Effects of Silicon and Fungicides on the Control of Leaf and Neck Blast in Upland Rice

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ABSTRACT

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Silicon (Si) has been shown to suppress diseases of rice such as blast when applied to Si-deficient soils. In 1995 and 1996, Si was applied at 1,000 kg ha⁻¹ to at two locations in eastern Colombia to determine if Si combined with reduced rates of fungicide could be used to manage leaf and neck blast effectively in upland rice. Two applications of edifenphos and three applications of tricyclazole were made at 0, 10, 25, or 100% of their labeled rates after amendment of soil with Si. At both locations, Si alone and Si combined with edifenphos reduced leaf blast severity by 22 to 75% when compared with nonamended, untreated controls, and suppression of leaf blast by Si alone was equal to or better than the full rate of edifenphos alone. Si alone suppressed neck blast as effectively or better than the full rate tricyclazole when severity was low; however, when severity was higher, a 10% rate of tricyclazole was needed in addition to Si. No differences in yield were observed between Si without fungicides and fungicides (full rate) without Si. Applications of Si made in 1995 had significant residual activity in terms of disease control and yield in 1996. The application of Si to Si-deficient soils may permit the use of reduced rates of fungicide to manage leaf and neck blast in upland rice.

Additional keywords: host resistance, *Magnaporthe grisea*

Rice blast, caused by *Magnaporthe grisea* (T.T. Hebert) Barr (anamorph = *Pyricularia grisea* (Cooke) Sacc.), is one of the most destructive diseases of rice (*Oryza sativa* L.) and is a serious constraint to production in most of the world's

rice-growing regions (3). The disease occurs mainly as leaf blast or neck blast (2,3). Although neck blast is the most destructive in terms of lost yield, leaf blast can cause severe damage before plants reach the reproductive phase of growth (3,19). Blast is especially problematic in temperate areas and in tropical uplands, such as those found in West Africa and the savannas of South America (3,4,29,30). Although upland rice accounts for only about 13% (19 million ha) of the total area planted to rice worldwide, it composes the majority of rice cultivated in parts of Asia, Africa, and South America (17).

Blast can be managed by changing planting date, avoiding excessive inputs of nitrogen, maintaining high levels of soil moisture, planting blast-resistant cultivars, and using fungicides (3,16,19). Fungicides provide good control of the disease, but the high cost of materials and application make them an unaffordable option for many of the world's rice growers (17). Greater success has been achieved through the planting of resistant cultivars; however, their effectiveness has proved to be short-lived in the field because of the development of new pathogenic races of *M. grisea* (4). *M. grisea* exhibits a great degree of variability and adaptability in nature, and its ability to generate new pathogenic races

not affected by deployed resistance genes has rendered most resistant cultivars ineffective within 1 to 2 years (1).

A promising alternative control for rice blast is the application of silicon (Si) fertilizers to soils deficient in the element. The rice plant has been shown to accumulate large amounts of Si from soil (11,13), and deficiencies of the element have been correlated with increased incidence of diseases such as blast and brown spot, caused by *Cochliobolus miyabeanus* (Ito & Kuriyayashi in Ito) Drechs. ex. Dastur. (11,13,20,22). Certain soils tend to be low in plant-available Si. Histosols, Oxisols, and Ultisols have been identified as Si-deficient (possessing Si at less than 24 ppm) due to high organic matter content or, in the case of the latter two types, high degrees of weathering, leaching, and acidity (22,26,27,30). Oxisols and Ultisols are the predominant soil types in the upland rice-growing areas of Latin America (22,30).

Amendment of Si-deficient soils with fertilizers containing calcium silicate has been shown to reduce incidence and severity of diseases such as brown spot, sheath blight, and rice blast (4-7,9,21,23,24). Datnoff and Snyder (7) found that Si alone reduced the incidence of neck blast by over 50% when compared with an untreated control, and did not differ significantly from benomyl, a fungicide registered for control of rice blast. In the same study, Si combined with benomyl reduced the incidence of neck blast by more than 80%. In eastern Colombia, amendment of soil with Si was shown to reduce the number of fungicide applications necessary to control rice blast (6,23).

Despite its potential as a management tool for rice blast, little is known about the feasibility of combining Si and fungicides to control blast (7,11,22,23). Filippi and Prabhu (14) reported that treatment of rice seed with pyroquilon effectively extended the duration of control of leaf blast in blast-resistant cultivars, indicating that host resistance can be used to increase the efficacy of fungicides. Because of the ability of Si to augment resistance to blast in the rice plant (18,28), studies were initiated to determine whether the amendment of Si-deficient soils with calcium silicate could reduce the rate of fungicide needed

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to control rice blast in an upland rice ecosystem. Additional studies were conducted to determine the efficacy of a single application of Si application over a 2-year period.

MATERIALS AND METHODS

Experiments were conducted in 1995 and 1996 at two different sites situated approximately 30 km east of Villavicencio, Colombia. The Santa Rosa research station, maintained by the Centro Internacional de Agricultura Tropical (CIAT) as a rice-breeding farm and rice blast nursery, was chosen as the first location for its inherently high severity of blast (5). The soil type was an Inceptisol, pH 4.7, with plant-available Si at approximately 4 ppm (as determined by the CIAT soil testing laboratory). The second site was located approximately 3 km east of Santa Rosa at the Instituto Colombiano de Agropecuaria's (ICA) La Libertad experiment station. The soil type (Oxisol) at the La Libertad site is representative of upland conditions in the savannas of Colombia. Soil pH was 4.7 and contained plant-available Si at less than 1 ppm.

Dolomitic limestone was incorporated into the soil approximately 20 days prior to planting at both locations. Soil fertility was maintained in accordance with CIAT recommendations. Si, in the form of wollastonite (CaSiO_3) (R. T. Vanderbilt, Norwalk, CT), was broadcast by hand at the rate of 0 and 1,000 kg ha^{-1} and incorporated approximately 5 days before planting by disking. Plots that did not receive Si were included as controls and were treated with agricultural lime (CaCO_3) at 1,150 kg ha^{-1} to raise the level of Ca to that of plots treated with calcium silicate. The blast-susceptible rice cv. Oryzica 1 was drill seeded at Santa Rosa at a depth of 3 cm and a row spacing of 0.26 m. The blast-susceptible cv. Linea 2 rather than Oryzica 1 was planted at La Libertad because Linea 2 is better adapted to the soil type and population of *M. grisea* (race profile) at La Libertad. The seeding rate was 80 kg

ha^{-1} at both locations. Planting dates at Santa Rosa were 17 May 1995 and 13 May 1996; at La Libertad, planting was done on 16 May 1995 and 16 May 1996.

At Santa Rosa and La Libertad, the tests were randomized complete block designs arranged as 2-by-4 factorials with five replications. Each plot was 5 by 8 m. The main effects were rate of calcium silicate, elemental Si at either 0 or 1,000 kg ha^{-1} , and rate of fungicide (0, 10, 25, or 100% of the labeled rate), providing a total of eight treatments per block. Each fungicide treatment was, in effect, a two-fungicide program. Each fungicide was applied separately in multiple-application blocks aimed at control of early-season leaf blast or late-season neck blast. Edifenphos (Hinosan 500EC; Bayer CropScience, Research Triangle Park, NC) was applied twice at 20 and 35 days after seeding (DAS) for control of leaf blast at 0, 100, 250, and 1,000 ml ha^{-1} . After the leaf blast epidemic, Tricyclazole (Bim 75WP; Dow AgroSciences, Indianapolis, IN) was applied at 0, 30, 75, and 300 g ha^{-1} at booting, 1% panicle emergence, and 50% panicle emergence for control of neck blast. Fungicide treatments were applied in 234 liters of water ha^{-1} using a manually pressurized backpack sprayer.

In 1995, each plot was subdivided into two 5-by-4-m sections to allow for the study of the efficacy of a single application of wollastonite for residual activity in 1996. In 1995, Si was applied as described in the previous section to one-half of each plot and the remaining half was left untreated until 1996. In 1996, the portion of each plot that did not receive wollastonite in 1995 was amended, and the portion that received wollastonite in 1995 was left unamended. For the purposes of analysis, the residual experiment was treated as a split-plot design with five replications. Whole plots were fungicide rate (0, 10, 25, or 100% of the recommended rate of edifenphos or tricyclazole) and subplots corresponded to the year of wollastonite application (1995 or 1996).

Data were collected in an identical fashion in 1995 and 1996. Prior to the appearance of disease, eight main tillers located in the center 6 m^2 of each plot were tagged with a 2-cm section of rubber tubing that had been coated with fluorescent paint. At both locations, leaf blast was evaluated throughout the epidemic by making visual estimates of the proportion of leaf area with disease on each leaf of the marked main tillers. At Santa Rosa, nine evaluations were made in 1995 beginning 1 June and ending 11 July; and eight evaluations were made from 6 June to 22 July 1996. A total of seven evaluations were made at La Libertad from 3 June to 4 July 1995, and six evaluations were made from 10 June to 11 July 1996.

Data were used to construct disease progress curves for each treatment. The efficacy of each treatment was determined by calculating the individual area under the disease progress curve (AUDPC) using the method of Shaner and Finney (25). The values obtained then were analyzed with the general linear model (GLM) procedure within the Statistical Analysis System (version 8.2; SAS Institute, Cary, NC). Least squares means were used to make comparisons between individual treatments. Preplanned comparisons included Si alone versus no fungicide, no Si, Si versus fungicides at each rate of application, and Si plus fungicides at each rate versus full rates of fungicide without Si.

Incidence of neck blast was estimated by evaluating 80 randomly selected panicles per plot at approximately 3 weeks post flowering. Incidence was scored on panicles with a rating of 5, 7, or 9, based on a 0-to-9 scale. The scale, developed by the International Rice Research Institute (IRRI), is as follows: 0 = no symptoms; 1 = lesions on pedicels and branches; 3 = lesions on branches and panicle axis; 5 = lesions partially surrounding base of panicle; 7 = lesions completely surrounding base of panicle, with greater than 30% of grains filled; and 9 = lesions completely surrounding base of panicle, with fewer than 30% of grains filled (15). Grains were harvested by hand at both locations. A 3-by-2-m section was marked within each subplot using a wire frame, and only those tillers within the frame were cut. Rough rice yields (kg ha^{-1}) were estimated from grain harvested in the 6 m^2 portion of each subplot and were adjusted to reflect a moisture content of 12%.

Samples of leaf tissue were collected at each location within 24 h of each evaluation of leaf blast in 1996 (both locations) to determine Si concentration of plants in nonamended and Si-amended plots at the time of assessment of disease. Approximately 500 g of stem and leaf tissue were collected and dried at harvest time to ascertain concentration of Si for correlation with neck blast (incidence and severity) and yield. Dried tissue was ground to a

Table 1. Comparisons of mean area under the disease progress curve (AUDPC) values of leaf blast of rice as affected by silicon (Si) alone or with edifenphos at Santa Rosa and La Libertad, Colombia, in 1995 and 1996

Si (kg ha^{-1})	Edifenphos (ml ha^{-1})	AUDPC ^z			
		Santa Rosa		La Libertad	
		1995	1996	1995	1996
0	0	6.7 a	4.3 a	1.3 a	0.9 a
0	100	4.8 b	2.7 c	1.3 a	0.9 a
0	250	4.4 b	3.9 b	0.8 bc	0.9 a
0	1,000	3.0 c	1.9 cd	1.1 ab	0.8 a
1,000	0	3.0 c	1.6 cd	0.4 de	0.3 b
1,000	100	2.3 cd	1.4 d	0.5 cde	0.3 b
1,000	250	2.5 c	2.2 bc	0.7 cd	0.3 b
1,000	1,000	1.7 d	1.4 d	0.3 e	0.2 b

^z AUDPC was calculated from nine (1995) or eight (1996) evaluations of leaf blast severity in Santa Rosa, and seven (1995) or six (1996) evaluations of leaf blast severity in La Libertad. Comparisons of any two values in the same column do not differ significantly ($P \leq 0.05$) as determined by comparisons of least-squares means. Each value is the mean of five replications.

fine powder using a Wiley mill. Si content of tissue samples was determined by first digesting 0.1 g of dried tissue as described by Elliot and Snyder (12), followed by automated colorimetric analysis. Data obtained were analyzed with the GLM procedure.

RESULTS

Effects of Si plus edifenphos on season-long severity of leaf blast. The application of Si, in the presence or absence of edifenphos, reduced the season-long severity of leaf blast at Santa Rosa and La Libertad in both years of the study (Table 1). A significant ($P \leq 0.05$) Si rate–fungicide rate interaction was detected at both locations in 1995 and at Santa Rosa in 1996, indicating that response to edifenphos was not consistent between levels of Si (Table 2). Therefore, data were analyzed separately by rate of Si and edifenphos.

In Santa Rosa, Si applied at 1,000 kg ha⁻¹, without tricyclazole, significantly reduced the AUDPC for leaf blast in 1995 and 1996 compared with the nonamended control (no Si, no fungicide; $P \leq 0.05$; Table 1). Si with tricyclazole at 1,000 ml ha⁻¹ reduced the AUDPC of blast by 43% compared with Si without tricyclazole in 1995. Edifenphos at 1,000 ml ha⁻¹, without Si, reduced the AUDPC in both years compared with nonamended plots. Si without fungicide reduced disease severity as effectively as the full rate of edifenphos applied without Si in 1996.

In La Libertad, the overall severity of leaf blast was lower than at Santa Rosa. As in Santa Rosa, Si without edifenphos significantly reduced AUDPC values for leaf blast compared with the nonamended control in 1995 and 1996 ($P \leq 0.05$; Table 1). Although significant, the differences in AUDPC between Si without edifenphos and the nonamended control were small

and may have been of little epidemiological importance. Edifenphos, regardless of rate, did not reduce the AUDPC in either year of the study. Si without edifenphos significantly reduced AUDPC compared with edifenphos alone at 1,000 ml ha⁻¹.

Effects of Si plus tricyclazole on the incidence of neck blast. At both locations in 1995, there was a significant Si rate–fungicide rate interaction, whereas no interaction was detected in 1996 (Table 2). Data were analyzed separately by Si and rate of tricyclazole.

Si at 1,000 kg ha⁻¹, without tricyclazole, reduced incidence of neck blast compared with the nonamended control in 1995 and 1996 at both locations ($P \leq 0.05$; Table 3). Tricyclazole at 300 g ha⁻¹ without Si reduced neck blast significantly more than the nonamended control. At Santa Rosa, in both years of the study, Si without tricyclazole showed a higher incidence of neck blast than the 300 g ha⁻¹ rate of tricyclazole without Si. Increasing the rate of tricyclazole to 30 g ha⁻¹ in conjunction with Si reduced the incidence of neck blast

to the same level ($P \leq 0.05$) as the full rate of tricyclazole without Si. In 1996, Si plus tricyclazole at 300 g ha⁻¹ reduced neck blast compared with tricyclazole at the same rate without Si. In La Libertad, Si without tricyclazole reduced the incidence of neck blast as effectively as the full rate of tricyclazole without Si in 1995 and was significantly better than tricyclazole at 300 g ha⁻¹ without Si in 1996.

Effects of Si plus fungicides on yield.

At Santa Rosa, yields of rough rice were increased by the application of Si in both years of the study (Table 4). Si alone significantly increased yields by 53 and 51% compared with the nonamended control in 1995 and 1996, respectively ($P \leq 0.05$). In 1995, yields from plots treated with full rates of edifenphos and tricyclazole without Si were higher than those of the nonamended control and did not differ significantly from Si alone. In 1996, Si alone increased yields by 17% compared with full rates of edifenphos and tricyclazole alone.

Yields of rough rice were lower at La Libertad than at Santa Rosa in both 1995

Table 3. Effect of two rates of soil-applied silicon (Si) and four rates of tricyclazole on the severity of neck blast at Santa Rosa and La Libertad, Colombia, in 1995 and 1996

Si (kg ha ⁻¹)	Tricyclazole (g ha ⁻¹) ^z	Neck blast incidence (%) ^y			
		Santa Rosa		La Libertad	
		1995	1996	1995	1996
0	0	54 a	72 a	4.0 a	9.5 a
0	30	35 c	26 c	3.3 ab	3.3 bc
0	75	32 cd	20 cd	2.0 bc	2.5 c
0	300	29 cd	12 ef	1.3 c	5.5 b
1,000	0	46 b	44 b	1.8 bc	2.0 c
1,000	30	31 cd	18 de	1.8 bc	0.8 c
1,000	75	28 d	15 de	0.8 c	0.8 c
1,000	300	16 e	6 f	0.8 c	1.0 c

^y Percentage of 100 panicles per plot with symptoms of neck blast. Comparisons of any two values in the same column do not differ significantly ($P \leq 0.05$) as determined comparisons of least squares means. Each value is the mean of five replications.

^z Tricyclazole applied at booting, 1% heading, and 50% heading stages.

Table 2. Analysis of main effects and interactions for the effects of silicon combined with fungicides on leaf blast, neck blast, and yield of rice in 1995 and 1996 at Santa Rosa and La Libertad, Colombia

Year, location, source of error	df ^z	<i>P</i> > <i>F</i> ^y		
		Leaf blast AUDPC	Neck blast incidence (%)	Rough rice yield (kg ha ⁻¹)
1995				
Santa Rosa				
Silicon	1	<0.0001	<0.0001	0.0113
Fungicide rate	3	<0.0001	<0.0001	0.4018
Silicon × fungicide rate	3	<0.0001	0.1144	0.8334
La Libertad				
Silicon	1	<0.0001	0.0060	<0.0001
Fungicide rate	3	0.2079	0.0227	0.3546
Silicon × fungicide rate	3	0.0017	0.6634	0.9886
1996				
Santa Rosa				
Silicon	1	<0.0001	<0.0001	<0.0001
Fungicide rate	3	<0.0001	<0.0001	0.2053
Silicon × fungicide rate	3	0.0006	<0.0001	0.2019
La Libertad				
Silicon	1	<0.0001	<0.0001	0.0154
Fungicide rate	3	0.4853	<0.0001	0.1315
Silicon × fungicide rate	3	0.9706	0.0129	0.1479

^y $P > F$ = significance level of F test, and AUDPC = area under the disease progress curve.

^z df = degrees of freedom.

and 1996. Si applied at 1,000 kg ha⁻¹, without fungicides increased yields by 25% in 1995 and 23% 1996 compared with the nonamended control ($P \leq 0.05$; Table 4). At each rate of fungicide in 1995, yields were significantly higher for Si at 1,000 kg ha⁻¹ compared with Si at 0 kg ha⁻¹. In 1995, yields from plots treated with Si alone were increased by 34% over plots treated with full rates of edifenphos and tricyclazole alone; however, in 1996, no differences in yield were found between these treatments.

Residual effects of Si on leaf blast, neck blast, and yield. In Santa Rosa, applications of Si made in 1995 reduced the severity of leaf blast in 1996 (Table 5). Si applied in 1995 reduced AUDPC of leaf blast by 49% compared with the nonamended control ($P \leq 0.05$; Table 5). Mean values of AUDPC did not differ significantly between plots treated with Si in 1995 (residual Si) and plots treated in 1996, or between plots treated with edifenphos at only 1,000 ml ha⁻¹. Applications of Si made in 1996, in combination with edifenphos, significantly reduced AUDPC of leaf blast when compared with residual Si without fungicides. In general, all plots treated with edifenphos, with or without applications of Si in 1996, had significantly reduced AUDPC values when compared with residual Si without edifenphos.

The incidence of neck blast in 1996 was reduced by 40% by Si alone in 1995, com-

pared with the nonamended control ($P \leq 0.5$) (Table 5). No significant differences were observed in the incidence of neck blast between plots treated with Si in 1995 and those treated in 1996; however, the incidence of neck blast was higher for residual Si than in plots treated with tricyclazole alone at 300 g ha⁻¹. The addition of reduced rates of tricyclazole to residual Si did not control neck blast as well as the full rate of tricyclazole alone (*data not shown*).

Fresh applications of Si were more effective in increasing yield in 1996 at Santa Rosa than applications made in 1995. Although yields of rough rice from the residual plots were 33% higher than yields from the nonamended control, they were 12% lower than yields from plots amended with Si in 1996 ($P \leq 0.05$; Table 5). Yields for residual Si did not differ significantly from those of plots treated only with full rates of edifenphos and tricyclazole.

At La Libertad, applications of Si made in 1995 reduced the AUDPC of leaf blast in 1996. The AUDPC of leaf blast from plots amended with Si at 1,000 kg ha⁻¹ in 1995 was lower than for the nonamended control ($P \leq 0.05$; Table 5). Severity of disease for residual Si was not significantly different from that in plots amended with Si in 1996 or with edifenphos alone at 1,000 ml ha⁻¹.

Residual Si significantly reduced the incidence of neck blast by 48% compared with the nonamended control ($P \leq 0.05$;

Table 5). Neck blast was lower in plots that received Si at 1,000 kg ha⁻¹ in 1996 than for residual Si; however, the incidence of neck blast from plots treated with tricyclazole at 300 g ha⁻¹ was not different from that observed for residual Si.

Applications of Si made in 1995 did not significantly increase yields in 1996 compared with the nonamended control ($P > 0.05$). Yields for Si at 1,000 kg ha⁻¹ applied in 1996 were 18% higher than for residual Si ($P \leq 0.006$), but no significant differences in yield were found between residual Si and the full rate of tricyclazole.

Content of Si in plant tissue. The interaction between rate of Si and rate of fungicide was not significant at either location; thus, Si content was averaged across all rates of fungicide for Si at rates of 0 and 1,000 kg ha⁻¹ (Table 6). At both Santa Rosa and La Libertad, Si content was higher in both leaf and stem tissue from plots treated with Si at 1,000 kg ha⁻¹ in 1996 compared with the nonamended control; the content of Si was 33 and 20% higher in leaf and stem tissue, respectively, from Santa Rosa, whereas Si content increased by 50 and 43% in leaf and stem tissue, respectively, from La Libertad.

Si content of leaf and stem tissue was higher in 1996 from samples taken from residual plots at both locations compared with the nonamended control ($P \leq 0.05$; Table 6). At both Santa Rosa and La Libertad, content of Si in leaf tissue was greater in samples collected from plots treated with Si in 1996 than in samples from residual plots. There was no significant difference in the content of Si in stem tissue between plots amended with Si in 1996 and residual plots at Santa Rosa ($P > 0.05$), whereas Si content in stem tissue was significantly higher for Si applied in 1996 compared with that applied in 1995. Si content of leaf tissue was 20% lower in samples from residual plots compared with plots treated with Si in 1996 at Santa Rosa. At La Libertad, Si content in leaf and stem tissue dropped by 33% residual plots compared with plots treated in 1996 with Si at 1,000 kg ha⁻¹.

DISCUSSION

The application of Si proved to be an effective means of reducing the severity of

Table 4. Effect of two rates of soil-applied silicon (Si) and four rates of fungicide on the yield of rough rice at Santa Rosa and La Libertad, Colombia, in 1995 and 1996

Si (kg ha ⁻¹)	Fungicide ^a	Rough rice yield (kg ha ⁻¹) ^b			
		Santa Rosa		La Libertad	
		1995	1996	1995	1996
0	0/0	1,713 d	2,284 d	1,797 b	2,633 b
0	100/30	2,070 bcd	2,769 cd	1,824 b	2,637 b
0	250/75	2,050 cd	2,777 cd	1,777 b	2,602 b
0	1,000/300	2,715 ab	2,932 bc	1,685 b	2,824 ab
1,000	0/0	2,627 abc	3,445 a	2,253 a	3,231 a
1,000	100/30	2,777 a	3,373 ab	2,250 a	3,167 a
1,000	250/75	2,565 abc	3,682 a	2,246 a	2,556 b
1,000	1,000/300	2,816 a	3,380 ab	2,154 a	2,922 ab

^b Rough rice = yield prior to milling. Comparisons of any two values in the same column do not differ significantly ($P \leq 0.05$) as determined by comparisons of least-squares means. Each value is the mean of five replications.

^a First value in pair is the rate of edifenphos (ml ha⁻¹) applied at tillering and panicle initiation; second value is the rate of tricyclazole (g ha⁻¹) applied at booting, 1% heading, and 50% heading stages.

Table 5. Residual effects of silicon (Si) applied to soil in 1995 at Santa Rosa and La Libertad, Colombia, on the severity of leaf blast, measured as the area under the disease progress curve (AUDPC), incidence of neck blast, and yield of rough rice in plots treated with Si and fungicides at full rates in 1996^b

Si (kg ha ⁻¹)		Fungicide ^z	AUDPC		Neck blast incidence (%)		Rough rice yield (kg ha ⁻¹)	
1995	1996	1996	Santa Rosa	La Libertad	Santa Rosa	La Libertad	Santa Rosa	La Libertad
1,000	0	0	2.2	0.5	43.0	5.0	3,042	2,734
0	0	0	4.3*	0.8*	72.2*	9.5*	2,284*	2,632
0	1,000	0	2.0	0.3	44.5	2.0*	3,444*	3,231*
0	0	EF-TZ	2.7	0.8*	12.2*	5.5	2,932	2,824
1,000	0	EF-TZ	1.9	0.2*	9.3*	1.5*	3,101	2,689
0	1,000	EF-TZ	1.4*	0.2*	6.3*	1.0*	3,380	2,921

^b Means followed by * differ significantly ($P \leq 0.05$) from means from plots treated with Si without edifenphos or tricyclazole in 1995.

^a EF = edifenphos applied at 1,000 ml ha⁻¹ at tillering and panicle initiation; TZ = tricyclazole applied at 300 g ha⁻¹ at booting, 1% heading, and 50% heading stages.

leaf and neck blast in upland rice in two distinct soil types in eastern Colombia in 1995 and 1996. The results of these studies represent the first attempts to utilize soil applications of Si to reduce the amount of fungicides needed to control leaf and neck blast in upland rice. Regardless of the rate of fungicide applied, the percentage of Si in leaf tissue collected during the leaf blast epidemic and stem tissue collected at harvest from Si-amended plots was significantly higher than in tissue from untreated plots at both locations. Because calcium was applied to nonamended controls at levels equal to Si-amended plots, it is likely that control of blast in this study was due to the accumulation of Si in plant tissue. This result is in agreement with a previous study by Datnoff et al. (8), who analyzed leaf samples from Si-amended plots and found no increase in calcium as the rate of calcium silicate was increased, whereas the level of Si in tissue did increase. In general, the percentage of Si in leaf and stem samples from nonamended controls at La Libertad was lower than their counterparts at Santa Rosa. The amount of plant-available Si in the soil at Santa Rosa was slightly higher level than at La Libertad; therefore, the accumulation of Si in leaf and stem tissue fertilized with Si at Santa Rosa was of a lesser magnitude than at the highly Si-deficient site at La Libertad.

The primary goal of this study was to determine whether Si could suppress leaf and neck blast as effectively as the recommended rates of two fungicides commonly used in Colombia and, if not, whether blast suppression could be enhanced by applying reduced rates of those fungicides in conjunction with Si. When compared with the fungicide edifenphos applied at full and reduced rates, Si reduced the AUDPC of leaf blast and the amount of disease to the same level as the recommended rate of edifenphos (1,000 ml ha⁻¹) at Santa Rosa in 1995, and provided better control of leaf blast than edifenphos at La Libertad in 1995 and 1996 and at Santa Rosa in 1996. Datnoff et al. (7) demonstrated that neck blast in Florida could be controlled as effectively with Si at 2,000 kg ha⁻¹ as with benomyl at 1.68 kg ha⁻¹. In the present study, Si at 1,000 kg ha⁻¹ significantly reduced the incidence of neck blast compared with nonamended controls at both locations in 1995 and 1996. However, only at La Libertad, in both years of the study, did the level of control equal or surpass that of the full rate of tricyclazole (300 g ha⁻¹) applied without Si.

Based upon the results of our study, it appears that the application of fungicides to control leaf blast in rice grown on Si-deficient soils could be eliminated by Si fertilizers, even in areas with high endemic levels of blast. In the case of neck blast, high levels of disease severity may require a higher rate of Si, or the addition of a

fungicide such as tricyclazole at a reduced rate. Studies conducted in Colombia in 1994 (23) showed that fungicides applied at specific timings, especially at booting and early heading stages, provided control of blast as well as full spray schedules consisting of five applications. Also, the application of Si at 400 kg ha⁻¹ proved to be insufficient for the control of neck blast under conditions of high severity of disease, compared with the excellent control of blast achieved in the current studies with Si at 1,000 kg ha⁻¹. Understanding of the Si level in the soil for a given area and the history of disease severity would permit the selection of the ideal rate of Si, along with the correct rate and application timing of fungicides, to manage blast more effectively.

As demonstrated previously, depending upon the location, the application of Si to Si-deficient soils increased yield 20 to 35% compared with the nonamended control (8–10,23,24,27–29). In the present study, yields from plots that had been treated with Si at 1,000 kg ha⁻¹ were either equal to or greater than yields from plots treated with recommended rates of edifenphos and tricyclazole. It appears possible to eliminate applications of fungicide entirely, so long as an adequate amount of Si fertilizer is employed on Si-deficient soils.

It is critical that larger quantities of Si are used if levels of leaf and neck blast severity are high. This is illustrated from results obtained in 1994, in which the application of Si at only 400 kg ha⁻¹, which was adequate for improvement of yields at a location with a low soil concentration of plant-available Si, did not increase yields where plant-available Si was higher (23). By raising the rate of Si in 1995 and 1996 to 1,000 kg ha⁻¹, yields surpassed nonamended and fungicide-treated plots.

Applications of Si made in 1995 were found to have significant residual activity against leaf and neck blast in 1996 at Santa Rosa and La Libertad, confirming a previous report (9). At both locations, the

AUDPC of leaf blast was significantly lower in residual plots (treated in 1995 with Si) than in nonamended plots, and did not differ significantly from AUDPC of blast from plots treated with Si in 1996. It was necessary to apply the full rate of tricyclazole to residual plots at Santa Rosa, and a 10% rate at La Libertad, as well as fresh applications of Si, to control neck blast. However, incidence of neck blast was still significantly lower in residual plots than in nonamended control plots at both locations. Sufficient activity of Si may have remained in residual plots at Santa Rosa and La Libertad to raise yields compared with controls, despite the better performance of applications of Si made in 1996. More importantly, yields from residual plots were not significantly different than yields from plots treated with the full rates of edifenphos and tricyclazole alone. Although yields were higher, by as much as 30%, where applications of Si were made, than in residual plots, the level of Si in soil 1 year after amendment with Si was adequate for disease control and yield enhancement.

In all cases, Si accumulation was greater in leaf and stem tissue collected from plots amended with Si in 1996 than in tissue from Si-residual plots, but the amount of Si in tissue from residual plots always was greater than the nonamended controls. The residual activity of Si observed for both soil types under the cultivation of upland rice suggests that it may be possible to avoid annual applications of Si fertilizer. The amount of Si applied in this study, 1,000 kg ha⁻¹, represents a significant input, in both volume and cost. In the upland rice-growing regions of Colombia, there are no readily available sources of Si. The application of Si on a 2-year (or longer) schedule would make the use of this material more attractive to growers, not only in Colombia but also in other regions where upland rice is grown. Further research is needed to determine the rate of decline of Si in soils following application, and the

Table 6. Content of silicon (Si) in leaf and stem tissue of rice collected in 1996 from plots amended with Si (1,000 kg ha⁻¹) in 1995 or 1996 at Santa Rosa and La Libertad, Colombia

Location, year of application	Si (kg ha ⁻¹)	1996 Si content (decagrams kg ⁻¹) ^z	
		Leaf	Stem
Santa Rosa			
1996	0	2.6 a	2.9 a
1996	1,000	3.9 b A	3.6 b A
1995	0	2.6 a	2.8 a
1995	1,000	3.2 b B	3.5 b A
La Libertad			
1996	0	1.9 a	1.8 a
1996	1,000	3.8 b A	3.2 b A
1995	0	2.2 a	1.7 a
1995	1,000	2.5 b B	2.0 b B

^z Mean Si concentrations in leaf or stem tissue collected from either Santa Rosa or La Libertad, Colombia, in 1996 from plots treated in either 1995 or 1996 followed by the same lowercase letter do not differ significantly ($P \leq 0.05$) as determined by *t* tests performed on least-squares means. For comparisons, within a given location, of Si concentration in tissue from residual (1995 application) and fresh (1996 application) plots, any two values followed by the same uppercase letter do not differ significantly ($P \leq 0.05$) as determined by individual comparisons of least squares means.

concomitant effects on disease and yield. Residual activity of Si could be supplemented with fungicides (possibly at reduced rates) or by periodic additions of calcium silicate or other sources of Si, such as crop residue, that would allow the optimal level of plant-available Si to be maintained in Si-deficient soils.

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