Relationship Between Nitrogen Fertilization, Bacterial Leaf Blight Severity, and Yield of Rice

A. P. K. Reddy, J. C. Katyal, D. I. Rouse, and D. R. MacKenzie

Plant pathologist and soil scientist, All India Co-ordinated Rice Improvement Project (AICRIP), Hyderabad 30, A.P., India; and graduate assistant and associate professor, Department of Plant Pathology, The Pennsylvania State University, University Park 16802, respectively.

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ABSTRACT

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In a field study two rice cultivars were compared at various levels of nitrogen (N) fertility in three seasons for both yield and bacterial leaf blight (BLB) severity of rice. High N levels (> 100 kg/ha) increased disease and reduced yield in BLB-susceptible IET 2895. BLB-resistant IET 4141 was least affected by all N levels tested. The relationships between yield and N level and between BLB severity and N level were best described by quadratic and linear functions, respectively. The optimal level of N application (to derive maximum yield with minimum disease effects) was 76 kg/ha for the susceptible cultivar IET 2895. The strategy of eliminating topdressing of rice with N when BLB is severe is discussed in relation to the optimal N level.

Additional key words: Xanthomonas oryzae, Oryza sativa.

Bacterial leaf blight (BLB) of rice (*Oryza sativa* L.), caused by *Xanthomonas oryzae* (Uyeda and Ishiyama) Dowson, has recently become a major rice disease in tropical Asia because of widespread cultivation of nitrogen-responsive dwarf rice cultivars (11). Among the factors favoring BLB development, application of high levels of nitrogen (N) is important in increased disease incidence and severity (1,3,4,8,9,11,13,14). High N levels either favor pathogen multiplication and lesion enlargement (7) or, through increased vegetative growth of the plant, influence the microclimate in favor of the pathogen (11). In the absence of effective and economical chemical control measures (6,12), cultural practices such as wider spacing (2), closer spacing, and split N application (4,9,14) have been suggested as control methods. All of these recommendations have been based on the assumption that high N levels increase disease and reduce yield. We are not aware of attempts to quantify the relationship between yield reduction and increased BLB severity associated with high N level application to rice.

The objectives of this study were to: (i) determine the effect of N level on BLB development, using susceptible and resistant cultivars; (ii) analyze N response curves associated with BLB; and (iii) determine optimal N levels for a susceptible cultivar that would minimize disease impact and thereby maximize its genetic yield potential.

MATERIALS AND METHODS

To determine the effects of nitrogen fertilization on BLB severity and grain yield of rice, three experiments were conducted at the All India Co-ordinated Rice Improvement Project, Hyderabad. Rice selections IET 2895 (RP9-4 from the cross IR8 × V1263) and IET 4141 (RP633-590 from the cross IR8 × BJ1 × IR22) with similar agronomic characters but different susceptibility were used. Seedlings were grown in wet seed beds and transplanted 30 days after sowing (DAS) into main field plots. Before transplanting, a uniform basal application of K_2O (50 kg/ha) and P_2O_5 (75 kg/ha) was applied to the plots. Individual plot size was 5 × 4 m. Plants were spaced 20 cm between rows and 15 cm within rows. In the 1975 wet season (June–November) and the 1976 dry season (January–May), N levels of 0, 60, 120, and 180 kg/ha were tested. Nitrogen and cultivar treatments were arranged in a split-plot design with N levels as main plots and cultivars as subplots. Main plots were separated by earthen bunds, 10 cm high, and unplanted alleys, 1 m wide. Three equal applications of N were applied in the form of urea (46% N) 40 DAS (early tillering), 55 DAS (tillering), and 70 DAS (panicle initiation). Water was withheld from the plots 1 day before topdressing. Urea was hand broadcast into a 2–3 cm deep water layer and 2 days later plots were flooded again. Standard plant protection measures, similar to commercial practices, were taken to eliminate insect pests that might affect yield.

In the 1976 wet season the experimental design was 2 × 5 × 2 factorial with three replicates. The factors were: inoculated and uninoculated plots of five N levels (0, 50, 100, 150, and 200 kg/ha) and two rice cultivars, IET 2895 a susceptible variety (Susc-95) and IET 4141, a resistant variety (Res-41). Individual plots were 5 × 3 m, planted with spaces of 20 cm between rows and 10 cm within rows. The 50 and 100 N level treatments were applied at equal doses of urea 35 and 55 DAS. Nitrogen was applied in three equal doses 40, 55, and 70 DAS in the 150 and 200 N treatments. The mode of N application was similar to that used in earlier experiments. Uninoculated treatment plots received four bactericidal sprays (400 L/ha) of Celdion-S, manufactured by Takada Chemical Company, Tokyo, Japan (T.F. 130, 10% WP; 1 g/L) at 70, 80, 90, and 105 DAS.

In all experiments, the virulent bacterial isolate H413 (isolated in 1974 from diseased leaves collected from the BLB-endemic area in West Godavary district, Andhra Pradesh, and maintained in lyophilized condition) was used. Three-day-old cultures grown on peptone sucrose agar were suspended in water. The inoculum suspensions containing about 5 × 10^8 cells per milliliter were sprayed on foliage on three consecutive evenings at panicle initiation with a high-volume sprayer. The 1976 dry season plots were inoculated six times at 5-day intervals from panicle initiation. Overhead sprinklers were used during the 1976 dry season. The 1975 wet season and 1976 dry season terminal disease severities were recorded at the soft dough stage (115–120 DAS). All disease severity readings were taken as a visual estimate of the percentage

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of total leaf affected by BLB. In the 1976 wet season, disease severities were estimated at 10-day intervals from 10 days after inoculation to soft dough. Disease severity on the lamina and leaf sheath of the top three functioning leaves was scored in percent by averaging individual leaf observations on all tillers of eight plants for each plot. Yield (kg/ha) was estimated by harvesting the central rows of individual plots. The two outermost rows bordering the unplanted alleys were discarded. Grain was air-dried to 14% moisture. Statistical analyses included regression and analysis of variance (10) and were performed on The Pennsylvania State University IBM System 370 computer using standard library programs.

RESULTS

The 1975 wet season was most favorable for disease development, followed by the 1976 wet season and the 1976 dry season. A high degree of disease severity was not achieved in the 1976 dry season even though a water sprinkler system was used and plots were inoculated repeatedly. In the 1976 wet season experiment, no disease was observed in uninoculated plots. We therefore concluded that little cross infection occurred between inoculated and uninoculated plots.

Disease severity estimates and grain yield data for the 1975 and 1976 dry season experiments are presented in Table 1. For Susc-95, disease severity increased with each increment of N. The higher N levels were significantly different from the lower levels ($P > 0.05$), but levels of N on Res-41 did not significantly influence disease in either season.

Disease severity and yield data at the various N levels for inoculated and uninoculated plots for both cultivars in the 1976 wet season experiment are presented in Table 2. As in the two earlier experiments, high N levels significantly increased disease severity on Susc-95 in the inoculated plots. The yield response curve (YRC) had a positive slope at low N levels and a negative slope at high N levels (Fig. 1). In uninoculated plots of Susc-95, the YRC was positive at all N levels (Fig. 2). In the resistant cultivar, Res-41, disease did not increase significantly with N increments. Yield of Res-41 was similar in both inoculated and uninoculated plots.

Disease severity vs N level was best described by linear regression for each season. A quadratic relationship provided the best description of yield response vs N level for each season. The regression parameters and standard deviations of the regression coefficients of determination for the yield-response curves are presented in Table 3. A graphic presentation of disease increase and yield response to N level are given in Figs. 1 and 2 for 1975 wet season and 1976 dry season data, respectively. The YRC for Res-41, because of a low coefficient of determination, was not comparable with Susc-95 in the 1975 wet season. YRC of Res-41 and Susc-95 were significantly different in the 1976 dry season. The 1976 wet season YRC for inoculated and uninoculated plots of Res-41 did not differ significantly. The YRC for Susc-95 in the 1976 wet season differed between inoculated and uninoculated plots. Specifically, the coefficients of the linear term (but not the coefficients of the quadratic term) differed significantly, indicating that the normal yield associated with increasing N levels was similar in both treatments.

Calculation of an optimal N level in the presence of disease for Susc-95 was possible from the 1976 wet season data. The relative yields of the inoculated and uninoculated plots were compared for each N level as the ratio of yield in inoculated plots to yield in uninoculated plots, times 100.

The linear regression of percent yield vs disease of Susc-95 in inoculated plots, independent of N level was:

$$Y = 92.69 - 0.445\, X \qquad (1)$$

The statistical association of disease and N was:

$$X = 8.19 + 0.31\, N \qquad (2)$$

TABLE 1. Effect of nitrogen fertilization levels on *Xanthomonas oryzae*-susceptible rice cultivar IET 2895 and the resistant cultivar IET 4141

Nitrogen levels (kg/ha)	1975 Wet season[v] Yield (kg/ha)[x] IET 2895	IET 4141	Disease severity (%)[y] IET 2895	IET 4141	1976 Dry season[w] Yield (kg/ha) IET 2895	IET 4141	Disease severity (%) IET 2895	IET 4141
0	3,025 a[z]	3,692 a	33.3 a	6.6 a	4,364 a	4,585 a	10.8 a	0 a
60	4,414 b	4,552 b	38.3 a	10.0 a	5,229 b	6,052 b	22.3 b	1.5 a
120	3,637 ac	5,277 c	58.3 b	13.3 a	6,376 c	7,121 c	28.6 b	3.1 a
180	3,665 c	5,080 bc	75.0 b	16.6 a	5,929 cd	7,351 cd	43.0 c	4.5 a
Mean	3,685	4,681	51.2	11.6	5,477	6,275	26.0	2.3

[v]Wet season: June–November. Crop was transplanted on 28 July 1975 and harvested on 5 November 1975.
[w]Dry season: January–May. Crop was transplanted on 27 January 1976 and harvested on 10 May 1976.
[x]Average values of three replicates, corrected to 14% moisture.
[y]Average values of three replicates. Disease severity estimates of plots were based on the top three leaves (flag leaf and lower two leaves) of eight plants observed at the soft dough stage of plant growth on 20–23 October 1975 in wet season and 24–25 April 1976 in dry season.
[z]Values followed by the same letters in a column are not significantly different using the Tukey pairwise comparison test.

TABLE 2. Effect of nitrogen (N) fertilization levels on disease severity, grain yield, and N content for BLB-susceptible rice cultivar IET 2895 and resistant cultivar IET 4141 in 1976 wet season

Nitrogen levels (kg/ha)	Yield (kg/ha)[w] IET 2895 Uninoculated	Inoculated[y]	IET 4141 Uninoculated	Inoculated[y]	Disease severity (%)[x] IET 2895 Uninoculated	Inoculated[y]	IET 4141 Uninoculated	Inoculated[y]
0	3,683 a	3,348 a	3,383 a	3,229 a	0	5.9	0	0
50	4,966 b	4,068 b	4,516 b	4,065 b	0	21.6	0	0.1
100	6,133 c	4,574 c	5,983 c	5,426 c	0	46.0	0	0.7
150	7,116 d	4,708 c	6,550 d	6,039 d	0	57.9	0	2.4
200	7,200 d	4,618 c	6,733 d	6,144 d	2.6	65.0	0	4.2
Mean	5,819	4,263	5,434	4,981	0.5	39.2	0	1.5

[w]Average values of three replicates at 14% moisture.
[x]Average values of three replicates. Disease severity estimates of each plot were based on observations recorded on flag leaf and two lower leaves at soft dough stage.
[y]Inoculated on 27 and 30 August 1975.
[z]Values followed by the same letter in a column are not significantly different at 5% level using the Tukey pairwise comparison test.

Substituting equation 2 into equation 1 gives:

$$Y = 92.69 - 0.445\ (8.19 + 0.31\ N)$$

or

$$Y = 89.04 - 0.137\ N \qquad (3)$$

The relationship of the YRC to N in the presence of disease can be equated to the YRC to N in the healthy plots as follows:

$$45.19 + 0.454\ N - 0.001\ N^2 = 89.04 - 0.137\ N \qquad (4)$$

Solving for N gives the optimal level in the presence of disease as N = 76 kg/ha. This calculation is presented graphically in Fig. 3.

DISCUSSION

Increased N levels were associated with increased BLB and hence reduced yield. High disease severities negated N response. Beyond a critical N level, the law of diminishing returns operated in the susceptible cultivar. The genetic potential of BLB-vulnerable, high-yielding varieties may be realized through high N application only in disease-free seasons or when protected with bactericide.

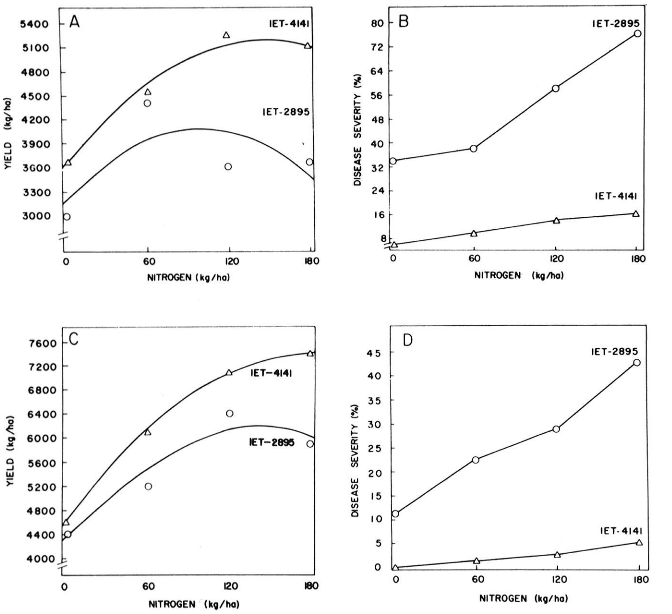

Fig. 1. Yield and bacterial leaf blight response curves to increasing N levels in two rice cultivars: **A** and **C** are yield response curves, **B** and **D** are disease severities in 1975 wet season and 1976 dry season, respectively.

Effective systemic bactericides are not currently available to Asian farmers (11,12). Planting resistant cultivars is therefore one alternative to mitigate BLB effects on yield (9). Several national programs and the International Rice Research Institute have developed BLB-resistant cultivars and a few are available for commercial cultivation. However, little is known about the durability of that resistance. The experience with resistant cultivars in Japan has shown only limited success (14).

Another alternative to check BLB epidemics in India would be through proper N management (4). A rational management program would include the application of N required to realize maximum yield with susceptible cultivars in disease-prone areas. We have shown that 76 kg/ha N is the optimum to derive a good yield from a susceptible cultivar (Fig. 3). This concept could be extended to other BLB-prone rice cultivars. N opitma could be determined to suit various rice-BLB agroecosystems.

Considerable information is available on varietal yield response to nitrogen (5). It has been reported that the optimal N level for tropical wet-season rice is 75 kg/ha. The figure we obtained is equivalent to that reported (5). According to an IRRI report (5), quadratic response functions accounted for more than 80% of the yield variability. The YRC with coefficients of determination (R^2 values) from quadratic fits of less than 80% came mostly from trials that had traditional varieties or were grown in the wet season. We observed that high coefficients of determination for quadratic functions of yield response curves explained 78–96% of the observed variability in healthy plants (resistant IET 4141 or uninoculated and Celdion-S protected plots of IET 2895), whereas in diseased plants in all seasons only 10–74% of the observed yield variability was explained by the quadratic function for the yield-response curves. In summary, low r^2 values were associated with disease (Table 3).

When interpreting YRC for rice to N levels, low N responses cannot necessarily be ascribed totally to lodging. There is a need to view other yield constraints associated with the wet season, such as insects, diseases, weeds, etc. Thus, partitioning wet season factors that affect N response curves will help to develop appropriate N management systems for rice culture in tropical areas. Even small amounts of disease (ie, $\leq$ 0.01 to 0.02%) at panicle initiation would cause severe damage in a susceptible cultivar (with "r" values sensu van der Plank (15) $\geq$ 0.15 with 35 days or more to harvest) grown at 150–200 N by harvest (Reddy et al, *unpublished*). By skipping an N topdressing at panicle initiation, the disease severity could possibly be reduced significantly. Farmers could decide whether a crop should be topdressed or not after observing the disease incidence and weather situation at panicle initiation (65–80 DAS), when normal and final topdressing is given to flooded rice in India. If more than three to five infected leaves per square meter ($<$0.01 to 0.02% severity) were observed at panicle initiation or earlier and rainy weather prevails, the final topdressing should be omitted to minimize BLB, optimize N response, and thereby obtain better rice yields.

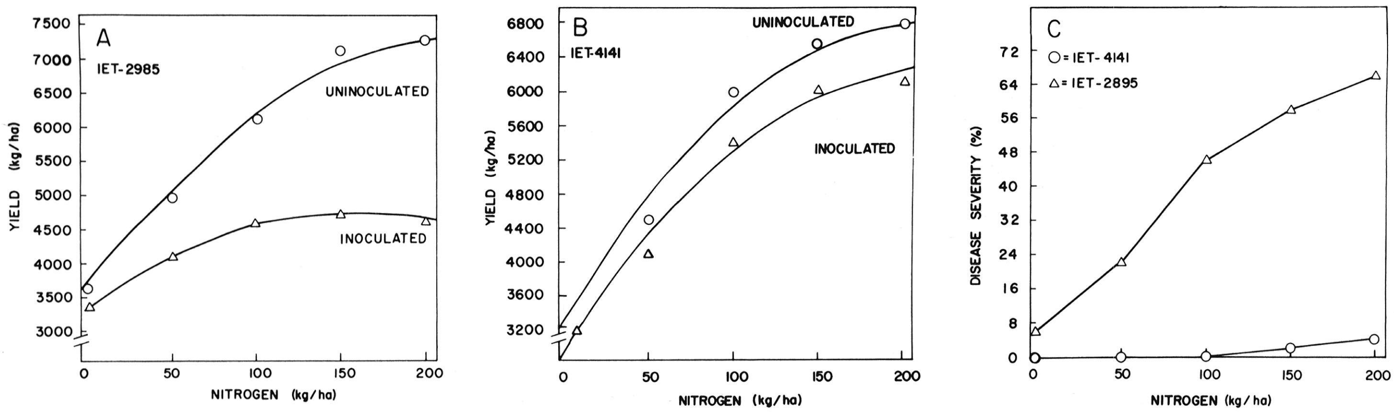

Fig. 2. Yield response curves to increasing N levels in the susceptible rice cultivar IET 2895 (**A**) and the resistant cultivar IET 4141 (**B**). Bacterial leaf blight severity for each cultivar in the 1976 wet season (**C**).

TABLE 3. Relationship between yield and nitrogen in BLB-resistant and susceptible rice cultivars in three seasons as described by best fitted regression equations

Year	Cultivar	Regression parameter[x]			Standard deviation of regression coefficient			R^2 adjusted[y]
		b_0	b_1x	b_2x^2	b_0	b_1x	b_2x^2	(%)
1975 Wet season	IET 2895	3,174	+18.92	–0.0945	390	10.40	0.0555	10.6
	IET 4141	3,653	+21.37	–0.034	185	4.94	0.0263	78.0
1976 Dry season	IET 2895	4,269 a[z]	+26.29 a	–0.0919 a	246	6.59	0.0351	74.2
	IET 4141	4,554 b	+31.25 a	–0.0866 a	208	5.58	0.0297	90.4
1976 Wet season	IET 2895							
	Uninoculated	3,614 a	+33.13 a	0.0738 a	216	5.12	0.0246	92.3
	Inoculated	3,343 b	+17.74 b	–0.0569 a	222	5.25	0.0252	60.4
	IET 4141							
	Uninoculated	3,287 a	+33.47 a	–0.0800 a	138	3.28	0.0157	96.4
	Inoculated	3,104 a	+28.24 a	–0.0632 a	181	4.29	0.0206	92.5

[x]Regression parameters were obtained using all data points (12 in 1975 wet season, 1976 dry season experiments, and 15 wet season experiments.
[y]Coefficient of multiple determination adjusted for degrees of freedom.
[z]Pairwise comparison of regression coefficients and parameters was made between two cultivars in 1976 dry season and between inoculated and uninoculated treatments within a variety for the 1976 wet season.

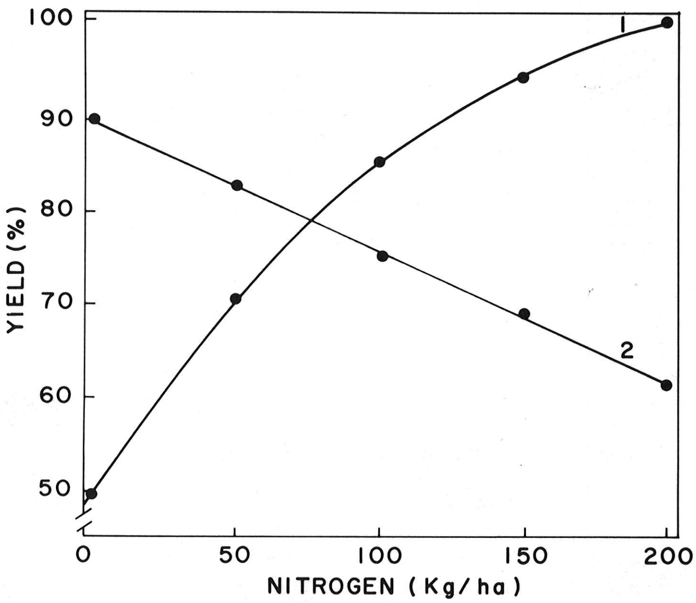

Fig. 3. Yield response of rice to increasing levels of N in cultivar IET 2895 in 1976 wet season in inoculated and uninoculated plots. Yield in uninoculated plots is expressed as percent of yield obtained at 200 N (curve 1). Yield in inoculated plots expressed as percent of uninoculated plots obtained at various N levels (curve 2). The intersecting point gives the N optimum (76 kg/ha).

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