known as Madhupur Tract. The soil of the experimental field is Chhiata clay loam, a member of the fine, hyperthermic Vertic Endoaquept (Saleque *et al.*, 2004). The initial soil chemical properties at 0-15 cm soil depth were as follows: pH 6.1, organic matter 2.02%, total N content 0.07%, available phosphorus (P) 10.14 mg kg^{-1} (0.5 M $NaHCO_3$ extracted), exchangeable potassium (K) 0.17 meq/100 g soil (Neutral 1.0 N NH_4OAc extracted), available sulfur (S) 20 mg kg^{-1} [$Ca(H_2PO_4)_2$ extracted], and available zinc (Zn) 2.8 mg kg^{-1} (0.01N HCl extracted).

Treatments consisted of six N rates: 0, 50, 100, 150, 200 and 250 kg ha^{-1} and the experiment involved two mega rice varieties in Bangladesh context- BRRI dhan28 and BRRI dhan29. These two varieties were grown under fully irrigated conditions.

BRRI dhan28 is a short duration (growth duration 140 days) and BRRI dhan29 is a long duration (growth duration 160 days) variety, respectively. Rice was transplanted in the first week of January with 40-45 day-old seedlings and harvested in May. Two to three seedlings were transplanted maintaining 20 cm × 20 cm spacing. The experiment was conducted in a randomized complete block design with three replications. Unit plot size was 5 m × 4 m. All plots were surrounded by soil levees of 30 cm high to avoid N contamination between plots. Nitrogen was applied 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. 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. At maturity the crop was harvested manually at 15 cm above ground level, however, 16 hills from each plot were harvested at the ground level for measuring yield components and straw yield. Rice plants from 5 m^2 area of the middle of each plot were harvested at above ground level and threshed. The grain yield was adjusted to 14% moisture content and was converted into t ha^{-1}.The straw yield as oven dry basis following standard procedures as described by Yoshida *et al.* (1976).

Dry matter weight of rice plant was determined at every 15 days from transplanting to maturity. Sixteen hills of rice plant from each plot were harvested at the base and the sample was oven dried at 70 °C for 72 hours. Oven dry weight of the samples was converted to dry matter per m^2. Nitrogen was determined from the collected plant samples by micro Kjeldahl method (Yoshida *et al.*, 1976). Total N uptake was determined by the following formulae:

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

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

Determination of Optimum Nitrogen Dose

Optimum dose of N was determined by differentiating the quadratic N response equation (Colwell, 1994). The form of the quadratic equation is given by,

$$\overline{Y} = a + bN + cN^2$$

Where $\overline{Y}$ is estimated seed yield (kg ha^{-1}), N is applied nitrogen fertilizer (kg ha^{-1}), *a*, *b* and *c* are regression coefficients.
Differentiating the equation, we get,

$$\frac{d\overline{Y}}{dN} = b + 2cN$$

The optimum dose of N will be at the point where $\frac{d\overline{Y}}{dN} = 0.$

Therefore,

$$0 = b + 2cN$$

$$\text{or,}\ N = -\frac{b}{2c}$$

However, the economic optimum dose of N will be:

$$N = \frac{E_n - b}{2c}$$

Where, $En = \frac{P_f}{P_y}$, P_f is price of nutrient kg^{-1} and P_y is price of seeds kg^{-1}.

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).

RESULTS AND DISCUSSION

Dry Matter Yield at Different N Rates

Nitrogen (N) and variety (V) interactions demonstrated non-significant effects on dry matter production at all the growth stages, however, at 90 DAT the interaction was significant (p<0.01) (Table 1). The individual effect of V on dry matter production was significant (p<0.05) except at 60 and 75 DAT. The individual effect of N was highly significant (p<0.01) except at 15 and 30 DAT. At all N treatments, dry matter production increased with the advancement of plant age both in BRRI dhan28 and BRRI dhan29. In BRRI dhan28, dry matter yield increased up to 75 DAT and the highest amount of dry matter achieved from this growth stage. But in BRRI dhan29, dry matter yield increased up to 90 DAT and the highest amount of dry matter was achieved at that growth stage. Fageria and Baligar (2001) also reported that dry matter yield increased with the advancement of plant age from initiation of tillering until flowering and then decreased. Dry matter loss from the vegetative tissues during the interval from flowering to maturity suggested active translocation of assimilates to the panicles (Fageria and Baligar, 1999). According to Norman *et al.* (1992), the decrease in dry matter shortly before maturity can also be partially explained by the senescence of the lower leaves.

Nitrogen Uptake at Different Growth Stages

Significance test of nitrogen uptake at different growth stages are presented in Table 2. Irrespective of treatments, N uptake by rice plant at the early growth stage (15 and 30 DAT) was very low, started to increase from 45 DAT and showed a peak at 75 DAT in both the varieties. In BRRI dhan28, the increase in N uptake at 30 DAT was 353% as compared to 15 DAT across N rates. At 45 DAT, the increase across N rates was 850% as compared to 30 DAT. The increase in N uptake was 80% at 60 DAT as compared to 45 DAT. At 75 DAT, the increase in N uptake was 31% as compared to 60 DAT across N rates. At 90 DAT, there was a 53% decrease in N uptake as compared to 75 DAT. In BRRI dhan29, the increase in N uptake at 30 DAT was 670% as compared to 15 DAT across N rates. At 45 DAT, the increase was 500% as compared to 30 DAT across N rates. The increase in N uptake was 75% at 60 DAT as compared to 45 DAT across N rates. AT 75 DAT, the increase in N uptake across

N rates was 34% as compared to 60 DAT. At 90 DAT, the decrease in N uptake was 21% as compared to 75 DAT across N rates. Fageria and Baligar (2001) also reported that nitrogen uptake increased with the advancement of the crop growth age up to the flowering stage and decreased thereafter. Another study found that rice yield was increased with increasing uptake of N until reaching a peak (Suzuki, 1997).

Table 1. Dry matter yield of two rice varieties at different N rates

N rate	Days after transplanting					
(kg ha^{-1})	15	30	45	60	75	90
	kg ha^{-1}					
			BRRI dhan28			
0	19	51	218	912	2460	1982
50	21	67	403	1623	3701	2838
100	19	67	426	2332	5375	3571
150	22	66	494	2611	6350	3812
200	19	58	518	2751	6793	5288
250	19	72	680	3088	7306	4866
Avg.	20	64	457	2220	5331	3726
			BRRI dhan29			
0	22	79	250	819	2060	3807
50	24	106	508	1592	4177	6045
100	27	118	611	2256	5756	7567
150	27	114	678	2625	5889	9458
200	21	123	641	2646	6503	10075
250	24	151	709	3640	7611	10086
Avg.	24	115	566	2263	5333	7840
$LSD_{0.05}$ for N	NS	NS	166.37	516.66	736.58	548.11
$LSD_{0.05}$ for V	2.65	16.31	96.06	NS	NS	316.45
$LSD_{0.05}$ for N×V	NS	NS	NS	NS	NS	775.14
CV (%)	20.6	31.1	32.0	22.7	13.6	9.3

NS non-significant at the 0.05 probability levels.

Table 2. Nitrogen uptake at different growth stages under different N rates in BRRI dhan28 and BRRI dhan29

N rate	Days after transplanting					
(kg ha^{-1})	15	30	45	60	75	90
	kg ha^{-1}					
			BRRI dhan28			
0	0.71	2.43	13.92	20.43	36.66	18.84
50	0.85	3.36	27.91	36.49	44.86	25.74
100	0.79	3.84	25.47	53.05	73.81	27.38
150	0.88	4.20	34.76	70.82	96.22	37.92
200	0.72	3.15	39.91	83.54	111.68	62.85
250	0.82	4.75	64.28	107.55	124.18	56.51
Avg.	0.80	3.62	34.38	61.98	81.24	38.21
			BRRI dhan29			
0	0.84	4.52	17.27	22.63	39.24	37.07
50	0.96	6.27	31.95	45.37	69.12	57.28
100	0.91	6.53	48.08	63.97	86.65	56.86
150	0.95	6.59	38.95	80.79	99.83	84.19
200	0.70	8.00	48.73	84.25	125.77	97.21
250	0.92	8.75	59.03	129.36	152.54	118.79
Avg.	0.88	6.78	40.67	71.06	95.53	75.23
$LSD_{0.05}$ for N	NS	1.84	13.94	15.42	18.37	11.42
$LSD_{0.05}$ for V	NS	1.06	NS	8.90	10.61	6.59
$LSD_{0.05}$ for N×V	NS	NS	NS	NS	NS	16.15
CV (%)	25.1	34.8	36.6	22.8	20.4	19.8

NS non-significant at the 0.05 probability levels.

Tiller Production at Different Growth Stages

Nitrogen treatment increased tillering significantly ($p<0.01$) except at the initiation of tillering stage (15 DAT) (Table 3). Tillering increased with the advancement of growth stage and maximum tiller production were achieved within 60 DAT both in BRRI dhan28 and BRRI dhan29. Tillering at 75 and 90 DAT showed a decreasing pattern compared to that of 60 DAT in both the varieties. At 15 DAT, BRRI dhan28 and BRRI dhan29 produced statistically similar number of tillers irrespective of N rates. A similar scenario was observed in tillering at 60 DAT. At 90 DAT, BRRI dhan29 produced higher number of tillers compared to BRRI dhan28 irrespective of N rates. But the varietal difference was not significant at this growth stage. At 30 DAT, BRRI dhan29 produced significantly higher number of tillers compared to BRRI dhan28 irrespective of N rates. A similar scenario in tillering was observed at 45 DAT irrespective of N rates. At 75 DAT, BRRI dhan29 produced significantly higher number of tillers in comparison to BRRI dhan28 irrespective of N rates. The decrease in tiller number was attributed to the death of some of the last tillers as a result of their failure in competition for light and nutrients (Fageria *et al*., 1997). These results are in accordance to the findings of Rajput *et al*. (1988). According to Yoshida *et al*. (1972), as the amount of nitrogen absorbed by the crop increases, there is an increase in the number of tillers per square meter.

Tiller and Panicle Production

The interactions of N × V was non-significant on tiller production (Table 4). The individual effect on N was significant on tiller production. The tiller number per square meter ranged from 212 to 348 in BRRI dhan28 and 190 to 359 in BRRI dhan29. In BRRI dhan28, about 64% of the variations in tillering occurred due to different N rates and the highest number of tiller was observed in the rate of 250 kg N ha^{-1}. About 89% of the variations in tillering occurred due to different N rates and the highest number of tiller was observed in the rate of 250 kg N ha^{-1} in BRRI dhan29. BRRI dhan29 produced higher number of tillers compared to BRRI dhan28 irrespective of N rates. But the varietal difference was not significant.

The N and V interactions showed non- significant (p>0.05) effect on panicle production. The individual effect of V also demonstrated insignificant effect on panicle m^{-2}. But the individual effect of N on panicle m^{-2} was significant. At N-control treatment, BRRI dhan28 produced 205 compared to167 panicle m^{-2} in BRRI dhan29. Receiving 50 kg N ha^{-1}, panicle m^{-2} in BRRI dhan28 and BRRI dhan29 was 219 and 220, respectively. Increasing N rate increased panicle production in both the varieties. At 150 kg N ha^{-1}, BRRI dhan28 and BRRI dhan29 produced 290 and 268 panicle m^{-2} which increased to 292 and 288, respectively with 200 kg N application.

Application of 250 kg N ha^{-1} increased panicle m^{-2} abruptly to 314 in BRRI dhan28 and 338 in BRRI dhan29. Number of panicles per unit area is the most important yield contributing trait which can be manipulated significantly with the N fertilization application at an appropriate growth stage during the crop growth cycle. Nitrogen applied late during the reproductive growth stage can be absorbed by the crop, but it is not utilized in grain yield improvement Fageria and Baligar (1999).

Table 3. Number of tillers at different N rates during the growth cycle

N rate (kg ha^{-1})	Days after transplanting					
	15	30	45	60	75	90
	Tillers m^{-2}					
			BRRI dhan28			
0	38	51	138	252	212	212
50	41	59	229	329	234	229
100	38	62	254	432	293	271
150	41	63	262	529	370	303
200	40	63	262	513	405	311
250	42	81	364	557	404	348
Avg.	40	63	252	435	320	270
			BRRI dhan29			
0	36	51	146	210	191	190
50	43	64	252	350	279	271
100	45	88	333	394	370	282
150	38	77	348	528	368	326
200	40	82	334	520	428	344
250	37	80	349	529	463	359
Avg.	40	74	294	422	350	295
LSD$_{0.05}$ for N	NS	16.59	56.51	56.36	49.76	37.72
LSD$_{0.05}$ for V	NS	9.58	32.62	NS	28.73	NS
LSD$_{0.05}$ for N×V	NS	NS	NS	NS	NS	NS
CV (%)	14.9	23.8	20.2	12.9	14.6	13

NS non-significant at the 0.05 probability levels.

Table 4. Effect of N application on different yield parameters of BRRI dhan28 and BRRI dhan29

N rate (kg ha^{-1})	Tiller m^{-2} (No.)	Panicle m^{-2} (No.)	Grains anicle^{-1} (No.)	1000 grain wt (g)	Sterility (%)
			BRRI dhan28		
0	212	205	87	20.3	30
50	229	219	114	20.1	22
100	271	258	100	20.1	27
150	303	290	94	20.4	23
200	311	292	101	19.9	24
250	348	338	99	19.4	24
			BRRI dhan29		
0	190	167	107	19.5	24
50	271	220	119	19.4	21
100	282	255	111	19.3	22
150	326	268	133	19.3	17
200	344	288	118	19.2	25
250	359	314	116	18.8	24
$LSD_{0.05}$ for N	37.72	36.01	16.41	0.44	3.59
$LSD_{0.05}$ for V	21.77	20.79	9.47	0.25	2.07
$LSD_{0.05}$ for N×V	53.34	50.93	23.21	0.62	5.07
F-test (N)	**	**	NS	*	**
F-test (V)	NS	NS	**	**	**
F-test (N×V)	NS	NS	NS	NS	NS
CV (%)	13	13.6	14.9	2.2	14.9

*, **, NS significant at the 0.05 and 0.01 probability levels and non-significant, respectively.

Grains Per Panicle, Grain Sterility and Thousand Grain Weight

The N × V interactions and the individual effect of N for grains panicle^{-1} were not significant ($p>0.05$). In BRRI dhan28, the higher number of grains panicle^{-1} was observed in 50 kg N ha^{-1} followed by that of 100 and 200 kg N ha^{-1}. The number of grains panicle^{-1} from 150 and 250 kg N ha^{-1} was observed statistically similar. The lowest number of grains panicle^{-1} was observed in control-N treatment. In BRRI dhan29, the higher number of grains panicle^{-1} was obtained from 150 kg N ha^{-1} followed by that of 50 kg N ha^{-1} and 200 kg N ha^{-1}. The number of grains panicle^{-1} from 100 kg N ha^{-1} and 250 kg N ha^{-1} was observed statistically similar. The lowest number of grains panicle^{-1} was obtained from control-N treatment. The individual effect of V for grains No. panicle^{-1} was significant ($p<0.01$). BRRI dhan29 produced significantly higher number of grains in comparison to BRRI dhan28 irrespective of different N rates. The increase in number of grains panicle^{-1} were 31% in BRRI dhan28 at 50 kg N ha^{-1} and 24% in BRRI dhan29 at 150 kg N ha^{-1} compared to control-N treatment. Thousand grain weight ranged from 19 to 20 g both in BRRI dhan28 and BRRI dhan29 irrespective of N rates. In BRRI dhan28, the sterility (%) ranged from 22-30% and in BRRI dhan29, 17-25% among different N rates. Grain weight was typically of minor importance in determining rice yield (Gravois and McNew, 1993). Another study also observed that 1000-grain weight is of minor importance in increasing rice yield and under most conditions, 1000-grain weight of field crops is a very stable varietal character (Yoshida, 1981).

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 (Figure 1). The quadratic regression equation ($Y = 2606.18 + 31.72x – 0.10x^2$, $R^2= 0.98$ for BRRI dhan28 and $Y= 2881.29 + 31.72x– 0.13x^2$, $R^2 = 0.99$ for BRRI dhan29) explained 98% of yield variation in BRRI dhan28 and 99 % 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. BRRI dhan28 and BRRI dhan29 yielded 2,486 and 2,908 kg ha^{-1}, respectively, which were 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}, increased BRRI dhan28 yield to 4,864 kg ha^{-1} while this increased for BRRI dhan29 was up to 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 (Table 5).

Maximum grain yield of 20 lowland rice genotypes was obtained at 150–200 kg N ha^{-1} at IRRI in Philippines (Singh *et al*., 1998). 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 (Fageria *et al*., 2003). In fertilizer experiments 90% of the maximum yield is often considered as an economical rate (Fageria *et al.*, 2003). The 90% of the maximum grain yield was obtained with the application of 136 kg N ha^{-1} and 90% of the maximum shoot dry matter yield was achieved with the application of 120 kg N ha^{-1} (Fageria *et al*., 2008). Another study revealed that maximum average grain yield of 20 lowland rice genotypes was obtained at 150 to 200 kg N ha^{-1} (Singh *et al*., 1998). It was observed that 120 kg N ha^{-1} is an optimum dose for a yield level of 7.45 and 6.80 t ha^{-1} in two consecutive years for direct wet season rice in Indo-Gangetic plain of Ludhiana, India (Singh *et al*., 2007).

Table 5. Optimum dose of nitrogen for BRRI dhan28 and BRRI dhan29 in Chhiata clay loam soil

Variety	Optimum dose (kg ha^{-1})	Economic optimum dose (kg ha^{-1})
BRRI dhan28	164	156
BRRI dhan29	164	158

Straw Yield

The interaction effects of N x V on straw yield were statistically significant (p<0.05). 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 (Figure 2). The quadratic regression equation ($Y= - 0.06\ x2+32.69\ x +2747.45$ for BRRI dhan28 and $Y= -0.11x2 +52.28x +3719.91$ for BRRI dhan29) explained 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. A highly significant positive correlation between shoot dry weight and grain yield of eight lowland rice genotypes was reported by Fageria and Filho, (2001). Similarly, shoot dry weight is an important plant component for determining grain yield in field crops (Fageria and Baligar, 2005).

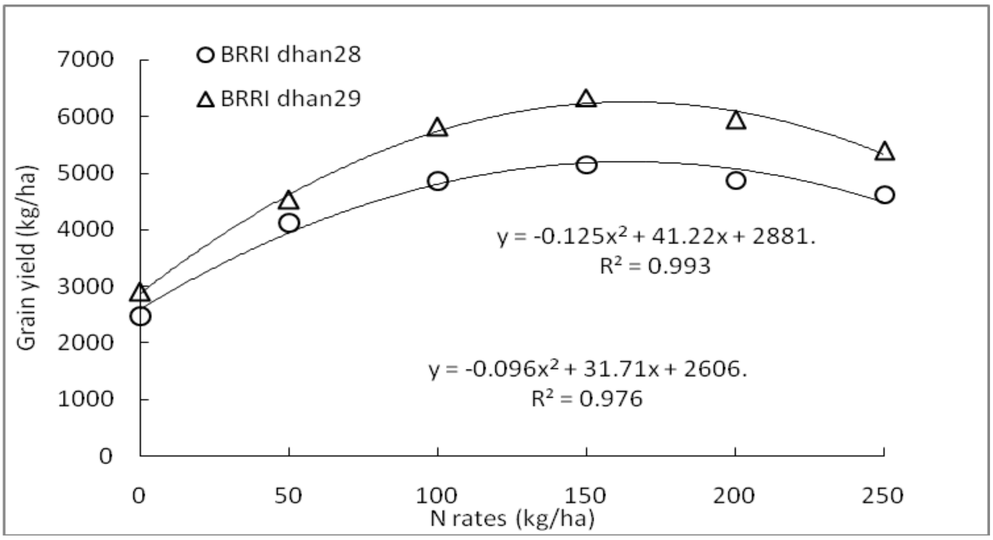

Figure 1. Grain yield of two rice varieties at different rates of nitrogen application

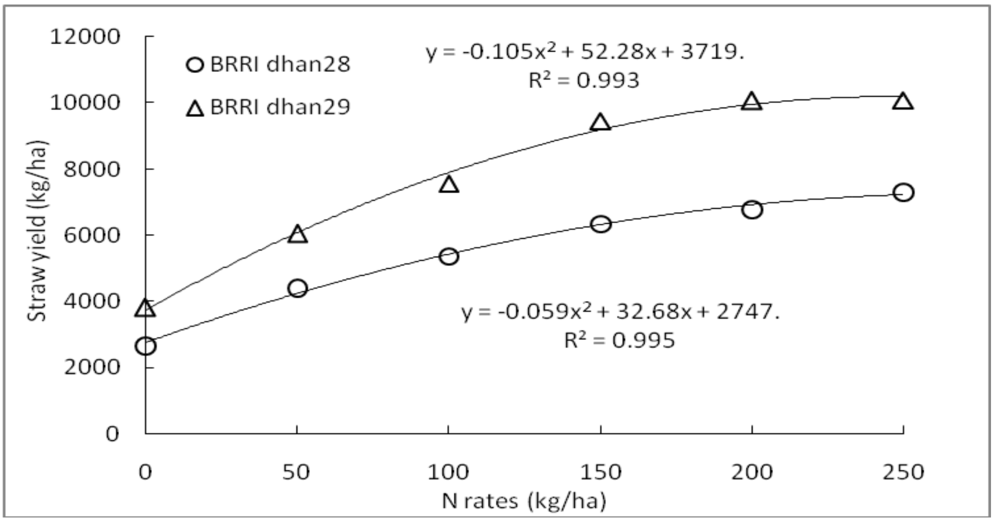

Figure 2. Straw yield of two rice varieties at different rates of nitrogen

Relationship between Dry Matter at Harvest and Grain Yield

A relationship between dry matter at harvest and grain yield was determined in BRRI dhan28 and BRRI dhan29 (Figure 3). Grain yield increased significantly (p<0.01) and quadratically with increasing straw yield in both the varieties. The quadratic regression equation ($Y = -0.001\ x^2 + 1.97\ x - 3006.97$ for BRRI dhan28 and $Y = -\ 0.002\ x^2 + 1.73\ x - 1396.82$ for BRRI dhan29) explained 92% of the relationship for BRRI dhan28 ($R^2 = 0.92$) and 98% of the relationship for BRRI dhan29 ($R^2 = 0.98$). At low level of straw production, grain yield increased linearly with the increase in dry matter, but reached at plateau at 6350 kg ha^{-1} in BRRI dhan28 and 9458 kg ha^{-1} in BRRI dhan29, respectively. Maximal grain yield of about 5154 kg ha^{-1} was achieved at about 6350 kg ha^{-1} of dry matter production in BRRI dhan28. This maximal grain yield (6341 kg ha^{-1}) was achieved at about 9458 kg ha^{-1} of dry matter production in BRRI dhan29. Fageria and Baligar (2001) reported that grain yield in cereals is related to biological yield and harvest index. The biological yield of a cereal crop is the total yield of plant tops and is an indication of the photosynthetic capability of the crop in question.

Relationship between N Uptake and Grain Yield

A relation between N uptake and grain yield was observed (Figure 4) at different growth stages. At 15 DAT, irrational relationship was observed between N uptake and grain yield both in BRRI dhan28 and BRRI dhan29. At 30 DAT, a natural logarithm equation was observed between N uptake and grain yield of rice. The logarithmic equation ($Y = 3252.01Ln(x) + 243.54$ for BRRI dhan28 and $Y = 4174.16Ln(x) -2741.30$ for BRRI dhan29) explained only 62 and 57% of the variation in grain yield respect to the variation in N uptake for BRRI dhan28 and BRRI dhan29, respectively. This may be explained by the fact that at the early growth stages of plant most of the N uptake is devoted to dry matter production only. At 45 DAT, the quadratic relationships were observed in both the varieties. Nitrogen uptake at 45 DAT explained about 85 and 90% variation in the grain yield of BRRI dhan28 and BRRI dhan29, respectively. Based on the regression equation, 34.8 kg ha^{-1} N uptake produced 4154 kg ha^{-1} grains in BRRI dhan28 and 48.1 kg ha^{-1} N uptake produced 5160 kg ha^{-1} grains in BRRI dhan29. At 60 and 75 DAT, 70.8 kg ha^{-1} and 96.2 kg ha^{-1}

N uptake contributed to 4154 kg ha^{-1} grains production in BRRI dhan28, respectively. Similarly in BRRI dhan29, 64 kg ha^{-1} and 86.7 kg ha^{-1} N uptake contributed in 5160 kg grains production, respectively. At 90 DAT, the contribution of N uptake to the highest yield production showed a decreasing trend both in BRRI dhan28 and BRRI dhan29 compared to the N uptake at 60 and 75 DAT. These results showed that grain yield depend on N uptake in rice plant up to a certain growth stage.

Varietal difference and the effect of N rates on the N uptake became more with advance of crop growth and the highest uptake was at 75 DAT stage. The data on growth parameters showed a positive relationship between rice growth and increasing N application. Grain and straw yield also responded encouragingly to higher N rates, however, it varied from variety to variety. Straw yield has significant quadratic association with grain yield, indicating the opportunity of grain yield improvement through the uplift of straw yield. The economic optimum rate of N for BRRI dhan28 and BRRI dhan29 appeared as about 160 kg N ha^{-1} where the farmers in Bangladesh applied only 117 kg and 135 kg N ha^{-1}, respectively. Sufficient N application is one of the strategies to boost straw yield and consequently grain yield.

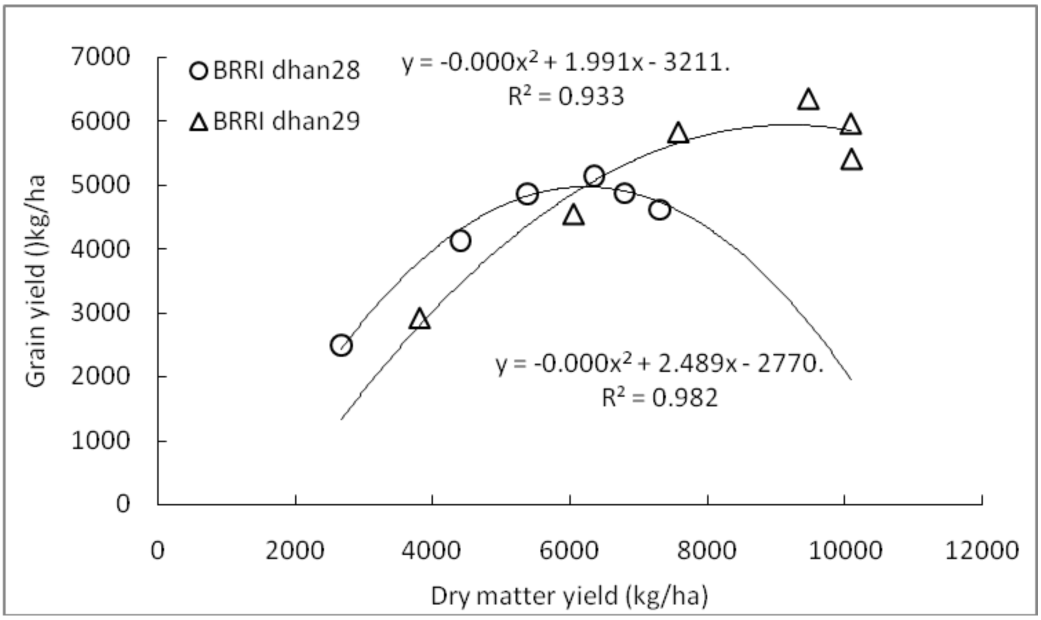

Figure 3. Relationship between dry matter yield at harvest and grain yield of two rice

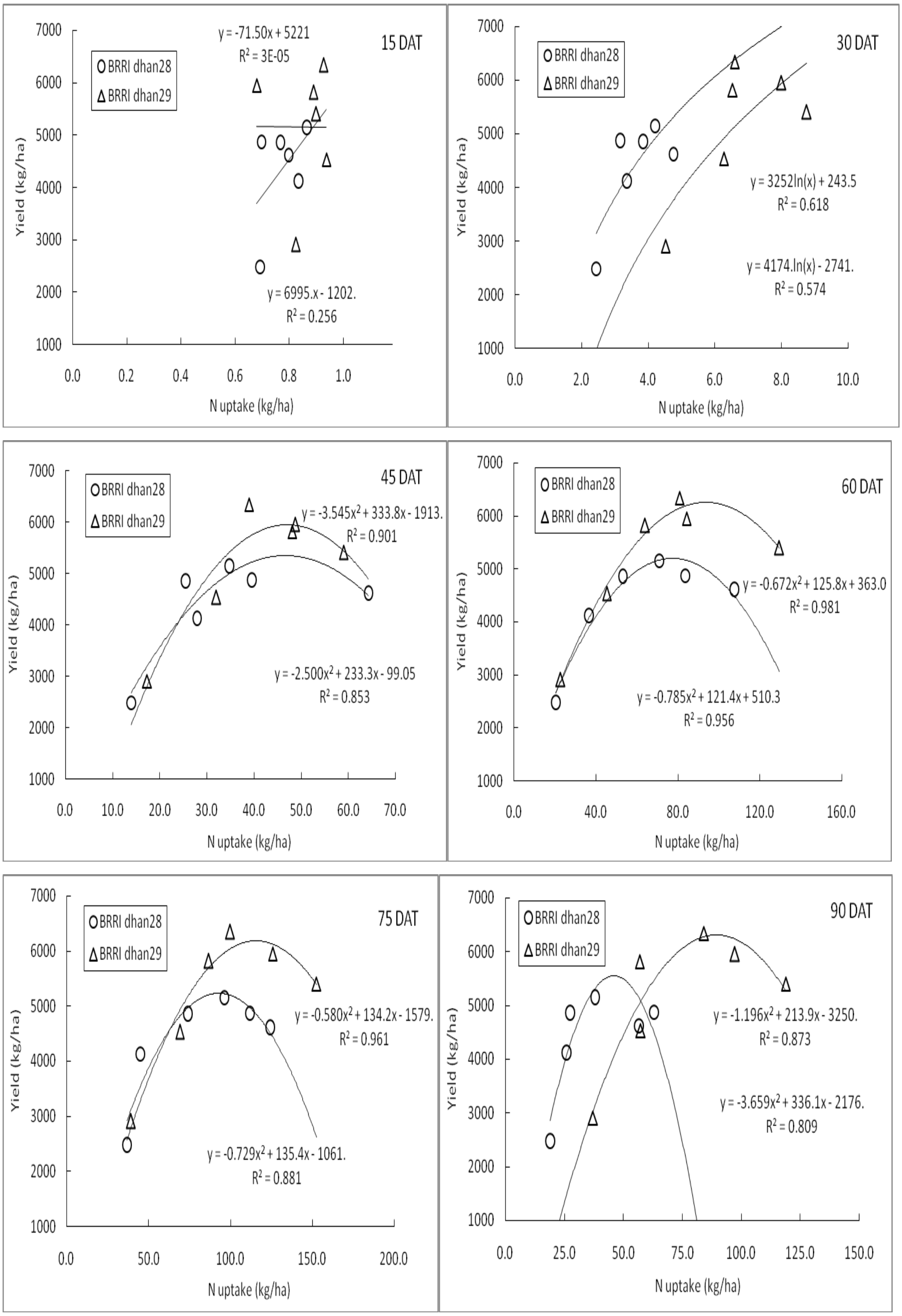

Figure 4. Relationship between N uptake and grain yield in BRRI dhan28 and BRRI dhan29

ACKNOWLEDGMENTS

The first author acknowledges the financial support of Government of Bangladesh through Strengthening of Breeder Seed Project, Bangladesh Rice Research Institute, Bangladesh, for the study.

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