Effect of silicon sources on rice diseases and yield in the State of Tocantins, Brazil

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ABSTRACT. The intensity of rice diseases in regions with poor levels of silicates (Si) in the soil, together with high control costs, can make the cultivation of rice unfeasible. Surprisingly, there are scarce research data available regarding the influence of Si on rice diseases in tropical lowland regions. Therefore, the aim of this study is to determine the effect of three silicon sources on rice yield and disease management. Three experiments were carried out from December 2005 to April 2006 at an experimental field area located in Formoso do Araguaia, Tocantins state, Brazil. Each experiment consisted of one silicon source (powder, granular or liquid) and the treatments consisted of six Si doses. All the treatments were performed in a completely randomized block design. The data presented in this study provide evidence that Si applications in Si-deficient soils of lowland regions, depending on the application source, dose and disease intensity, can decrease the severity of brown spot and the incidence of panicle blast. Calcium silicate effectively reduced the brown spot and the panicle blast, which resulted in an increased rice yield. In contrast, Ca and Mg silicate and potassium silicate did not show an efficient control of rice diseases nor an increase in productivity.

Keywords: *Oryza sativa*, *Bipolaris oryzae*, *Magnaporthe oryzae*, silicate.

RESUMO. Efeito de fontes de silício sobre as doenças e produtividade do arroz no Estado do Tocantins, Brasil. A intensidade de doenças do arroz em regiões com solos pobres em silício, aliada aos altos custos de controle, podem inviabilizar economicamente o cultivo do arroz. Por existir poucas pesquisas avaliando a influência do silício nas doenças do arroz em regiões tropicais de terras baixas, esse estudo objetivou avaliar o efeito de três fontes de silício na produção e manejo de doenças do arroz. Três experimentos foram realizados entre dezembro de 2005 e abril de 2006, em um campo experimental localizado em Formoso do Araguaia, Estado do Tocantins, Brasil. Cada experimento consistiu da avaliação de um fator (fonte de silício em pó, granular ou líquido), conduzido em delineamento experimental de blocos inteiramente casualizados com seis níveis (doses de silício). Os resultados obtidos mostram que a aplicação de silício em solos deficientes desse elemento, em regiões de terras baixas, promove redução da severidade da mancha parda e a incidência da brusone das panículas, dependendo da fonte de silício, dose e pressão da doença. Silicato de Ca reduziu efetivamente a mancha parda e a brusone, resultando em aumento da produtividade. Entretanto, silicato de Ca e Mg e o silicato de potássio não mostraram eficiência no controle das doenças ou aumento da produtividade.

Palavras-chave: *Oryza sativa*, *Bipolaris oryzae*, *Magnaporthe oryzae*, silicato.

Introduction

There are several ecosystems and growing environments suitable for rice production throughout the world, both in upland and lowland settings. However, in certain areas of Asia, Africa, Central and South America, including Brazil, some soils are particularly poor in plant-available silicates (Si) (ALVAREZ; DATNOFF, 2001). Brazil is a major rice producing country with approximately three million hectares cultivated with rice in 2009 under upland and irrigated conditions (IBGE, 2007; RODRIGUES et al., 2003a).

In poor tropical regions, the high intensity of diseases may cause problems that make the rice production unfeasible. Brown spot (Bs), leaf blast (Lb), panicle blast (Pb) and other rice diseases cause considerable yield loss, in particular, in the state of Tocantins, Brazil (SANTOS et al., 2003a, b and c). The high incidence of diseases in this and other regions within Brazil is partially due to several

cultural practices such as early season planting, double cropping, high plant density per unit area and the choice of early-maturing, short-stature, high-tilling varieties (SANTOS et al., 2003b). The strategies for disease control are limited because the cultivars that have a significant level of resistance against such diseases do not sustain adequate levels of resistance over a period longer than two years (SANTOS et al., 2003b). Silicon has been implicated as a factor influencing the degree of plant resistance to biotic or abiotic stresses (EPSTEIN, 1999). Presumably, silicon accumulation on leaf surfaces, inside epidermal cell walls, middle lamellae and intercellular spaces might limit fungal penetration and invasion by acting as a physical barrier (KIM et al., 2002). Several studies demonstrated that Si-induced resistance in rice plants is not solely limited to a passive mechanical barrier, nor is it merely due to an induced defense as previously proposed (CAI et al., 2008). Pathogenicity data indicate that silicon absorption by susceptible cultivars can raise the level of resistance to that of a partially resistant cultivar grown without silicon treatment and with a similar control of leaf blast (KIM et al., 2002).

Among other practices, silicon fertilization may constitute an effective alternative for disease control in staple crops such as rice. In addition, when the silicon fertilization is applied before sowing or at different developmental stages of rice plants, it may decrease the number of fungicide applications over the entire crop cycle (KORNDÖRFER et al., 1999). Currently, ecologically sustainable practices are necessary to decrease the disease management costs and to protect the natural environment in irrigated, tropical lowlands such as the state of Tocantins in Brazil.

Since scarce research data is available regarding the influence of Si on rice diseases in tropical lowland regions, this study aimed to determine the effect of three Silicon sources on rice yield and disease management in flood-irrigated areas in the state of Tocantins, Brazil.

Material and methods

Three experiments were carried out from December 2005 to April 2006 at an experimental field area in Formoso do Araguaia, Tocantins State, Brazil (11°47'S, 49°41'W) located at an altitude of 197 masl. The soil type of the experimental area had hydrophobic characteristics (Haplic Gleisol). A soil analysis was performed before sowing and presented the following physicochemical properties: clay 20.9,

silt 20.0, and sand 59.1 (g kg^{-1} - texture); pH 5.2 (water); Ca 1.8, Mg 0.56, Al 0.1, H + Al 6.67 (cmol$_c$ dm^{-3} - determined in KCl 1 N); Si 5,0 (mg kg^{-3} – determined in KCl), P 28.2, K 66.0, Cu 0.8, Zn 1.6, Fe 57.0 and Mn 8.0 (mg dm^{-3} - determined in Mehlich 1 solution: HCl 0.5 N + H$_2$SO$_4$ 0.025 N).

The three experiments were located at a distance ranging from 50 to 70 m from each other. Each experiment was carried out in one plot of 6.0 m of length and 3.0 m of width, which gives an area of 18 m^2. Only one source of silicon was applied to each plot (powder, granular or liquid) and the treatments consisted of six Si doses. All the treatments were performed according to a completely randomized block design with four replicates. The total silicon content from each fertilizer was extracted with hydrochloric and hydrofluoric acids (FOX et al., 1969), and it was determined by the colorimetric method. Boric acid was used to inactivate any excess of hydrofluoric acid. The soluble silicon content was determined by solubilizing the fertilizer with sodium carbonate and ammonium nitrate. The three silicon source treatments were:

(A) Powder source: thirty days before sowing, calcium silicate was applied by casting distributing the following doses: 0.0 (control), 0.5, 1.0, 2.0, 4.0 and 6.0 ton. ha^{-1}, and it was incorporated at a depth of 0.10 to 0.15 m into the soil. Calcium silicate contained 12.8% of elemental silicon and 0.39% of available Si.

(B) Granular source: calcium and magnesium silicate were applied at the sowing time together with the fertilizer at the following doses: 0.0, 0.05, 0.1, 0.2, 0.4 and 0.6 ton. ha^{-1}. The silicon content in Ca and Mg silicate was 12.6% of total Si and 3.4% of available Si.

(C) Liquid source: potassium silicate (K$_2$SiO$_3$) was applied by direct leaf spray at the following doses: 0.0 (water control), 0.25, 0.5, 1.0, 1.5 and 2.5 L ha^{-1}. The application was done during two stages of the crop: thirty days after sowing and at the stage of initial booting. A 20 L knapsack sprayer was used to apply Si to the leaves with a volume rate of 300 L ha^{-1}. Potassium silicate presented 11.3% of total Si and 4.87% of available Si.

The rice cultivar SCS 112 was used because it is widely adopted in the region and is susceptible to blast rice and brown spot. The seeding density was 100 seeds linear^{-1} meter and 17 cm between ridges. The initial fertilization was performed by distributing the fertilizer (5-25-15 NPK, P$_2$O$_5$, K$_2$O) at a doses of 350 kg ha^{-1} in all the experimental plots. Twenty-five days after germination (DAG), the plots were flooded with a water level of 15 cm. Additional nitrogen was supplied 60 DAG by applying urea at doses of 100 kg ha^{-1}. Pre-

planting weed control was performed using glyphosate herbicide at a dose of 2.0 L ha^{-1}. During post-emergence, the weed control was performed with the herbicide Bispyribac at a dose of 120 mL ha^{-1}. There were no fungicide applications during the experiment.

The severity of brown spot (*Bipolaris oryzae*) on the flag leaf, the severity of leaf blast (*Magnaporthe oryzae*) and the incidence of blast on panicles were evaluated according to the plant disease scale of the Centro Internacional de Agricultura Tropical (CIAT, 1983). The brown spot severity was assessed by visual analysis in each plot. The leaf blast was evaluated at 40 DAG, and the panicle blast was assessed at the grain filling stage. The leaf blast severity was assessed by a grade scale from 0 to 9, where: 0 = healthy tissue; 1 <1% of affected tissue; 3 = 1 to 5% of affected tissue; 5 = 6 to 25% of affected tissue; 7 = 26 to 50% of affected tissue and 9 > 50% of affected tissue. Subsequently, we used the methodology developed by Santos et al. (2005) where each point of leaf blast severity was converted to percentage of affected leaf area through the mean value corresponding to each used point. This methodology is useful to graphically show the effect of Si on leaf blast severity. A survey of 200 panicles per plot was performed to determine the incidence of panicle blast. The ratio between the number of sick plants and the total number of surveyed plants in each plot was calculated.

The silicon content of soil and leaves was measured according to the methodology described by Korndörfer et al. (1999) and Rodrigues et al. (2003b), respectively. The silicon content of soil was assessed at the flowering stage in each replicate. The soil silicon was extracted with acetic acid. Subsequently, the content of available silicon was quantified with a colorimetric method. The analysis of silicon content in plants was also measured at the flowering stage. The silicon was extracted from plant leaves despite the organic matter oxidation (ELLIOTT; SNYDER, 1991). To assess the yield, grains were harvested in the four central lines of each plot to avoid border effects.

The data were analyzed with a regression analysis. Regression equations and determination coefficients were calculated (LITTLE; HILLS, 1978). Tests for linear correlation were performed between means of Si content in plant tissue, Si content in soil, disease severity (brown spot and leaf blast) and disease incidence (panicle blast). A test of linear correlation between the dose of Si and the yield means was also performed. All analyses were conducted using the ASSISTAT-Statistical Assistance Software (SILVA; AZEVEDO, 2009).

Results and discussion

Powder source

The severity of brown spot (Bs) and the incidence of panicle blast (Pb) significantly decreased with increasing doses of calcium silicate application (Figure 1). The increasing doses of powder source reduced the mean Bs severity from 20.6 to 2.4% and the mean Pb from 37.5 to 3.0% when compared with the control treatments without silicon. However, no significant reduction was observed in the leaf blast disease. The grain yield gradually and proportionally increased according to the increasing doses of Si application in the soil (Figure 2A). In addition, plants that received the largest doses of thermophosphate presented the highest amount of Si in their leaves. These results showed that a higher accumulation of Si positively influenced the control of brown spot and leaf blast as well as the rice productivity.
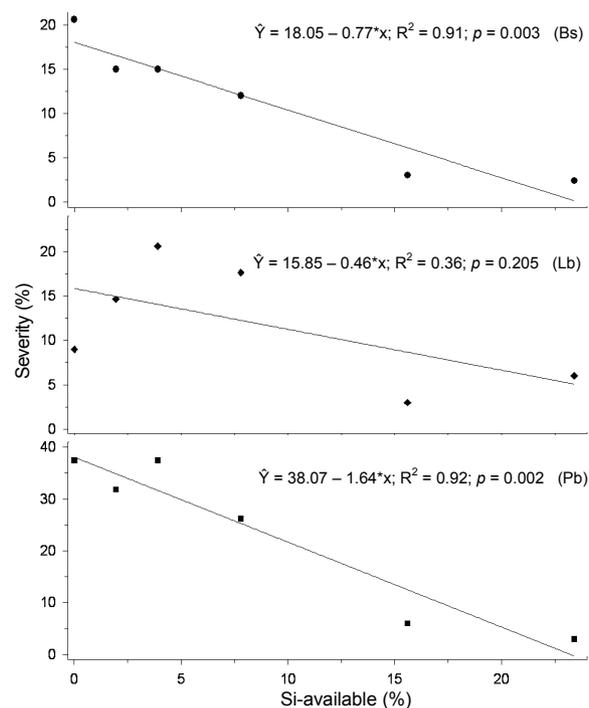

Figure 1. Brown spot (Bs) severity, leaf blast (Lb) severity and panicle blast (Pb) incidence in rice as a function of the increasing doses of calcium silicate (powder source).
**significant at 1% (p < 0.01); *significant at 5% (0.01 =< p < 0.05) and ns non-significant.

With the calcium silicate source, the severity of brown spot and the panicle blast incidence were negatively correlated (p < 0.01) with the content of silicon in the plants, while no significant correlations were found between Si content in plant or soil and leaf blast severity (Table 1).
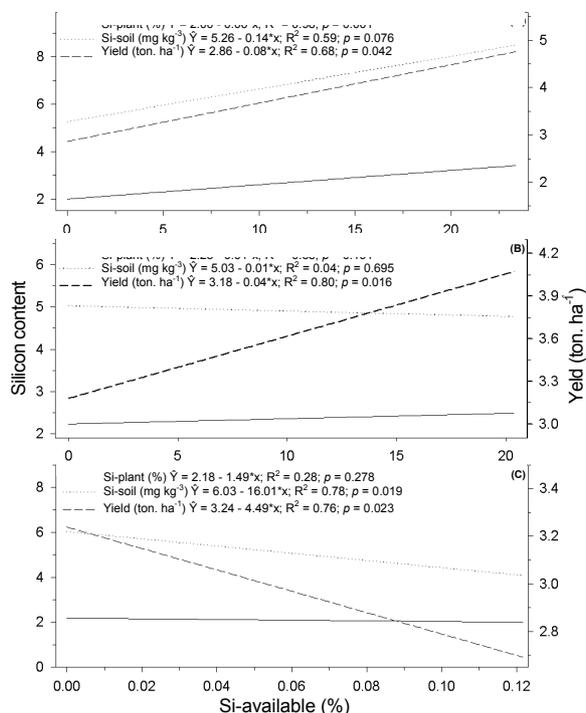
Figure 2. Rice grain yield (ton. ha^{-1}) and amount of Silicon in plant and soil according to increasing doses of (A) calcium silicate; (B) Ca and Mg silicate and (C) Potassium silicate.

A positive correlation ($0.01 < p < 0.05$) was found between Si content in plant and rice yield. The Si content in plant was more strongly correlated with brown spot severity and panicle blast incidence than the Si content in soil. The correlation between yield and all the diseases (brown spot, leaf blast and panicle blast) with the powder source was negative.

Granular source

Increasing doses of granular Ca and Mg silicate significantly decreased the panicle blast incidence from 37.5 to 2.4% (Figure 3). The severity of brown spot and leaf blast did not show a significant reduction.

The application of granular silicate in the soil significantly affected the rice yield because it increased from 3.1 to 4.0 ton. ha^{-1} (Figure 2B). The increasing amount of silicon in the plant tissues associated with a better control of panicle blast

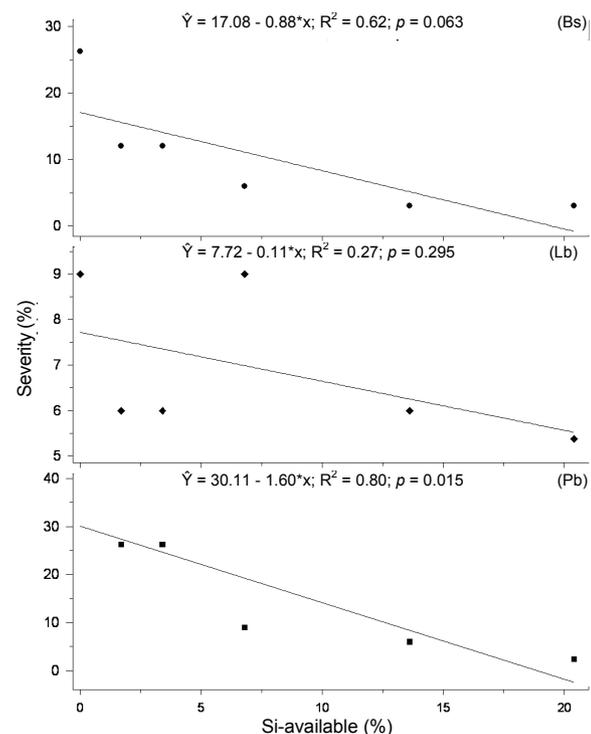probably contributed to the positive effect on crop productivity.

Figure 3. Brown spot severity, leaf blast severity and panicle blast incidence in rice as a function of increasing doses of calcium and magnesium silicate (granular source).

Correlations between diseases in rice and the Si content of both plant and soil were not found with Ca and Mg silicate (Table 1). Similarly, the productivity did not correlate with the Si content of both plant and soil. Moreover, no correlations between yield and brown spot, leaf blast or panicle blast were found.

Liquid source

Increasing doses of foliar applications of liquid potassium silicate were not efficient to decrease the severity of leaf blast (Figure 4). However, they significantly decreased the severity of brown spot and the incidence of panicle blast from 37.5 to 26.25%. The applied doses of liquid silicate did not affect the severity of leaf blast and the grain yield (Figure 2C).

Table 1. Pearson correlation coefficients for brown spot severity (Bs), leaf blast severity (Lb), panicle blast incidence (Pb) and rice yield vs. Si content (plant and soil) with powder, granular and liquid source applications.

	Silicon source								
	Powder			Granular			Liquid		
	Si soil	Si plant	Yield	Si soil	Si plant	Yield	Si soil	Si plant	Yield
%	corr	corr	corr	corr	corr	corr	corr	corr	corr
Bs	-0.75[ns]	-0.94**	-0.91*	0.54[ns]	-0.38[ns]	-0.74[ns]	-0.79[ns]	-0.54[ns]	-0.76[ns]
Lb	-0.32[ns]	-0.67[ns]	-0.75[ns]	0.64[ns]	-0.06[ns]	-0.54[ns]	-0.60[ns]	-0.28[ns]	-0.20[ns]
Pb	-0.74[ns]	-0.97**	-0.92**	0.33[ns]	-0.55[ns]	-0.80[ns]	-0.73[ns]	-0.65[ns]	-0.87*
Yield	0.72[ns]	0.85*	-	-0.12[ns]	0.27[ns]	-	0.76[ns]	0.27[ns]	-

**significant at 1% ($p < 0.01$); *significant at 5% ($0.01 =< p < 0.05$); [ns]non-significant.

Nevertheless, the external presence of silicon from the application of potassium silicate to the leaves probably inhibited the infection by the pathogen.
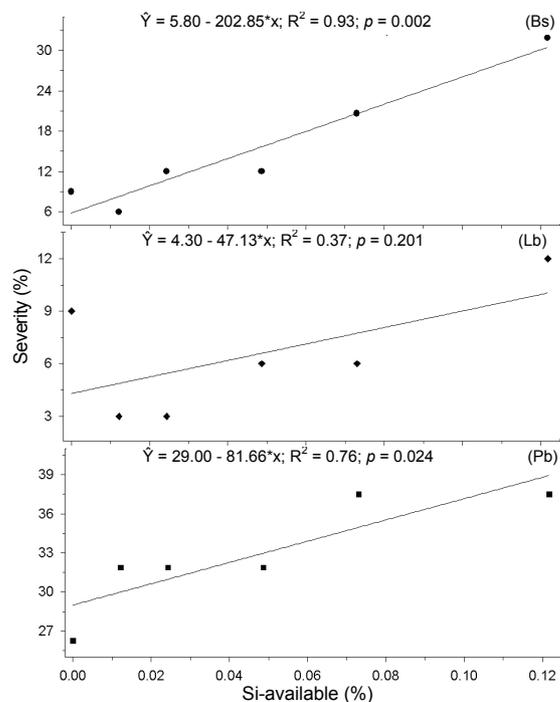

Figure 4. Brown spot severity, leaf blast severity and panicle blast incidence in rice as a function of increasing doses of potassium silicate (liquid source).

All the diseases were not correlated with the Si content of plants and soil in the liquid source treatment (Table 1). The yield was not correlated with the Si content of plant and soil either. The yield and panicle blast were negatively correlated ($0.01 < p < 0.05$), while the severity of brown spot and the incidence of leaf blast were not correlated with yield.

The data presented in this study provide evidence that Si applications to Si-deficient soils in lowland regions decreased the severity of brown spot and the incidence of panicle blast depending on the application source, dose and disease severity. Although previous studies reported a positive effect of Si on the control of leaf blast in rice (SANTOS et al., 2003b and c), the present work showed that the application of Si did not control the diseases mentioned above. The rice yield positively responded to the reduction in brown spot and panicle blast infections due the calcium silicate application. In contrast, the tested doses of Ca and Mg silicate and potassium silicate doses did not efficiently control the rice diseases and did not enhance the productivity.

Previous reports have evidenced that Si fertilizer applied to Si-deficient soils reduced the intensity of brown spot, leaf blast and panicle blast as well as increased the rice productivity (SANTOS et al., 2003a, b and c; SEEBOLD et al., 2000). Santos et al. (2003a) showed that calcium silicate powder reduced the panicle blast severity and increased the rice yield by 33% compared to the untreated control. Santos et al. (2003b) showed that increasing doses of metasilicate resulted in an increased productivity of irrigated rice. However, Tokura et al. (2007) and Reis et al. (2008) observed that, when Si was applied without incidence of diseases, there was no significant effect on the rice productivity.

The mechanism of Si-induced resistance in rice has been attributed to the formation of a silicate epidermal cell layer (KUMAR et al., 2007; UENO et al., 2004). This layer is believed to prevent physical penetration and to make the plant cell walls less susceptible to enzyme degradation by fungal pathogens. Therefore, we believe that a similar mechanism may have occurred in our study system, which blocked the access of *Bipolaris oryzae* and *Magnaporthe oryzae* into the leaves. The evaluation of leaf blast, according to the methodology adopted in this study (CIAT, 1983), occurred at 40 DAG. However, at this time, the disease was more intense and the assimilation of Si was still not significant. According to Seebold et al. (2000), higher inherent severity of disease at specifics sites may require larger amounts of Si fertilizer to effectively reduce the leaf and neck blast. On the other hand, the evaluation of brown spot and panicle blast occurred in an area next to a rice field; thus, the intensity of both diseases was higher and the Si-assimilation was not enough to block the access of these fungi into the leaves.

When applied to the leaves, the liquid source of silicon did not result in significant foliar absorption and was not efficient in the control of brown spot, leaf blast and panicle blast nor did it result in significant increase of rice production. However, in the case of panicle blast, this study showed a decrease of this disease and an increase of the rice yield when liquid Si was applied. Therefore, the results of our study suggest that Si application could be a useful tactic for disease managing in rice. Furthermore, this strategy may address the current need of reducing the doses of fungicide application and may provide an alternative to rice growers in areas where blast-resistant cultivars have become susceptible due to shifts in the *M. oryzae* populations.

Conclusion

Calcium silicate sources can be used successfully in the integrated management of brown spot and panicle blast in flood-irrigated areas of tropical lowland regions. Depending upon the source and dose of Si fertilizer applied to Si-deficient soils, the severity and incidence of these diseases can be reduced and the yield increase.

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