Original Article

# SILICON FERTILIZATION IMPROVE YIELD AND QUALITY OF RICE AND PEARL MILLET IN CERRADO SOILS

## *ADUBAÇÃO SILICATADA AUMENTA A PRODUTIVIDADE E QUALIDADE DE ARROZ E MILHETO EM SOLOS DO CERRADO*

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**ABSTRACT:** Although silicon (Si) fertilization in rice (*Oryza sativa*) plants have already been studied, most of the Brazilian studies have focused on the acidity correction effects of sources and the application rate, but not on Si supply. Moreover, beneficial effects are rarely linked to other Si-accumulation plants such as pearl millet (*Pennisetum glaucum*), which is extensively grown in low soluble Si of Cerrado soils. The objective of this study was to evaluate the Si sources and application rates on the yield and quality of two commonly cultivated grain crops (rice and pearl millet) in Cerrado soils. The experiments were conducted on two crops (rice and pearl millet) and two soil types (Rhodic Haplustox-LV and Quartzipsamment-RQ) in a completely randomized factorial scheme with four replicates, four Si rates (0; 200; 400, and 800 kg ha$^{-1}$ Si); and three sources (calcium and magnesium silicate, wollastonite, and silicic acid). All plots receiv**ed** the same quantities of Ca and Mg to equilibrate these levels in both soils. Ca and Mg silicate and wollastonite produced linear increases in soluble Si (0.5 mol L$^{-1}$ acetic acid), in LV, RQ, and in Si uptake by rice and pearl millet. Increases in shoot dry weight were observed in rice and pearl millet from maximum rates of 542, 550 and 480 kg ha$^{-1}$ Si in RQ, respectively. Ca and Mg silicate levels were higher than wollastonite in the dry weight of both plants.

**KEY WORDS**: Fertilization. Silicate. Graminea. Soil.

## INTRODUCTION

Several benefits of Si have already been known, although it is not considered to be an essential element for the plants. For rice, which is a Si-accumulation plant (EPSTEIN, 2009), it can lead to an increase in photosynthetic activity, yield (CARVALHO-PUPPATTO et al., 2004; DETMANN et al., 2012), number of grains per panicle (MARCHESAN et al., 2004), quality (MAUAD et al., 2003), tolerance to drought (CHEN et al., 2011), pests (RANGANATHAN et al., 2006; HOSSEIN et al., 2011), and diseases (TATAGIBA et al., 2014).

The area under the Cerrado vegetation in the central region of Brazil occupies 23% of the area, showing great potential to grain yield and grain-producing grasses. However, several classes of soils are highly weathered, with low pH and nutrients and Si levels in soil (LOPES, 1996; PEREIRA 2004). In addition, the successive cultivation of graminea with a high Si uptake could reduce the soluble Si levels in soils, which are lower than in temperate countries (Mc KEAGUE; CLINE 1963; FOY, 1992). It could be necessary to provide Si fertilization to these soils to improve grain crop yields.

The intensity of the response to Si fertilization depends on the levels in soils, sources and application rates. A Si content of less than 9.8 and 13 mg dm$^{-3}$ soluble in 0.5 mol L$^{-1}$ acetic acid is considered responsive to the application of this element for rice yield (KORNDÖRFER et al., 1999; BARBOSA FILHO et al., 2001). Those levels are specially found in sandy and loamy sandy soils. Slags are the least expensive and most used Si source used in Brazilian agriculture. Enormous quantities of slags are generated from the steel and iron processing by industries every year.The utilization of this material for agriculture could reduce the environmental problems because larger areas are necessary for its deposition and storage. However, it is important to know the solubility of the slag in soil in order to provide Si to plants, once Si availability to plants depends on the origin and grain size (PEREIRA et al., 2004, 2010). Regarding the application of Si rates, values lower than 960 kg ha$^{-1}$ of Si are generally used in rice studies (KORNDÖRFER et al., 1999; MAUAD et al., 2003; BARBOSA FILHO et al., 2004).

Several studies conducted have shown positive results of Si fertilization in rice plants in Brazil. However, they focused on the evaluation of

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the acidity correction and Ca, Mg, and Si supply under field conditions (BARBOSA FILHO et al., 2001; KORNDÖRFER et al.,2001; CARVALHO-PUPPATTO et al.,2003) and pots (PEREIRA et al.,2004; KORNDORFER et al., 1999; CAMARGO et al., 2007b) and only a few studies (RAMOS et al., 2008) have evaluated the benefits of Si supply for the rice crops on its uptake, yield and quality without the additional effects (increasing on pH and Ca and Mg content in soils) of silicate applied in tropical soils. The Ca and Mg levels in soil had to be used in the same quantities when different silicate rates were applied in soil, as already done in incubation studies of Si sources and rates (CAMARGO et al., 2007a; PEREIRA et al., 2007, 2010).

In addition, the beneficial effects of various Si sources and application rates are rarely linked to other Si-accumulation plants such as the pearl millet (Epstein, 2009). This crop is important to the Cerrado region due to the fact that its utilization as non-tillage and animal feeding (RODRIGUES et al., 2001) and its cultivation area have increased in the last decade. Although the Si contents in the leaves of pearl millet are lower than those observed in the leaves of rice plants (MITANI; MA, 2005), positive results on the reduction of mildew severity, which is an important disease of this crop, have already been observed when Si was applied (DEEPAK et al., 2008). Silicon fertilization could improve yield and quality of grains for the pearl millet, as shown in the literature of the rice crops.

Considering the low soluble Si levels in soils under the Cerrado region, and high uptake by the grain crops, studies about the potential benefits of silicon supply are necessary. The objective of this study was to evaluate the Si sources and application rates on yield and quality of rice and pearl millet (two commonly cultivated crops) in the Cerrado soils.

## MATERIAL AND METHODS

Four experiments were conducted in greenhouses at the Center for Nuclear Energy in Agriculture/USP, Piracicaba, SP (22 º 42 ' 30 " LS e 47 º 38 ' 00 " LW), São Paulo state from October, 2002 to March, 2002. The experiments were entirely randomized with four replicates comprising four silicon application rates (0, 200, 400 and 800 kg Si $ha^{-1}$), three sources: calcium and magnesium silicate (24.2% Si, 29.5% Ca, and1.1% Mg), wollastonite (12% Si, 28% Ca, and 7% Mg) and pure silicic acid (29% Si). These treatments were applied to two crops (rice and millet) and two soil types (Rhodic Haplustox-LV and Typic Quartzipsamment-RQ). Ca and Mg were added to all pots in order to balance levels throughout all treatments.

Soil chemical analysis of RQ (660 g $kg^{-1}$ sand, 60 g $kg^{-1}$ silt and 280 g $kg^{-1}$ clay) revealed: pH($CaCl_2$)=3.9, Si (0.5 mol $L^{-1}$acetic acid)=2.0; OM=29 g $dm^{-3}$; P anionic exchange resin=1 mg $dm^{-3}$; K,Ca, Mg, and cation exchange capacity (CEC) =2.6, 13, 4 and 83.6 $mmol_c$ $dm^{-3}$, basis saturation (V) and Al saturation (m)=3.8 and 23%. Chemical analysis of LV (880 g $kg^{-1}$sand, 20 g $kg^{-1}$ silt, and 100 g $kg^{-1}$clay) revealed: pH($CaCl_2$)=4.1, Si (0.5 mol $L^{-1}$acetic acid)=3.0; OM=30 g $dm^{-3}$; P anionic exchange resin =4 mg $dm^{-3}$; K,Ca, Mg, and CEC =2.7; 8. 3 and 60.7 $mmol_c$ $dm^{-3}$, V and m=7.5 and 23%.

Soil samples of 0-20 cm depth were collected from uncultivated areas to avoid the influence of prior fertilization. The samples were air dried and passed through a five mm sieve and placed in five liter pots. To standardize particle size, the silicon sources were passed through a sieve 20 (ABNT) yielding particle sizes between 0.30 and 0.84 mm. Thirty days before planting, the silicon sources were thoroughly mixed in the pots with fertilizer (200 mg $kg^{-1}$ N, 200 mg $kg^{-1}$ P and 150 mg $kg^{-1}$ K) to meet the nutritional needs of the crops.

Ten seeds were sown in each pot for both rice (cultivar IAC 202) and pearl millet (cultivar BN 12). After formation of the third leaf, the pots were thinned to three plants each. Pots were irrigated every 2 days with deionized water, according to water loss by weight in order to maintain 80% of water-holding capacity.

Plant material was collected at 140 days after rice sowing and 120 days after pearl millet sowing and separated into shoots (stems and leaves), roots and spikelets and grains. The number of voids to rice plants was also counted. After drying in a forced air oven at 65º C, the dry weight of shoots, roots and grain and absorbed Si were measured (ELLIOT;SNYDER, 1991). Homogeneous soil samples were taken before planting and after harvest in order to to evaluate the concentration of soluble Si in 0.05 mol $L^{-1}$ acetic acid (KORNDÖRFER et al., 1999).

Resulting data were tested by analysis of variance (ANOVA) and F test. Silicon sources were compared by the Tukey test at 5% of probability and the application rates were evaluated by polynomial regression analysis.

## RESULTS AND DISCUSSION

After 30 days of incubation, wollastonite and Ca and Mg silicate applications linearly increased soluble Si content in soil (Figures 1 and 2). These results confirm that the materials were reactive, given that Si was available for rice and pearl millet since sowing. Silicic acid was not reactive due to its low solubility, which was confirmed by Benedito (2004) and Camargo et al.(2007a).

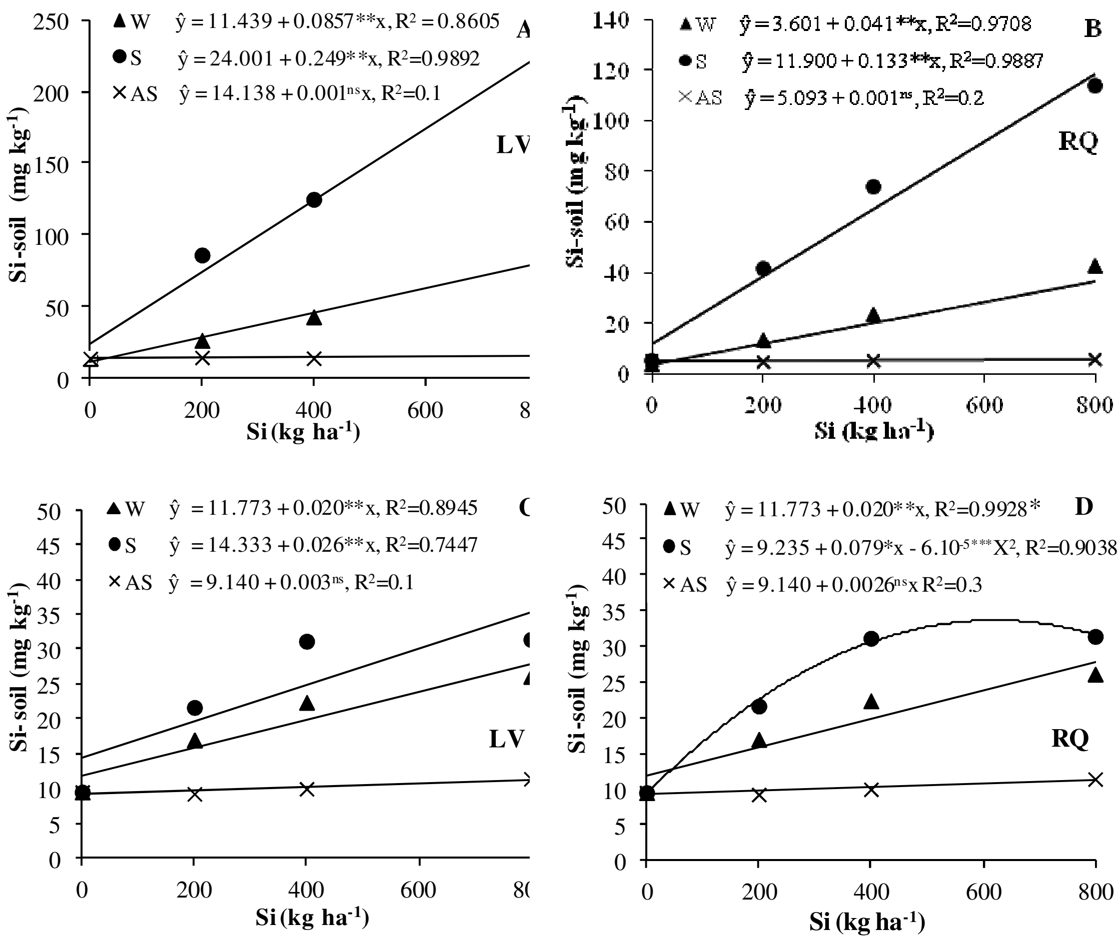


**Figure 1.** Soluble Si in 0.5 mol $L^{-1}$ acetic acid of soil samples collected before (A,B) and after (C, D) harvesting of rice grown on a Typic Quartzipsament (RQ) and a Rhodic Haplustox (LV) as a function of the Si application rate of wollastonite (W, ▲), Ca-Mg silicate (S, ●) and silica acid (AS, ×).Significant (*) and non significant (ns) by the F test ($p < 0.05$).

Soluble Si content was greater in LV than in RQ (Figures 1 and 2), and was classified as medium and low, respectively (KORNDÖRFER et al., 2001). Higher values for the loamy sandy soil make sense given its higher clay content which is a source of soluble Si, in agreement with Raij;Camargo (1973), Camargo et al., (2007a), Camargo et al. (2007b), and Pereira et al.(2010).

Silicate applied at a rate of 800 kg Si $ha^{-1}$ in RQ and LV soils, increased Si soluble in soil linearly by 5 and 6 times, respectively, compared to the control. Higher Ca silicate values can be attributed to the high capacity of 0.5 mol $L^{-1}$ acetic acid to solubilize Si from silicate, which was not observed for wollastonite (PEREIRA et al., 2004; CAMARGO et al., 2007 b).

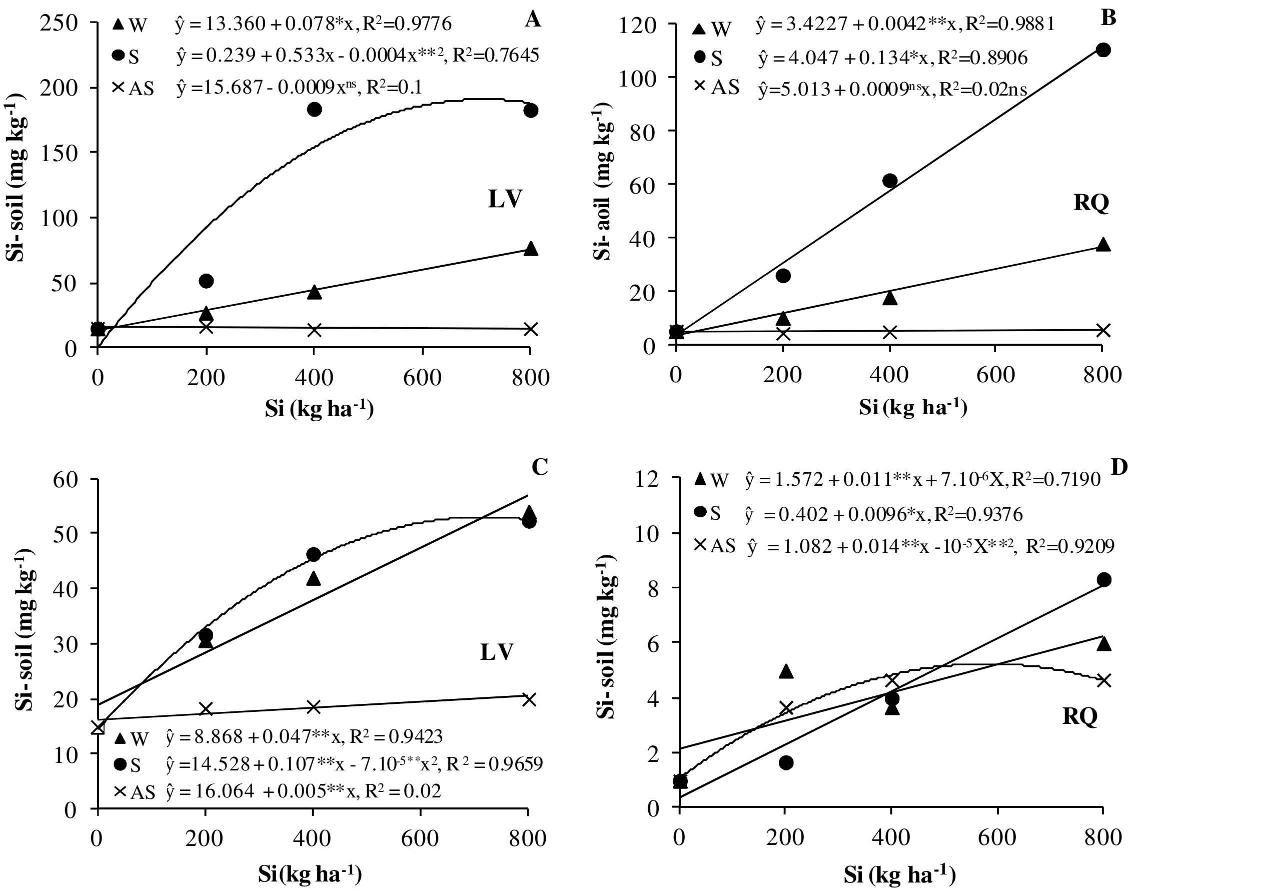


**Figure 2.** Soluble Si in 0.5 mol $L^{-1}$ acetic acid of soil samples collected before (A,B) and after (C, D) harvesting of pearl millet grown on a Typic Quartzipsament (RQ) and a Rhodic Haplustox (LV) as a function of the Si application rate of wollastonite (W, ▲), Ca-Mg silicate (S, ●) and silica acid (AS, ×).Significant (*) and non significant (ns) by the F test ($p < 0.05$).

The pH increase with silicate and wollastonite application rates after the harvest of rice and pearl millet was in the range 4.4-5.6, which could lead to an overestimation of the soluble Si in soils. However, the increased soluble Si in soil (Figures 1 and 2) was reflected in the shoot dry weight of the two cultures in RQ (Figure 3C, 3F) as well as in the rice grain dry weight (Figure 3B). Because Ca and Mg levels were balanced in all plots, the results obtained can be attributed to the applied Si that was absorbed by the plants (Figure 3 D, G, and H). This is also evidenced by the lower Si content in both soils after harvesting the rice and pearl millet (Figures 1C, 1 D, 2C, 2D). Si rates applications of 400 kg $ha^{-1}$ Si, 500 kg $ha^{-1}$ Si and 935 kg $ha^{-1}$ Si have already increased grain weight (MAUAD et al., 2003; RAMOS et al., 2008), shoot dry weight (PEREIRA et al., 2004) and grain yield (BARBOSA FILHO et al., 2004), respectively.

Reductions in transpiration and increases in photosynthetic activity (Epstein, 2009), although not evaluated here, may have contributed to the increases in plant dry matter observed in this study.

Silicate and wollastonite rates increased Si uptake linearly in shoot dry weight in rice plants. These results are in agreement with experiments conducted in pots using 400 kg $ha^{-1}$ Si (silicate) in flooding rice (RAMOS et al., 2008), and 500 kg $ha^{-1}$ Si (wollastonite) in upland rice (PEREIRA et al., 2007). Although increases on Si uptake by rice were linear up to 800 kg $ha^{-1}$ Si, the maximum grain and shoot dry weight production was obtained in RQ with rates of 542 and 550 kg $ha^{-1}$ Si, respectively (Figure 3B and C). This could be explained by the higher Si uptake by shoots compared to grains. Lower Si rates used in other studies provided only increases in Si uptake and grain, but not in shoot dry weight (MAUAD et al.,2003; RAMOS et al., 2008). For the pearl millet, a lower rate (480 kg $ha^{-1}$) provided the maximum shoot dry weight (Figure 3 B). Si rates linearly increased root dry weight (Figure 3E) and Si uptake by shoots (Figure 3G, H) but it was lower to Si uptake by rice (Figure 3D). Ca and Mg silicate also produced greater rice and pearl millet root mass in both soils (Table 1) due to the higher Si content from this source.

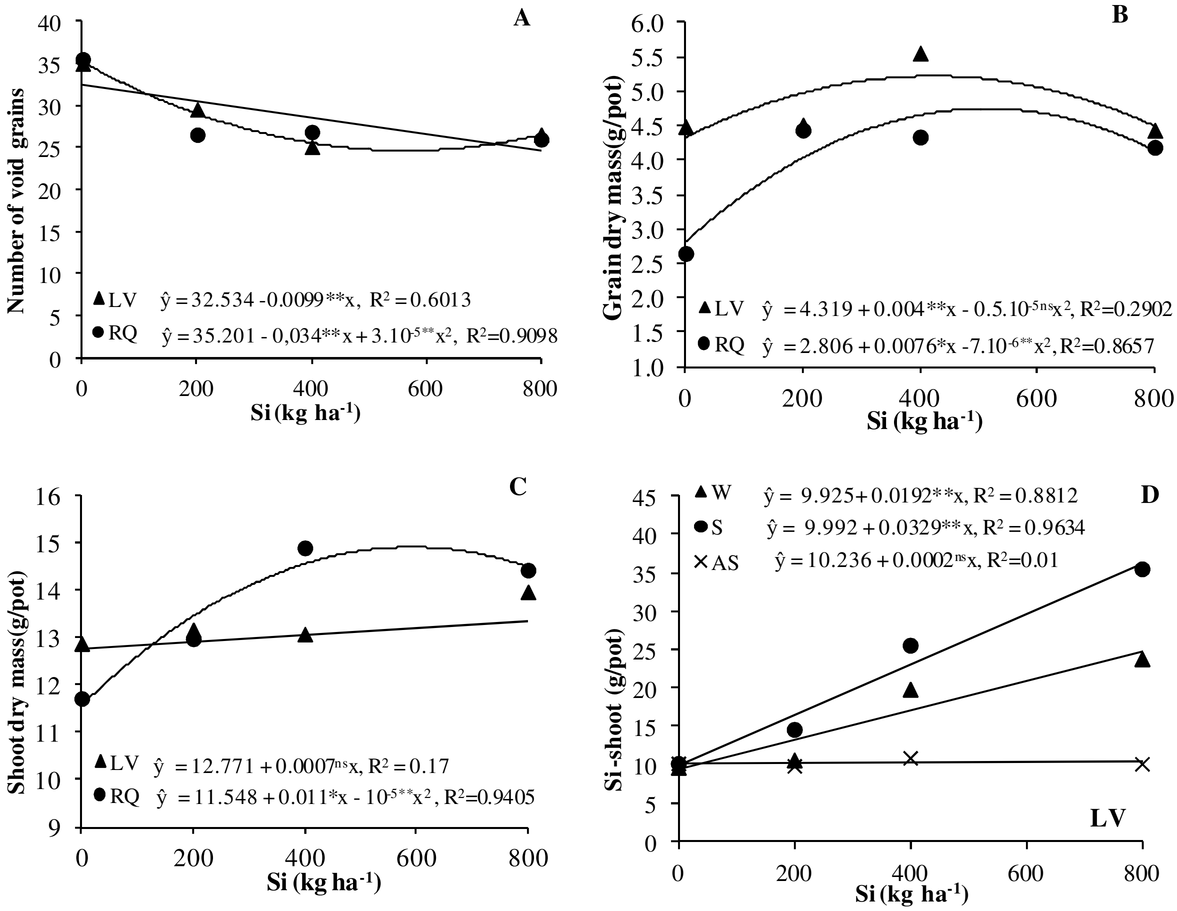


**Figure 3.** Number of grain void, grain and shoot dry weight, Si by uptake by rice (A-D) grown in Rhodic Haplustox (LV) and Quartzipsament (RQ) with Si rates application of wollastonite (W, ▲), Ca-Mg silicate (S, ●) and silica acid (AS, ×).Significant (*) and non significant (ns) by the F test ($p < 0.05$).

Differences were also not observed among Si sources (Table 1). This could be related to its higher soluble Si content compare to RQ soil (KORNDÖRFER et al., 2001) and consequent lower capacity to respond to Si amendments.

**Table 1.** Dry weight of grain (G), shoot(H), root ® of rice and pearl millet grown in Rhodic Haplustox (LV) and Quartzipsament (RQ) with Si rates application of wollastonite (W), Ca-Mg silicate (S) and silicic acid (AS).

| Si | Rice (g) | | | | | | Pearl Millet (g) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | LV | | | RQ | | | LV | | | RQ | | |
| | G | H | R | G | H | R | G | H | R | G | H | R |
| W | 4.5ns | 13.3ns | 7.78a | 3.7ab | 12.5b | 7.6ab | 3.1ab | 14.7ns | 6.24b | 2.4ns | 14.6a | 7.8b |
| S | 4.9ns | 14.2ns | 8.49a | 4.4a | 14.4a | 10.7a | 3.6a | 15.0ns | 6.7a | 3.1ns | 14.4a | 8.6a |
| AS | 4.8ns | 13.1ns | 6.71b | 3.5b | 12.7b | 6.7b | 2.8b | 12.9ns | 5.4b | 2.5ns | 12.8b | 7.4b |
| **MSD** | **-----** | **1.4** | **0.96** | **0.8** | **-----** | **2.4** | **0.6** | **2.1** | **0.9** | **-----** | **1.2** | **7.4** |

W=wollastonite, S= calcium and magnesium silicate, AS=silicic acid; G=grain, H=shoot, R=root. Minimum Significant Difference(MSD): means followed by the same letter in the column did not differ by Tukey´s test ($p<0.05$). ns=non-significant; * significant at a 5% significance level.

LV soil did not significantly influence Si uptake or shoot dry weight of rice and pearl millet.

The number of rice grain voids decreased with the Si applied in both soils (Figure 4 A), accompanied by an increase in grain mass (Figure 4 B). Grain void (x) reduction was a consequence of increased silicon uptake in shoots (y) in RQ ($y = 32.822 - 0.857\ X$, $R^2 = 0.42$*) and LV ($y = 33.029 =- 0.886\ X$, $R^2 = 0.35$*). This benefit has already been shown by Mauad et al.(2003) and Barbosa

Filho et al.(2004) for the rice plants, but the present study showed the direct effect of Si without the influence of an increase in pH or Ca, Mg contents in the soil.

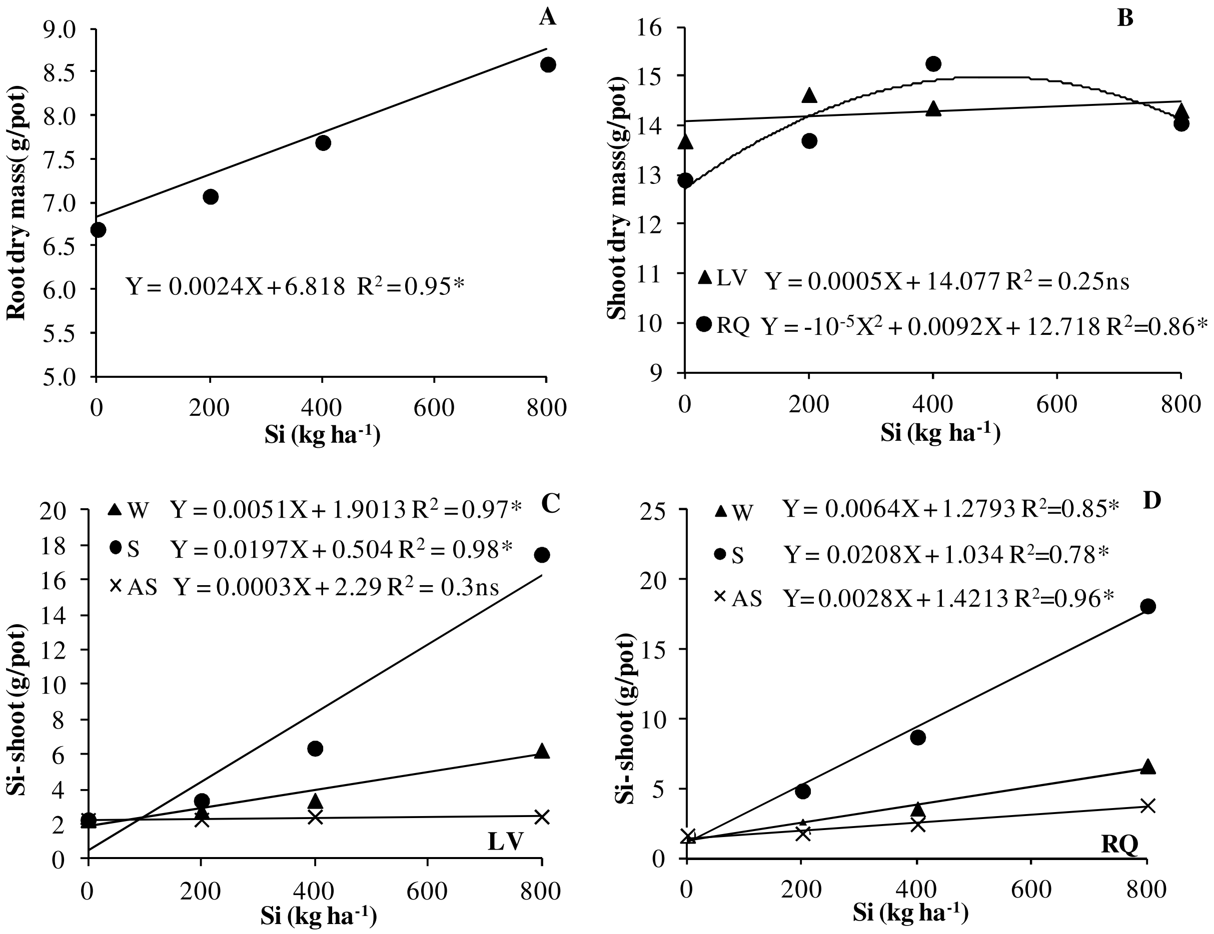


**Figure 4.** Shoot dry weight of pearl millet (A-D) grown in a Rhodic Haplustox (LV) and a Typic Quartzipsament (RQ) with Si rates application of wollastonite (W, ▲), Ca-Mg silicate (S, ●) and silica acid (AS, ×).Significant (*) and non significant (ns) by the F test ($p < 0.05$).

The decrease in rice grain voids can be explained by Si deposition in the rice hull which arose from intense transpiration from the panicle during grain growth (EPSTEIN, 2009). Although no change in shoot dry weight and grain in LV was observed, the Si uptake increased quality, having probably consumed more Si than necessary for the rice grown in this soil.

## CONCLUSIONS

The application of calcium and magnesium silicate and wollastonite led to linear increases in the levels of soluble silicon in Rhodic Haplustox and Quartzipsamment soils and a silicon uptake in the shoots of rice and pearl millet under greenhouse conditions. Maximum rates of Si 542, 550 and 480 kg ha$^{-1}$ in RQ soil provided maximum grain yield, shoot dry matter of rice and pearl millet, respectively.

The grain void in rice plants was linearly reduced with Si application rates and Si uptake.

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**RESUMO:** Embora já tenha sido estudada a adubação silicatada em arroz, a maioria dos estudos brasileiros tem focado nos efeitos da correção da acidez de fontes e doses aplicadas e não no fornecimento de Si. Aliado a isso, os efeitos benéficos são raramente associados a outras plantas acumuladoras como o milheto, que é intensamente cultivado nos solos com baixo Si solúvel da região do Cerrado. O objetivo desse trabalho foi avaliar fontes e doses de silício na produção e qualidade de duas culturas comumente cultivadas (arroz e milheto) em solos de cerrado. Os experimentos foram conduzidos em duas culturas (arroz e milheto) e dois solos (Neossolo Quartzarênico-RQ e Latossolo Vermelho-Amarelo-LV) em um delineamento inteiramente casualizado composto de quatro doses de silício equivalentes a 0; 200; 400 e 800 kg ha$^{-1}$Si, três fontes (silicato de cálcio e magnésio-S; wollastonita-W; ácido silícico-AS) e quatro repetições. Os tratamentos receberam a mesma quantidade de Ca e Mg para equilibrar as quantidades desses nutrientes dos solos. O silicato e a wollastonita aumentaram linearmente o Si solúvel em ácido acético 0,5 mol L$^{-1}$ no LV e no RQ e a absorção pela parte aérea do arroz e milheto. Silicato de cálcio e magnésio e a wollastonita aumentaram linearmente o Si solúvel no solo e a absorção de Si pelo arroz e milheto. Máxima produção de grãos e massa seca da parte aérea do arroz e milheto foram obtidas com doses de 542, 550 e 480 kg ha$^{-1}$ no RQ, respectivamente. As doses de Si proporcionaram redução do número de grãos chochos e aumento na absorção de Si pela parte aérea. O silicato proporcionou maior produção de massa seca comparada a wollastonita nas duas culturas.

**PALAVRAS-CHAVE**: Adubação. Silicato. Gramíneas.Solo.

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