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Optimum Nitrogen Dose and its Use Efficiency of a Bacterial Blight Disease Resistant Rice ALART Material in Chhiata Clay Loam Soil

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ABSTRACT

Given the widespread deficiency of nitrogen in Bangladesh, its optimum dose of advanced breeding lines needs to be determined before releasing them as a variety. A field experiment was conducted with advanced line BR8938-19-4-3-1-1-P2-HR3 (BBRAL) using BRRI dhan28 as a susceptible check. Both the genotypes received six nitrogen doses – 0 to 200 kg N ha^{-1} with an interval of 40 kg ha^{-1} from urea in a split-plot design. Both the tested genotypes received flat standard doses of P, K, S, and Zn. A quadratic regression model was used to determine the optimum N requirement. Quadratic equations $\hat{y} = 3.46 + 0.04N - 0.00013N^2$, ($R^2 = 0.95$, $p = 0.006$) for the bacterial blight resistant line BR 8938-19-4-3-1-1-P2-HR3, and $\hat{y} = 3.73 + 0.04N - 0.00012N^2$, ($R^2 = 0.99$, $p = 0.006$) for the check variety BRRI dhan28 explained the relationship for N rates and estimated grain yield. The calculated economic optimum N dose using the quadratic regression model for BBDRL (Bacterial Blight Disease Resistant Rice) and the susceptible check BRRI dhan28 was 153 and 162 $kgNha^{-1}$, respectively. The application of 153 and 162 kg N ha^{-1} predicted the estimated yield of 6.81 and 7.21 for the advanced line and BRRI dhan28, respectively. Nutrient use efficiencies, such as agronomic use efficiency, apparent recovery of applied N, internal use efficiency and nitrogen harvest index of the tested advanced line, were similar to those of BRRI dhan28.

Keywords: Bacterial Blight line, grain yield, N response curve, N requirement, N efficiencies.

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important staple food crop for more than 3 billion people in the world and 135 million people in Bangladesh. The demand for rice is predicted to rise from 439 million tons (mt) in 2010 to 496 mt by 2020, 553 mt by 2035, and 623 mt by 2050 (Timsina *et al.*, 2021). The yield of rice largely depends upon the nutritional status of the soil and the availability of nutrients from chemical fertilizers. Increase in rice production depends on improved varieties coupled with judicious fertilizer use, and appropriate irrigation management (Gairhe *et al.*, 2018) and other cultural practices. Among the major nutrient elements, nitrogen (N) is the most limiting nutrient for rice crop growth and yield, and it is required in compared to other nutrients (Djaman *et al.*, 2018). N is universally deficient in almost all the agricultural soils and cropping systems of the world, so it is essential to use external nitrogen inputs (N fertilizers) to produce the crops for satisfying the ever-increasing demands of human populations (Mohan *et al.*, 2015). Globally, farmers using around 108 million metric tons of nitrogenous fertilizer each year (FAO, 2024). Nitrogen is the most yield-limiting and widely applied nutrient in Bangladeshi rice fields in all rice growing seasons, as rice genotypes exhibit a stronger response to applied N than other major nutrients. Nitrogen

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management is essential in growing rice, and N fertilization can largely improve rice productivity and profitability. Rice crop generally requires 20 kg N for each ton of grain yield under optimum conditions (Attanandana *et al.*, 2010). The N requirement of rice varies with the rice genotypes (Saleque *et al.*, 2005; Jing *et al.*, 2008; Hirzel *et al.*, 2011). Biomass production of irrigated rice is mainly driven by the supply of N. Even the demand of the rice plant for other macro-nutrients are also depends on N supply. While increased N application may increase grain yield in rice, it often increases plant N uptake and consequently grain N concentration (Wood *et al.*, 2021). While increased grain protein concentration (GPC) may be advantageous nutritionally and also for some grain quality such as head rice yield, it often affects overall palatability (Meng *et al.*, 2024). Conventionally, to fulfil this large requirement of N, farmers completely depend on chemical nitrogen.

Excess use of N in crop input can cause imbalance of ecosystem functions and services (Hutchinson *et al.*, 2003; Meena *et al.*, 2014), exacerbates soil degradation and environmental pollution (Ladha *et al.*, 2016; Islam *et al.*, 2022; Yu *et al.*, 2018) and even soil acidification (Guo *et al.*, 2010, Schroder *et al.*, 2011).

Recently, BRRI dhan28 lost its popularity because of bacterial leaf blight. The invention of BBRAL is a breakthrough in Bangladesh to substitute BRRI dhan28. It is empirical to understand the N fertilizer requirement along with the N use efficiency of the advanced disease-resistant line compared to popular variety BRRI dhan28.

MATERIALS AND METHODS

Experimental location

In Boro 2020-21, the experiment was conducted at the Bangladesh Rice Research Institute (BRRI) farm, Gazipur. The climate of the experimental location is subtropical in nature and experiences periodic southwestern monsoon with an average annual rainfall of 2000 mm. The 80% of the rainfall occurs from mid-June to the end of September. The lowest mean temperature (15°C) prevails in January and the highest (30°C) in May. The soil of the experimental site belongs to Chhiata clay loam, a member of fine, hyperthermic Vertic Endoaquepts. The soil of the experimental field had a clay loam texture and a pH of 6.70. The other nutrient status was as follows: organic carbon 1.18%, total N 0.13%, exchangeable K 0.12 meq/100g soil, available S 14.0 mg kg^{-1} and available Zn (DTPA extraction) 1.5 mg kg^{-1}.

Experimental design and treatments

The experiment was conducted in a split-plot design with three replications, where N fertilizer doses were assigned in main-plot and rice genotypes in sub-plot. The individual main-plot size was 7 m x 3 m. Six N levels with the application rates of 0, 40, 80, 120, 160 and 200 kgha-1 were evaluated with PVT-DRR (BB) line BR8938-19-4-3-1-1-P2-HR3 and BRRI dhan28 as susceptible check. All plots had received a blanket dose of chemical fertilizer P-K-S-Zn @ 20-60-10-2 $kgha^{-1}$, respectively. All fertilizers except urea were applied as basal at final land preparation. Urea was applied into three equal splits in with first top-dressing on 15 days after transplanting (DAT), second one on 30 DAT and the rest one on 5 days before panicle initiation (PI) stage. Thirty-five-day-old seedlings of each rice genotypes were transplanted on 30 December 2020. Irrigation, weeding and other cultural management practices were done equally as per needed. At maturity, 1st the check variety BRRI dhan28 was harvested on 17 April 2021 and the PVT-DRR (BB) line BR8938-19-4-3-1-1-P2-HR3 was harvested on 24 April.

Data collection analysis

Plant height was recorded at maturity from 3 hills per plot from the soil surface to the tip of the tallest panicle of each hill. Number of tillers and panicles per m2 were counted from 16 hills in each plot. Number of filled and unfilled grains per panicle were counted from five panicles in each plot. Panicle length (cm) was measured from the panicle neck to the apex of the panicle from five panicles. Grain yield was calculated from the area of 5 m^2 at 15 cm above ground level, however, 16 hills from each plot were harvested at the ground level for straw yield. The grain yield was recorded at 14% moisture content and straw yield as oven dry basis. Plant samples were analyzed for N content and N uptake. The grain and straw samples were analyzed for their N content by the micro-Kjeldahl method (Nelson & Sommers, 1973) and the crop N uptake was calculated from dry biomass (grain + straw) weight and N concentrations (Sarkar *et al.*, 2016).

Optimum and economic dose of N

Differentiation of the quadratic equation between derived from the relationship between N and grain yield derived the optimum and economic optimum dose of N (Gomez and Gomez, 1984) as follows:

Y = a + bN + cN2……………......................(1)

Differentiating the above equation with respect to N,

$$\frac{dY}{dN} = b + 2cN$$

The optimum dose of N to maximize the yield would be at the level of N when

$$\frac{dY}{dx} = 0$$

or,

$$b + 2cN = 0$$

$$Ny = -\frac{b}{2c} \quad \text{……….........…………………(2)}$$

Economic optimum dose,

$$N_P = \frac{1}{2c}\left(\frac{P_f}{P_y} - b\right) \quad \text{………………..……….(3)}$$

where, P_f is price of fertilizer N (USD per kg) and Py is price of grain (USD/t).

Agronomic N use efficiency (ANUE)

$$ANUE = \frac{(Y_N - Y_0)}{N_F} \quad \text{………………………….(4)}$$

where,

ANUE = agronomic N use efficiency (kg grain/kg N)

Y_N = yield of N-applied plots

Y_0 = yield of N control plots

N_F = applied N (kg/ha) from N fertilizer

Apparent recovery efficiency (ARE)

$$ARE\ (\%) = \frac{(U_N - U_0)\times 100}{N_F} \quad \text{……........……….(5)}$$

where,

ARE = apparent recovery efficiency (%)

U_N = total nitrogen uptake (kg) from N-applied plots

U_0 = total nitrogen uptake (kg) from N control plots

N_F = applied N (kg/ha) from N fertilizer

Internal N use efficiency (INE)

INE(t/kg)=YN-Y0-UN-UO .... (6)

Partial factor productivity: Partial factor productivity refers to the yield of rice per kg of applied nutrient.

Nitrogen harvest index (NHI)

$$NHI = \frac{NU_G}{(NU_G + NU_S)} \quad \text{…..……………………(7)}$$

where,

NHI = Nitrogen harvest index

NU_G = Nitrogen uptake by grain

NU_S = Nitrogen uptake by straw

Statistical analysis

The analyses were carried out using the STAR (Statistical Tool for Agricultural Research) software version 2.0.1 and MS Excel.

RESULTS AND DISCUSSION

Grain yield

Nitrogen fertilization significantly increased grain yield of both the BBRAL (Bacterial Blight Disease Resistant Rice) and BRRI dhan28 in Boro season (Fig. 1). With native soil N fertility, BBRAL and BRRI dhan28 yielded 3.26 and 3.64 t ha^{-1}, which increased with the application of N and continued increase progressively with the increased doses of N fertilizer. However, the rate of yield increase was slower with the higher doses of N. The grain yield of rice reached to a plateau at the N level of 160 kg ha^{-1} and showed a declination with the highest N dose of 200 kg ha^{-1}.

Similar trend was observed for straw yield (Data not shown). The improved growth attributes, viz. plant height and dry-matter production, might be responsible for improved yield attributes. The straw yield of both varieties in Boro season significantly responded to the applied N rates. The straw yield of both varieties increased with the increase of N rates and was highest 7.16 tha^{-1} for V1 and 7.36 tha^{-1} for V2 with 200 kg Nha^{-1} which was statistically identical to 160 kg Nha^{-1}.

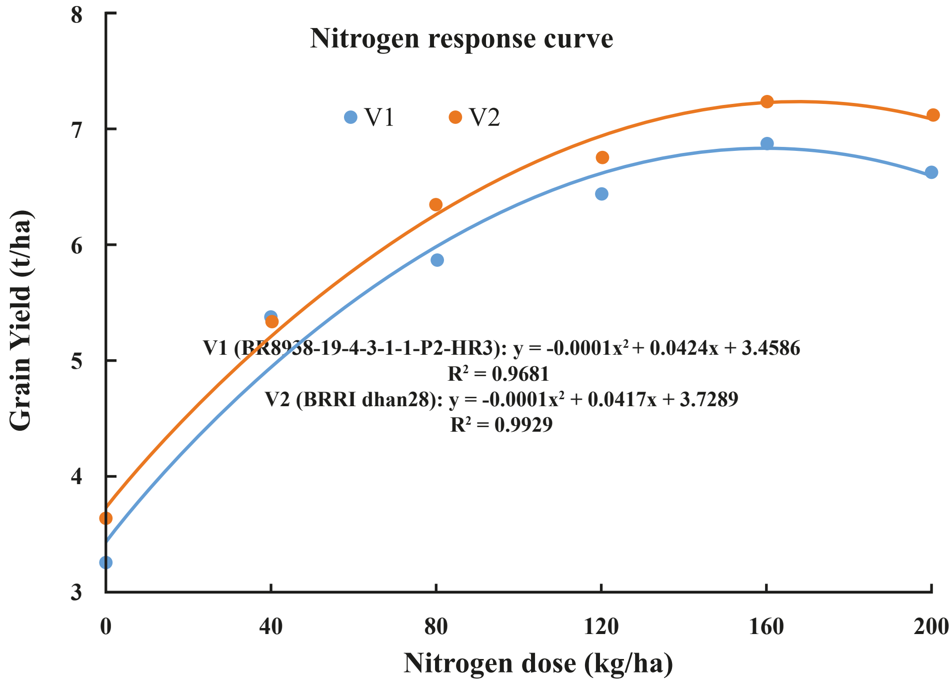

Fig. 1. Nitrogen response curve of PVT-DRR (BB) and BRRI dhan28 rice genotypes in Boro 2020-21, BRRI, Gazipur.

Grain yield showed a significant quadratic response to the N fertilizer application (Fig. 1). The quadratic response curve for the BBRAL and BRRI dhan28 as shown (Fig. 1) had significant coefficient of determination (R^2), intercepts, and coefficients both linear and quadratic terms for both genotypes (Table 1). The intercept for the BBRAL was 3.46±0.28 compared to 3.73±0.14 for BRRI dhan28. The p value of the intercepts was 0.0011 for BBRAL and 0.0001 for BRRI dhan28, respectively. BRRI dhan28 showed significantly greater intercept than that of BBRAL. The *'b'* coefficient for both genotypes was 0.04 with significant p value, indicates that the coefficient was not significantly different between two genotypes. The *'c'* coefficients for both the genotypes were statistically similar and very low, -0.00013 for BBRAL and for BRRI dhan28 it was -0.00012. The regression equation signifies that there was varietal difference in grain yield but both genotypes responded similarly with receiving N fertilizer application. There was insignificant genotype×N interaction on grain yield of rice.

Solving the equation (2) the calculated maximum dose of N for BBRAL was 158 kg Nha^{-1} and that for BRRI dhan28 was 167 kg ha^{-1}.

According to the equation (3), the economic optimum dose of N was 153 kg ha^{-1} and 162 kg ha^{-1}, respectively. Tayefe *et al.* (2014) and Moro *et al.* (2015) reported similar result the grain yield to N fertilization. Pamela *et al.* (2009) illustrated that grain yield showed a significant quadratic response to N fertilization. Khatun *et al.* (2014) reported economic optimum dose of N for BRRI dhan28 and BRRI dhan29 as 156 and 158 kg ha^{-1}, respectively. Soil, varietal, location, and yearly differences in N requirement for rice may vary substantially (Islam *et al.*, 2015; Bhuiyan *et al.*, 2017). Bhuiyan *et al.* (2017) reported economic optimum dose of N for BRRI dhan29 as 166 and 155 kg ha^{-1}, in two consecutive years. Islam *et al.*, (2015) obtained economic optimum dose N for BRRI dhan29 as 145 kg ha^{-1} in the first year and 200 kg ha^{-1} in the second year in the same field. The large variation in N dose may be attributed to the variation in climatic elements, mainly high night temperature during the growing season.

In comparison of two rice genotypes, BRRI dhan28 responds better than the PVT-DRR (BB) line BR8938-19-4-3-1-1-P2-HR3 in the same N doses.

Table 1. Parameters of the regression equation between applied N and grain yield of two rice genotypes.

	BBRAL	*t-stat*	*p-value*	BRRI dhan28	*t-stat*	*p-value*
Intercept	3.46±0.28	12.45	0.0011	3.73±0.14	27.52	0.0001
N	0.04±0.01	6.49	0.0074	0.04±0.00	13.10	0.0010
N^2	-0.00013	-4.27	0.0235	-0.00012	-8.16	0.004
R^2	0.97		0.006	0.99		0.006

Nitrogen content and uptake

The application of fertilizer significantly influenced nitrogen content and uptake in grain and straw in both varieties (Table 2). Varietal difference in nitrogen concentration appeared significant. The tested advanced line had consistently greater grain N concentration at all the levels of applied N except at the highest rate. At N-control plot, BBRAL had grain and straw N concentration of 0.78 and 0.42% compared 0.69 and 0.43% in BRRI dhan28. The nitrogen concentration in grain and straw increased gradually with increasing the N doses in both the genotypes. The highest N concentration (1.04% and 1.05%) was noted with the highest level of N application (200 kg ha^{-1}) similar trend was observed for straw N content. Contrary to the grain N, straw N concentration was slightly higher in BRRI dhan28 than BBRAL at all levels of N applications. It was found that total N uptake by rice plant increased with increased N rates up to a certain level (160 kg Nha^{-1}), then it decreased. The trend of N uptake by straw and grain followed the similar trend of N concentration. Varietal difference in uptake was different from that in concentration trend. At 0 to 120 kg ha^{-1} level of N application, BBRAL had slightly higher grain N uptake than that of BRRI dhan28. On the contrary, 160 and 200 kg ha^{-1} doses of N application BRRI dhan28 had higher grain N uptake than that of BBRAL. Varietal difference in straw N uptake was slightly different from that of straw N uptake. At 40 kg ha^{-1} N application, straw N uptake in both the genotypes was the same 24.84 kg ha^{-1}, but in all other N doses BRRI dhan28 had greater straw N uptake than that of BBRAL. BRRI dhan28 had greater total N uptake than that of BBRAL except at in 40 and 80 kg ha^{-1} levels of N application. Yesuf and Balcha, (2014) also reported that N uptake increases sharply with an increase in the application of N doses up to a certain level, and further increases in the N dose the N uptake remaining static.

Table 2. Nitrogen response in the N content and N uptake of PVT-DRR (BB) and BRRI dhan28 rice genotypes in Boro 2020-21, BRRI, Gazipur.

N (kgha^{-1})	N content (%)		N uptake (kgha^{-1})		Total N uptake (kgha^{-1})
	Grain	Straw	Grain	Straw	
	BBRAL (BR8938-19-4-3-1-1-P2-HR3)				
0	0.78	0.42	25.43	14.87	40
40	0.81	0.45	43.50	24.84	68
80	0.91	0.47	53.33	28.25	81
120	0.97	0.50	62.37	33.25	95
160	1.01	0.52	69.39	36.24	106
200	1.04	0.54	68.85	38.66	108
	BRRI dhan28				
0	0.69	0.43	25.12	16.00	41
40	0.75	0.46	40.05	24.84	65
80	0.78	0.48	49.45	30.82	80
120	0.85	0.51	57.46	34.83	93
160	0.99	0.53	71.58	38.48	110
200	1.05	0.55	74.76	40.48	115
LSD (0.05)	0.08		0.04		
T X V	4.16		4.33		
CV (%)	3.21		3.67		

Nitrogen use efficiency

Agronomic N use efficiency (ANUE) decreased with the increasing doses of N application steeply (Table 3). Varietal difference was distinct at the 40 kg N ha^{-1} level, but at 160 kg N level, varietal difference diminishes for ANUE. The BBRAL had 22.6 kg/kg compared 22.4 kg/kg. It means that the BBRAL would produce 22.6 kg grain per kg of the applied N and that would be 22.4 for BRRI dhan28. BBRAL showed similar apparent recovery (41%) of applied N compared to BRRI dhan28 which had 43% apparent recovery of N. In the N-control plot, BBRAL showed slightly lower internal use efficiency of N (82 kg of grain per kg of N uptake) compared to 89 in case of BRRI dhan28. At 160 kg N ha^{-1} level, internal use efficiency of N of the tested genotypes were similar, 55 kg kg^{-1} for BBRAL and 52 kg kg^{-1} for BRRI dhan28. The fact indicates that the BBRAL was less efficient to utilize native N from soil, slightly more efficient to utilize applied N.

The reciprocal of internal use efficiency of N indicate the amount of N required to plants absorb to produce one ton of rice grain. The lower the N absorb, the higher the utilization efficiency, means less amount of N require per ton of rice grain. N uptake in N-control plots was the lowest (Table 2), Table 3 shows that the least amount of N was required to produce 1 ton of grain. BBRAL and BRRI dhan28 required only 12 and 11 kg N, respectively, to produce 1 ton grain, while at 160 kg N ha^{-1} level, 1 ton of rice grain production required 18 and 19 kg N for BBRAL and BRRI dhan28, respectively.

Partial factor productivity (PFP) is another important parameter of N use efficiency, which tells how much of rice grain is produced per kg of N application through fertilizer. Both the check variety BRRI dhan28 and the new genotype had similar PFP. At 160 kg N ha^{-1} level, BBRAL had PFP of 43 compared to 45 with BRRI dhan28. At 80 – 200 kg N ha^{-1} level, the PFP of BBRAL was about 2 kg consistently lower than that of BRRI dhan28.

Nitrogen harvest index (NHI) translates the proportion of absorbed N translocated to grain. According to this index, BBRAL showed slightly superiority to BRRI dhan28. From 0 – 160 kg N ha^{-1} level, NHI in BBRAL was about 0.02 greater than that of BRRI dhan28.

Table 3. Nitrogen use efficiencies of BR8938-19-4-3-1-1-P2-HR3 and BRRI dhan28.

N kg ha^{-1}	Agron. N use (kg/kg)		Apparent Recovery (%)		Internal use efficiency (kg/kg)		kg N req. for ton grain		Partial factor productivity		Nitrogen harvest index	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
0	-	-	-	-	82	89	12	11	-	-	-	-
40	52.8	42.5	70	60	75	71	13	14	134	134	0.64	0.61
80	32.5	33.8	51	49	63	69	16	14	73	79	0.64	0.62
120	26.4	26.0	46	43	58	60	17	17	54	56	0.66	0.62
160	22.6	22.4	41	43	55	52	18	19	43	45	0.66	0.62
200	16.8	17.4	34	37	49	47	20	21	33	36	0.65	0.65

V1 = BR8938-19-4-3-1-1-P2-HR3, V2 = BRRI dhan28

CONCLUSIONS

Application of N doses greatly increase the yield and yield contributing characters of tested two rice genotypes. Comparatively higher grain yield obtained in the check variety BRRI dhan28 than the advanced line BR8938-19-4-3-1-1-P2-HR3 in the same dose of applied nitrogen. The calculated maximum doses of N for advanced line BR8938-19-4-3-1-1-P2-HR3 and the check variety BRRI dhan28 in Boro season were 158 and 167 kgha^{-1}, respectively, while the economic optimum doses were 153 and 162 kgNha^{-1}, respectively. The bacterial blight disease resistant line BR8938-19-4-3-1-1-P2-HR3 can give a good yield with medium doses of N which may be a good rice variety in bacterial blight disease proon area of Bangladesh.

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