Effects of Nitrogen Timing and Split Application on Blast Disease in Upland Rice

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ABSTRACT

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Nitrogen is essential for increased upland rice productivity, but the severity of blast disease increases with N application. The potential to suppress blast disease through timing and splitting of N application was tested during the 1987 and 1988 wet seasons in the Philippines on a strongly acidic soil. We studied the effects of 90 kg of N per hectare applied as two early-split applications, two late splits, three equal splits, and five equal splits on disease progress, crop growth, and yield. A no-N check was included. Leaf blast was suppressed when N was applied late (30 and 60 days after seeding) compared with early- and equal-split applications. Panicle blast was less in the no-N check but was not consistently reduced by any of the other treatments. Leaf and panicle blast correlated with total dry matter ($r = 0.60$–0.70), Si/N ratio ($r = -0.50$ to -0.80), and with the concentrations of Si ($r = -0.40$ to -0.70) and N ($r = 0.50$–0.80). Increased leaf blast was attributable to both increased tissue susceptibility and increased canopy density. In inoculated plots, total dry matter (5.6 t/ha) and grain yields (1.1 t/ha) were reduced compared with fungicide-treated plots (6.3 and 1.8 t/ha), and the yield loss was correlated with the incidence of severe panicle infection ($r = 0.86$). Nitrogen treatments had no significant effect on grain yields. None of the treatments controlled both leaf and panicle blast and increased yields.

Additional keywords: *Oryza sativa*, *Pyricularia grisea*, *P. oryzae*

Upland rice (*Oryza sativa* L.) is grown on about 20 million hectares worldwide with low yields of only 1 t/ha (3). Nitrogen is one of the essential inputs needed to increase yields in upland rice (13). The most serious disease of upland rice is blast, caused by *Pyricularia grisea* Sacc. (=*P. oryzae* Cavara) (26). Blast severity increases when N is applied or when the rate of N application is increased (1,25). Because the choice of disease control measures is limited for upland rice farmers, knowledge of interactions among agricultural practices and blast is needed to integrate disease management systems within overall cultural practices (16).

The split application of N is recommended to increase the efficiency of N fertilization in upland rice and to reduce N losses (13). In drought-prone upland conditions in Brazil, the application of N in a single dose at panicle initiation reduced leaf and panicle blast compared with N applied at planting (10). In contrast, the split application of N tends to reduce blast in irrigated rice (2,4,15,17,31). For upland rice in Asia, the influence of N management on blast disease has not been systematically studied. We investigated the effects of alternative ways of splitting and timing N fertilizer applications on the development of leaf and panicle blast in upland rice in relation to canopy development, nutrient uptake, and yield.

MATERIALS AND METHODS

The experiments were conducted at Cavinti, Laguna, Philippines, an upland rice research site of the International Rice Research Institute (IRRI). The soil was a well-drained Ultisol (Orthoxic Palehumult) with a clayey texture (pH = 4.6, organic C = 2.4%, total N = 0.23%, available P [Bray 2 extractable] = 9 ppm, cation exchange capacity [CEC] = 19.8 meq/100 g). These properties are similar to those observed in many soils where upland rice is grown in Asia.

Experimental design. Four treatments, in which the number and timing of applications of 90 kg of N per hectare were varied, were compared with a control in which no N was applied. The treatments included no N, two early-split applications (60 kg/ha at planting and 30 kg/ha at 30 days after seeding [DAS]), two late splits (30 kg/ha at 30 DAS and 60 kg/ha at 60 DAS), three equal splits (30 kg/ha at planting and 30 and 60 DAS), and five equal splits (18 kg/ha at planting and 15, 30, 45, and 60 DAS). Two levels of disease were created by a fungicide treatment and an inoculation treatment. A split-plot design was used in 1987 with four replications of the two disease levels as main plots and the five N treatments as subplots. In 1988, a randomized complete block design with five replications was used in which the five N treatments were combined with the two disease levels for a total of 10 experimental units per replication.

Management. Cultivar UPLRi-5 was sown (25-cm rows, 80 kg of seed per hectare) at the beginning of the wet season (15 June 1987 and 9 June 1988). Seed was treated with carbosulfan at 12 g a.i./kg of seed to prevent insect damage to seedlings. Plots were 36 m^2 in 1987 and 28.5 m^2 in 1988 and were divided into harvest (6.25 m^2) and sampling areas. At planting, solofos and muriate of potash were applied in the furrow at

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45 kg of P per hectare and 43 kg of K per hectare, respectively, in 1987 and at 40 kg of P per hectare and 30 kg of K per hectare, respectively, in 1988. Plots were weeded by hand. Nitrogen was applied as urea into the furrow at planting. Successive doses were top-dressed between rows.

Inoculation and fungicide treatments. Fungicide-treated plots were not inoculated. The seed was treated with pyroquilon (50WP) at 2 g a.i./kg seed and plots were sprayed four or five times with tricyclazole (75WP) at 250 g a.i./ha beginning 30 DAS until heading. In 1987, the final application was delayed until after heading because of logistical problems. For the inoculation treatment, seedlings of cultivars UPLRi-5 and IR50 were grown in plastic cups with 300 ml of fertilized field soil. Two-week-old seedlings were inoculated by exposure for several days at the IRRI blast nursery. After the seedlings showed sporulating lesions, four cups were placed in the center of each plot beginning 17 DAS in 1987 and 14 DAS 1988 then replaced by a second set after 1 wk.

Data collection. Foliar blast was visually assessed as the percent diseased leaf area based on the five topmost leaves of 20 randomly chosen tillers. In 1987, detailed assessment of leaf blast was made at 34, 44, 56, and 90 DAS. Because the shape of the disease progress curve was similar across treatments in 1987, leaf blast progress in 1988 was monitored only in the treatment receiving three N applications. The other treatments were evaluated once at 42 DAS. One week before harvest, 100–150 panicles were chosen at random from each experimental unit and panicle blast was assessed using a 0–9 scale, with 9 representing lesions girdling the panicle base and less than 30% of the spikelets filled (1). The incidence of severe infection was calculated based on the proportion of plants with ratings 7 or 9 (5).

Tillers were counted on four marked linear meters per plot at 30 and 60 DAS and expressed as tillers per square meter. Canopy height measurements and visual estimates of canopy cover (32) were made at 30 and 60 DAS in four random 1-m^2 samples per plot. Total dry matter was determined in each plot at 45 and 85 DAS. Samples were taken from 3.5 m^2 (two subplots of seven 1-m rows each) in 1987 and from 0.75 m^2 (three 1-m rows) in 1988.

In 1987, shoot samples were taken at 45 and 85 DAS and combined to form a composite sample for each N treatment. Samples were analyzed for total N, P, Ca, Si, and Mn (33). In 1988, samples were taken from each experimental unit at 35 and 60 DAS and analyzed separately. Nutrient uptake in inoculated plots was calculated based on total dry matter at 45 and 85 DAS.

Rainfall and standard meteorological data were obtained from the agrometeorological station at the site (IRRI Climate Unit, *unpublished*). In 1987, air temperature, relative humidity, leaf wetness, and soil moisture tension were recorded only in the treatment with three N applications. In 1988, measurements were also recorded in the no-N treatment. A thermohygrograph (model 8341, G. Lufft, Stuttgart, Germany) connected to a wetness sensor at two-thirds canopy height was placed at the center of the field. Two tensiometers per plot were installed in each experimental unit at a depth of 15 cm.

Analysis. Analysis of percent diseased leaf area was performed with transformed data (arcsine square root/100). Transformation improved data distribution and homogeneity of variances. Treatment comparisons of disease data were done by orthogonal contrasts (28). Means of crop data are presented with *F* values and LSD ($P = 0.05$). As in a previous study (6), grain yield loss attributable to blast was estimated for

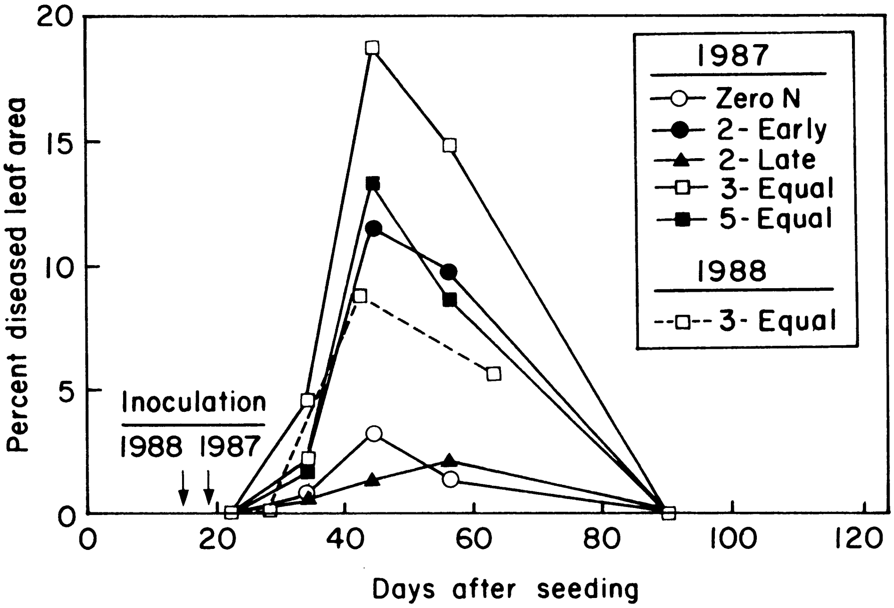

Fig. 1. Leaf blast progress during 1987 and 1988 as influenced by timing of nitrogen application. Zero-N = no nitrogen applied. 2-Early = 90 kg of N applied as two splits of 60 kg/ha at planting and 30 kg/ha at 30 days after seeding (DAS); 2-Late = 90 kg of N applied as two splits of 30 kg/ha at 30 DAS and 60 kg/ha at 60 DAS; 3-Equal = 90 kg of N applied as three splits of 30 kg/ha at planting and 30 and 60 DAS; and 5-Equal = 90 kg of N applied as five splits of 18 kg/ha applied at planting and 15, 30, 45, and 60 DAS.

Table 1. Leaf and panicle blast intensity as affected by disease level and N application in two upland rice trials[w]

Treatment means and contrasts	Leaf blast[x]		Panicle blast[x]	
	1987	1988	1987	1988
Treatment means[y]				
No N	3.2 (0.2)	1.2 (0.1)	35.9 (15.8)	27.2 (3.3)
Two early splits	11.5 (0.6)	12.5 (0.3)	47.9 (11.4)	62.0 (6.5)
Two late splits	1.4 (0.3)	2.1 (0.3)	41.5 (15.4)	69.3 (4.4)
Three equal splits	18.7 (0.4)	8.7 (0.2)	38.2 (16.1)	78.8 (12.2)
Five equal splits	13.3 (0.2)	7.4 (0.4)	54.9 (28.0)	77.7 (10.7)
Contrasts[z]				
1 No N vs. 90 kg N	0.0015	0.0001	0.0387	0.0001
2 Two early and two late vs. three and five equal	0.0002	0.1727	0.6313	0.1402
3 Two early vs. two late	0.0003	0.0001	0.2468	0.6546
4 Three equal vs. five equal	0.0823	0.6239	0.0080	0.9308

[w] Disease levels were fungicide-treated or inoculated with *Pyricularia grisea.* N treatments were no N and 90 kg of N per hectare applied as two early splits (60 kg at planting and 30 kg at 30 days after seeding ([DAS]), two late splits (30 kg at 30 DAS and 60 kg at 60 DAS), three equal splits (30 kg at planting and 30 and 60 DAS), and five equal splits (18 kg at planting and 15, 30, 45, and 60 DAS).

[x] Leaf blast scored as percent diseased leaf area 44 DAS in 1987 and 42 DAS in 1988. Panicle blast scored as incidence of severe panicle infection after Bonman et al (5).

[y] Values are means of untransformed data across replications; means of fungicide-treated plots are in parentheses.

[z] Orthogonal contrasts for N application of inoculated plots are presented with the probability level for observed *F* values greater than tabular *F* values.

treatments receiving N as the difference between the treatment yield and the highest yielding treatment within each year, calculated as the percent loss.

RESULTS

Meteorological conditions. Rainfall amount and distribution varied greatly within growing the seasons, and soil moisture status responded to these changes. Soil moisture tension exceeded 20 kPa from 35 to 52, 74 to 78, and 103 to 111 DAS in 1987 and at 74 to 77 and 84 to 97 DAS in 1988. In both years, temperature (19–28 C) and relative humidity (more than 9 hr above 90%) during the crop season were within the optimum range for disease development (30), and leaf wetness exceeded the 9-hr minimum wetness duration required for infection (18,30). From 40 to 100 DAS in 1988, the treatment with three N applications had lower temperature (−2.2 C), higher relative humidity (+1.2%), and longer leaf wetness (+2.5 hr) within the canopy than the no-N treatment.

Disease progress. The pattern of leaf blast progress was similar in both years with a peak at about 40–45 DAS (Fig. 1). In 1987, the first symptoms of leaf blast appeared simultaneously in all treatments, but the rate of disease increase differed among treatments. Leaf blast severity in inoculated plots was higher in 1987 than in 1988, whereas panicle blast incidence was lower in 1987 (Table 1). Fungicide applications controlled leaf blast in both years (<0.7 and <0.4% diseased leaf area). The incidence of severe panicle blast was higher in fungicide-treated plots in 1987 (11–28%) than in 1988 (3–12%).

Except for panicle blast in 1987, the interaction between N treatments and disease treatments (inoculated or fungicide-protected) was highly significant. This result is expected when fungicide treatment effectively controls the disease. Orthogonal contrasts using means from the inoculated plots showed that N application significantly increased leaf and panicle blast compared with the no-N treatment (Table 1, contrast 1). Nitrogen applied twice, at planting and at 30 DAS (early split), gave significantly higher leaf blast severity than when applied 30 and 60 DAS (late split) (Table 1, contrast 3). In 1987, leaf blast was most severe with N equally split. Leaf blast did not differ significantly between two splits and equal splits in 1988 (Table 1, contrast 2). Panicle blast infection did not differ significantly among treatments receiving N, except in 1987, where the treatment receiving three applications showed significantly lower incidence of severe panicle blast than the treatment receiving five equal-split applications (Table 1, contrast 4).

Table 2. Number of tillers per square meter 30 and 60 days after seeding (DAS) as affected by disease level and N application in two upland rice trials[x]

N application and *F* value	1987		1988	
	30 DAS	60 DAS	30 DAS	60 DAS
N application[y]				
No N	386 b	404 a	289 bc	411 a
Two early splits	528 a	443 a	368 ab	448 a
Two late splits	381 b	445 a	271 c	441 a
Three equal splits	529 a	422 a	303 a–c	380 a
Five equal splits	529 a	440 a	380 a	444 a
F value[z]				
Disease level	1.2 NS	0.2 NS	6.0 *	0.1 NS
N application	4.5 **	0.5 NS	3.6 *	3.5 *
Interaction	0.95 NS	0.3 NS	0.12 NS	0.85 NS

[x] Disease levels were fungicide-treated or inoculated with *Pyricularia grisea*. N treatments were no N and 90 kg of N per hectare applied as two early splits (60 kg at planting and 30 kg at 30 DAS), two late splits (30 kg at 30 DAS and 60 kg at 60 DAS), three equal splits (30 kg at planting and 30 and 60 DAS), and five equal splits (18 kg at planting and 15, 30, 45, and 60 DAS).

[y] Values are the means of inoculated plots across replications. Means in a column followed by the same letter are not significantly different according to LSD ($P = 0.05$).

[z] NS = *F* test was not significant; * = *F* test significant at $P = 0.05$; ** = *F* test significant at $P = 0.01$.

Table 3. Total dry matter (kg/ha) 45 and 85 days after seeding (DAS) as affected by disease level and N application in two upland rice trials[x]

N application and *F* value	1987		1988	
	45 DAS	85 DAS	45 DAS	85 DAS
N application[y]				
No N	1.36 c	2.74 a	1.13 b	3.70 b
Two early splits	2.77 a	3.11 a	2.20 a	4.06 b
Two late splits	1.34 c	2.92 a	1.23 b	5.01 ab
Three equal splits	1.92 bc	3.15 a	1.82 a	4.69 ab
Five equal splits	2.06 b	3.13 a	1.83 a	5.90 a
F value[z]				
Disease level	0.78 NS	3.1 NS	0.59 NS	3.43 NS
N application	8.11 **	0.27 NS	6.32 **	7.35 **
Interaction	0.66 NS	0.12 NS	0.34 NS	0.94 NS

[x] Disease levels were fungicide-treated or inoculated with *Pyricularia grisea*. N treatments were no N and 90 kg of N per hectare applied as two early splits (60 kg at planting and 30 kg at 30 DAS), two late splits (30 kg at 30 DAS and 60 kg at 60 DAS), three equal splits (30 kg at planting and 30 and 60 DAS), and five equal splits (18 kg at planting and 15, 30, 45, and 60 DAS).

[y] Values are the means of inoculated plots across replications. Means in a column followed by the same letter are not significantly different according to LSD ($P = 0.05$).

[z] NS = *F* test was not significant; * = *F* test significant at $P = 0.05$; ** = *F* test significant at $P = 0.01$.

Crop development. Crop development was similar in both years. However, when N was applied at sowing, heading was complete and flowering had begun by 95 DAS. Panicles were only half to three-fourths emerged at 95 DAS in the other treatments.

At 30 and 60 DAS, canopy height ranged from 25 to 40 cm and from 40 to 60 cm; canopy cover ranged from 6 to 25% and from 20 to 40%, respectively. Interaction effects on tiller number (Table 2) and total dry matter (Table 3) were not significant. In 1987, early and equal N-split treatments resulted in a significantly higher number of tillers at 30 DAS, compared with treatments that received no N at planting (no-N and late-split applications) (Table 2). The number of tillers at 30 DAS was higher, and treatment differences were greater in 1987 than in 1988. The number of tillers 60 DAS was similar among treatments in both trials.

Except for the sample taken at 85 DAS in 1987, total dry matter varied with the N application treatments (Table 3). In general, significantly higher total dry matter at 45 DAS was observed in plots where N was applied at planting compared with the no-N and the two late-N treatments, which did not receive N at planting (Table 3).

Tiller number was strongly correlated with leaf blast in 1987 but not in 1988 (Table 4). Total dry matter and plant nutrient element concentrations showed similar correlation coefficients in both years with higher coefficients for leaf blast than for panicle blast. Correlations for nutrient uptake and disease, especially Si and Mn, were lower than for nutrient concentration and disease. Leaf blast tended to be positively correlated with plant N and Mn concentration but negatively correlated with P and Si concentrations. Among all elements analyzed, only percent Si and the Si/N ratio were negatively correlated with both leaf and panicle blast. Correlation coefficients tended to be higher in 1987 but were statistically significant only in 1988 because of a greater number of degrees of freedom (49 in 1988 vs. nine in 1987).

Total dry matter and grain yields were lower in 1987 than in 1988 (Table 5). N application had no significant effect on grain yields and significantly increased total dry matter only in 1988. In 1988, the late- and equal-split applications of N resulted in significantly higher total dry matter than the no-N treatment. The grain yields in fungicide-treated plots were significantly higher than in the inoculated plots in both years. The yield differential between the two disease levels was generally greatest with N application in equal splits (Table 5). The estimated percent yield loss was correlated with the incidence of severe panicle blast ($r = 0.86$).

DISCUSSION

We found that the rate, frequency, and timing of N application had a much greater influence on leaf blast than on panicle blast, as was observed in previous reports (10,15). There was no consistent reduction in panicle blast with any of the various N application treatments. However, the no-N treatment had less panicle blast than the treatments where N was applied, and this result was consistent across years. There was a slight difference in heading date in the no-N plots compared with the other treatments, but this was probably not sufficient to influence the relative occurrence of panicle blast. In the present study, the timing effect of N fertilizer application had more pronounced effects than those reported for drought-prone upland conditions in Brazil (10). The timing of N application (i.e., early vs. late application) had a much more important influence on leaf blast than the number of split applications of the same N dose. Leaf blast was consistently suppressed when N was not applied at planting (Table 1).

The generally high disease intensity of leaf blast in 1987 and panicle blast in 1988 (Table 1) might be attributable to increased host susceptibility caused by a water deficit (12). High soil moisture tension values occurred during the vegetative growth stage from 35 to 52 DAS in 1987 and during the reproductive growth stage from 84 to 97 DAS in 1988, periods critical for leaf and panicle blast development. The high panicle blast intensity in fungicide-treated plots in 1987 was probably attributable to the delayed application of fungicide.

We hypothesized that an increase in the number of equal applications of a given quantity of N would reduce blast severity, as had been reported for irrigated rice (2,4,15,17,31). On the contrary, leaf blast did not decrease with increased frequency of N application. Instead, leaf blast in 1987 and panicle blast in 1988 tended to increase with three or five equal-split applications compared with two-split applications (Table 1). Furthermore, adjustments in the timing and splitting of N application did not significantly increase yield (Table 5).

It is well known that N fertilization favors the development of blast (23), but the mechanisms are not well understood. Fertilization with N increases host tissue susceptibility (19–21,27), but our data

Table 4. Correlation coefficients (r) for correlation of canopy and nutrient variables with severity of leaf blast (percent disease leaf area) and panicle blast (percent severe panicle blast)

	Leaf blast		Panicle blast	
Variable[y]	**1987**	**1988**	**1987**	**1988**
Leaf blast	...	...	0.30	0.37
Tillers (per m²)	0.93*[z]	0.38	0.70	0.01
Canopy height (cm)	0.67	−0.19	0.46	0.42
Canopy cover (%)	0.80	0.05	0.56	0.63**
Total dry matter (kg/ha)	0.62	0.66**	0.60	0.55**
N (%)	0.54	0.56**	0.77	0.53**
P (%)	−0.61	−0.63**	0.43	−0.50**
Si (%)	−0.72	−0.55**	−0.58	−0.37
Mn (%)	0.82	0.63**	0.50	...
Si/N ratio	−0.70	−0.62**	−0.77	−0.52**
N (kg/ha)	0.64	0.73**	0.71	0.61**
P (kg/ha)	0.61	0.48*	0.64	0.37
Si (kg/ha)	0.50	0.39	0.14	0.39
Mn (kg/ha)	0.68	0.41*	0.53	...

[y] Data for tillers per square meter, canopy height, and canopy cover taken at 30 days after seeding (DAS) for correlations with leaf blast and at 60 DAS for correlations with panicle blast. All other data taken at 45 DAS for leaf blast correlations and at 85 DAS for panicle blast correlations.

[z] * And ** indicate F test significant at $P = 0.05$ and $P = 0.01$, respectively.

Table 5. Total dry matter and grain yield as affected by disease level and N application in two upland rice trials

	Total dry matter (t/ha)[w]			Grain yield (t/ha)[w]		
Trial[v]	**F**	**I**	**F − I**	**F**	**I**	**F − I**
1987						
No N	5.95	5.18	0.77	1.57	0.94	0.63 *[x]
Two early	6.28	3.93	2.35	1.75	0.93	0.82 **
Two late	5.25	4.82	0.43	1.48	1.11	0.37 NS
Three equal	5.34	5.76	−0.42	1.49	1.27	0.22 NS
Five equal	5.94	5.60	0.34	1.59	0.83	0.76 **
Mean[y]	5.80	5.10	0.70	1.60	1.00	0.60 **
LSD ($P = 0.05$)						0.44
F value						
Disease level			2.2 NS[z]			37.7 **
N application			0.4 NS			0.5 NS
Interaction			1.2 NS			1.9 NS
1988						
No N	4.66	4.69	−0.03 NS	1.56	1.12	0.43 NS
Two early	6.24	5.62	0.62 NS	1.75	1.21	0.54 NS
Two late	7.24	6.92	0.32 NS	1.87	1.21	0.65 *
Three equal	7.52	5.97	1.55 NS	2.18	1.06	1.11 **
Five equal	8.39	6.69	1.70 NS	2.14	1.41	0.73 *
Mean	6.80	6.00	0.80 **	1.90	1.20	0.70 **
LSD ($P = 0.05$)			1.90			0.55
F value						
Disease level			4.1 *			32.8 **
N application			6.1 **			1.5 NS
Interaction			0.7 NS			0.9 NS

[v] Disease levels were fungicide-treated (F) or inoculated with *Pyricularia grisea* (I). N treatments were no N and 90 kg of N per hectare applied as two early splits (60 kg at planting and 30 kg at 30 days after seeding [DAS]), two late splits (30 kg at 30 DAS and 60 kg and 60 DAS), three equal splits (30 kg at planting and 30 and 60 DAS), and five equal splits (18 kg at planting and 15, 30, 45, and 60 DAS).

[w] F − I = difference between fungicide-treated and inoculated.

[x] NS, *, and ** indicate LSD at respective N application not significant, significant at $P = 0.05$, and significant at $P = 0.01$, respectively.

[y] Values are means across N treatments.

[z] NS, *, and ** indicate F test for treatment effects not significant, significant at $P = 0.05$, and significant at $P = 0.01$, respectively.

also indicate two possible indirect roles of N. The first role is increasing crop canopy density. The early- and equal-split N treatments showed greater leaf blast in both years than the late and no-N treatments (Table 1). The early- and equal-split treatments also had more tillers per unit area at 30 DAS, coinciding with the initial phase of leaf blast development (Fig. 1). Total aboveground dry matter during early rice growth (45 DAS) also was stimulated by the early and more frequent N splitting treatments (Table 3). The microclimatic measurements taken in 1988 showed that the three-split treatment had a longer mean daily duration of leaf wetness (+2.5 hr) than the no-N treatment. Because canopy density was greater in the treatments receiving N at an early stage of crop growth, it is likely that two factors contributed to the N timing effects on leaf blast—a more favorable microclimate and more susceptible host plants. To partition these two effects, experiments using canopy density as a variable would have to be conducted.

The second possible indirect role of N could be increasing overall water consumption. In upland rice, N application increases water consumption by increasing the leaf area index and, thereby, increasing the total plant transpiration (29). N application will tend to increase the plant water deficit if the water supply is limiting. An enhanced plant water deficit greatly increases host susceptibility to blast (12). This condition may be analogous to the case of Fusarium foot rot of wheat, where N enhances disease indirectly by increasing leaf area and water consumption, resulting in lower plant water potentials, which, in turn, favors the pathogen (8). Differences in soil moisture could be partially responsible for the higher leaf blast with N application. This hypothesis requires further testing.

The Si/N ratio has been used as an indicator for the potential of disease development (17,24). Correlations with disease intensity reported by Paik (24) and Lee and Lee (17) were high (−0.78 to −0.96 and −0.55 to −0.98). Our results showed relatively high and stable correlations between the Si/N ratio and disease, but because of fewer degrees of freedom for the statistical test, correlations were significant only in 1988 (Table 4). Treatments with higher N concentration showed lower Si concentration.

Our results also indicate that Mn content may be important in the physiological susceptibility of rice to blast. The association between Mn content and leaf blast found in the present field study was also encountered in a previous greenhouse study of N and Si effects on blast resistance (20).

It may not be possible to use the Si/N ratio (7,17,24), Mn content, or other nutrient variables alone as indicators for the potential of leaf and panicle blast development in upland rice because soil moisture also alters host predisposition. The *r* values in our experiments were lower and less significant than those reported for irrigated conditions in Korea, probably because the greater variation in soil moisture that is present only in upland conditions also affected nutrient uptake (22) and host susceptibility (12).

N application and timing effects on yields were small or inconsistent (Table 5), although leaf and panicle blast were affected by N treatments. Yields in general were low (Table 5) but comparable to yields in other experiments in this strongly acid infertile soil (11,14). Factors other than N are limiting yields because none of the N treatments increased yield over the control. The soil N content (0.23%) at Cavinti indicates a sufficient N supply for moderate rice crop yields (9).

Pronounced differences between the inoculated and fungicide-treated plots in 1987 (0.2–0.8 t/ha) and 1988 (0.4–1.1 t/ha) demonstrate that blast reduced grain yield in our experiments. This reduction was correlated with the incidence of severe panicle blast infection. As with blast in lowland rice (6), this result shows the importance of panicle blast occurrence in causing yield reduction. Control of panicle blast should be the focus of future work on blast management.

Investigation of the concept of threshold levels of nutrient ratios is needed in relation to plant nutrient demand patterns and host-pathogen interactions. Straightforward agronomic manipulations had limited, or even counter-productive, effects in controlling rice blast on this strongly acidic soil. Further progress can be made only with more detailed studies on how the plant physiological processes involved in nutrient uptake and use interact with blast disease.

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