SILICON ACCUMULATION AND WATER DEFICIT TOLERANCE IN *Brachiaria* GRASSES

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ABSTRACT: The beneficial effects of silicon (Si) fertilization have been observed for several plant species, especially when submitted to stress, either biotic or abiotic. Among the possible reasons for the greater adaptability and resistance of brachiaria grass in areas of low fertility soils in Brazilian savanna, stands its capacity of absorbing and accumulating Si in aerial parts. To evaluate the effect of Si on dry matter yield of *Brachiaria decumbens* Stapf and *Brachiaria brizantha* Hochst, grown under two soil moisture regimes, a trial was set up in a completely randomized design factorial scheme (5 × 2 × 2), with five Si rates: (0; 242; 484; 968 and 1,452 kg ha^{-1}), two soil water tensions (60% and 80% of field capacity) and the two brachiaria species. The experiment was installed in a greenhouse, using one of the most representative soils in the region under cerrado, Typic Haplustox. Both brachiaria species can be considered Si-accumulating plants, since they present high Si contents in their aerial parts. Application of Si to the soil increased the contents of this element in both grass species but did not change their tolerance to water deficit, and did not affect dry matter yield.
Key words: calcium silicate, pasture, water stress, soil moisture

ACÚMULO DE SILÍCIO E TOLERÂNCIA AO DÉFICIT HÍDRICO EM CAPINS DO GÊNERO *Brachiaria*

RESUMO: Efeitos benéficos da adubação com silício (Si) têm sido observados em várias espécies vegetais, especialmente quando estas estão submetidas a estresse biótico ou abiótico. Entre as possíveis razões para a maior adaptabilidade e resistência do capim braquiária nas áreas de baixa fertilidade do solo das regiões do cerrado brasileiro, esta associada à sua capacidade em absorver e acumular Si na parte aérea. Este trabalho teve como objetivo avaliar o efeito da aplicação de Si sobre a produção de matéria seca de duas espécies das gramíneas *Brachiaria decumbens* Stapf e *Brachiaria brizantha* Hochst, cultivadas sob dois regimes de umidade no solo. Os ensaios foram instalados em delineamento inteiramente casualizado, em esquema fatorial (5 × 2 × 2) com cinco doses de Si (0, 242, 484, 968 e 1452 kg ha^{-1}), duas tensões de água no solo (60% e 80% da capacidade de campo) e as duas espécies de braquiária. O experimento foi instalado em casa-de-vegetação, utilizando um dos mais representativos solos da região sob cerrado, Latossolo Vermelho-Amarelo. As duas espécies de braquiária podem ser consideradas plantas acumuladoras de Si, por apresentarem altos teores de Si na parte aérea. A aplicação de Si no solo aumentou os teores deste elemento nas duas espécies de gramíneas testadas, mas não modificou a tolerância das duas gramíneas ao déficit hídrico, e não afetou a produção de matéria seca.
Palavras-chave: silicato de cálcio, pastagem, estresse, umidade do solo

INTRODUCTION

Silicon (Si) has received little attention from plant nutrition scientists, most likely because it is not included in the group of elements considered as essential to plants. Notwithstanding, beneficial effects of Si have been demonstrated for many plant species, especially when these plants are submitted to some type of stress, whether biotic or abiotic (Takahashi, 1995; Korndörfer et al., 1999; Faria, 2000; Datnoff et al., 2001). By and large, grasses are classified as Si-accumulating plants, since they deposit this element in cell walls, in the cell lumen and in extracellular sites. Silicon absorbed by the roots in the form of monosilicic acid (H_4SiO_4) is carried through the plant and deposited in the leaves. Incorporated within the cells in the cell wall, especially in epidermal, stomatal and leaf trichome cells, or deposited, together with other elements, giving rise to amorphous deposits known as phytoliths (Jones & Handreck, 1967; Yoshida, 1965).

One of the reasons, still little discussed, for the ruggedness shown by brachiaria grasses when developing under savanna soils, could be its greater capacity in absorbing and accumulating Si. The role played by Si in these plants can be linked to a reduction in the toxic effects of aluminum, manganese and iron, as previously observed for other grasses, and also because it is responsible for regulating transpiration, which is the likely reason for the resistance shown by this grass to water deficits which occur in the savanna, in addition to protecting the leaves against pest and disease attacks (Cocker et al., 1998; Ma et al., 1997; Datnoff et al., 2001).

The objective of this work was to study the effect of silicon fertilization on silicon accumulation by tropical forages (brachiaria grass), on their tolerance to water stress and on dry matter yield, when grown, under greenhouse conditions.

MATERIAL AND METHODS

The experiment was conducted in the greenhouse over surface samples (0-20cm) of a medium-textured Typic Haplustox, with low Si content (5.0 mg dm^{-3} - extracted with acetic acid 0.5M), representative of extensive pasture-growing areas. The soil chemical characteristics before installation of the experiment were: pH = 5.2 (H_2O); P = 1.4 mg dm^{-3}; K = 48.0 mg dm^{-3}; Al = 9 mmol$_c$ dm^{-3}; Ca = 2 mmol$_c$ dm^{-3}; Mg = 1 mmol$_c$ dm^{-3}; CEC = 63.3 mmol$_c$ dm^{-3}; V = 6.0 %; m = 71.0%; O.M. = 2.1 dag kg^{-1}. Soils physical characteristics were: Coarse sand = 436 g kg^{-1}; Fine sand = 345 g kg^{-1}; Silt = 27 g kg^{-1}; Clay = 192 g kg^{-1}. The textural analysis was performed through the pipette method (EMBRAPA, 1997).

Treatments consisted on the addition of five calcium silicate rates: 0; 1,000; 2,000; 4,000; and 6,000 kg ha^{-1}, corresponding to 0; 242; 484; 968; and 1452 kg ha^{-1} Si; two soil moisture levels (field capacity, FC = maximum water retention capacity): 80% FC and 60% FC; and two grass species: *Brachiaria decumbens* (brachiaria grass) and *Brachiaria brizantha* (signal grass). Wollastonite ($CaSiO_3$) was utilized as the Si source Si = 24.3%; CaO = 42.0%; MgO = 1.5%). To make up for the effects of Wollastonite on pH, as well as on soil Ca and Mg contents, calcium carbonate ($CaCO_3$) was applied at rates of 4,511; 3,759; 3,007; 1,504 and 0 kg ha^{-1}; magnesium sulfate ($MgSO_4$) was also applied at the following rates: 497; 414; 331; 166 and 0 kg ha^{-1} respectively, for treatments containing 0, 242, 484, 968 and 1,452 kg ha^{-1} Si. This procedure allowed all pots containing soil to attain the similar pH, Ca and Mg values after incubation.

After 30 days of incubation (80% of FC) the brachiaria seeds were sown at the rate of 50 seeds per pot. Pots were watered daily until total seed germination occurred. Thinning was performed five days after germination, leaving 20 plants per pot and soil moisture was controlled there after, with half of the pots maintained at 80% and the other half maintained at 60% FC. Three cuts were performed; the first 30 days after germination, the second 22 days after the first, and the third 26 days after the second.

Trials were set up in completely randomized experimental design, in a 5 × 2 × 2 factorial scheme: five Si rates, two moisture levels and two brachiaria species (n = 5) treatment means were compared by the Tukey test ($P = 0.05$).

Two soil samplings were performed, one right after the incubation period and the other at the end of the experiment (after the third cut). Samples were analyzed for pH ($CaCl_2$), Si (Korndörfer et al., 1999), Ca and Mg (Malavolta et al., 1997). The dried plant material was ground in a Willey-type mill (2 mm sieve) and analyzed for Si content, according to Elliot & Snyder (1991).

RESULTS AND DISCUSSION

The Si contents available in the soil samples collected at the end of the experiment, i.e., 110 days after silicate application, increased as the applied Si rates increased, going from 5.8 mg dm^{-3} to 27.9 mg dm^{-3}, respectively, for the rates of 0 kg ha^{-1} and 1,452 kg ha^{-1}, confirming the high reactivity of the calcium silicate (Wollastonite). The pH ($CaCl_2$) was maintained at 4.8.

The two grass species have different behaviors with respect to Si extraction from the soil *B. brizantha* absorbed less Si than *B. decumbens*, thus leaving a greater amount of residual Si in the soil. The soil cultivated with *B. decumbens* presented 17.5 mg dm^{-3} Si at the end of the experiment, while the soil cultivated with *B. brizantha* presented 20.3 mg dm^{-3} Si.

The two field capacities applied to the soil presented different behaviors in relation to soil Si at the end of the experiment. A smaller soil Si content (18.0 mg dm^{-3}) was observed at the higher water content, i.e., when there was greater soil water availability. Conversely, the soil residual Si was greater (19.8 mg dm^{-3}) at the lower water content. The smaller Si absorption or accumulation by the plants in treatments receiving less water can partially explain the differences in soil Si contents, i.e., the greater the extraction by the plant, the smaller the availability in the soil.

With regard to Si content in the aerial part of the plants, *B. decumbens* (9.8 g kg^{-1}) was superior to *B. brizantha* (9.2 g kg^{-1}) for the three cuts, presenting differences in the first two cuts (Figure 1). These differences in Si contents of the aerial part indicate a differential behavior between the two species relatively to Si absorption and accumulation. When the sum of the three cuts is considered, an increase of approximately 170% in the amount of accumulated Si was observed in the aerial part, i.e., from 142.6 to 450.9 mg pot^{-1}, respectively in the control and at the 1,452 kg ha^{-1} rate (Table 1), and that demonstrates that the two brachiaria species, as well as the majority of grasses, are considered as Si-accumulating species (Elawad & Green, 1979; Korndörfer et al., 1999; Rodrigues, 2000).

There was greater Si accumulation in the plant when soil moisture was maintained at 80% of the FC (Figure 2). The 80% FC accumulated about 1.4-fold more Si than the 60% FC when the sum of the three cuts is considered, i.e., silicon absorption increased as water availability increased, and that corroborates the hypothesis that Si is passively absorbed via mass flow, following the water during the transpiration process, as proposed by Jones & Handreck (1967).

The accumulated Si (sum of the three cuts) was different between the two brachiaria species. *B. decumbens* accumulated approximately 8% more Si in its aerial part as compared to *B. brizantha*. When the three cuts are individually analyzed, it can be observed that the second cut accumulated the greatest amount of Si for both species, explaining the greater dry matter yield of this cut (Table 2). Clark et al. (1990), working with sorghum and millet grown in an acid soil with 60% Al saturation and pH 4.0, observed that for sorghum productivities equal to 325 to 3600 kg ha^{-1}, the accumulated Si ranged from 8.1 to 18.8 g kg^{-1}, respectively. The accumulated Si in millet at productivities of 1,980 to 3,460 kg ha^{-1}, ranged from 27.9 to 43.4 g kg^{-1}.

The soil water regimes influenced dry matter yield of the three cuts individually, and their sum. The 80% FC yielded 30% more dry matter than the 60% FC, i.e., the more available water in the soil, the greater the dry matter yield (Table 2).

No effect of Si application on dry matter yield was detected for any of the cuts or even for the sum of the three cuts. These results contradict those obtained by Korndörfer et al. (2001) in a field work conducted in the Triângulo Mineiro region, using a Typic Haplustox, for

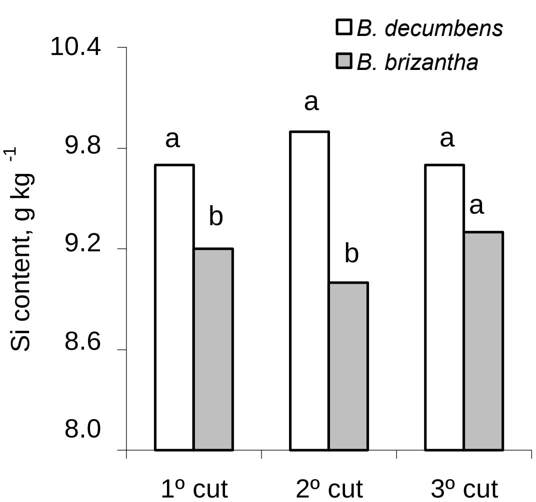

Figure 1 - Silicon content in the aerial part of two *brachiaria* species in three cuts (mean of two soil water tensions and five silicate rates).

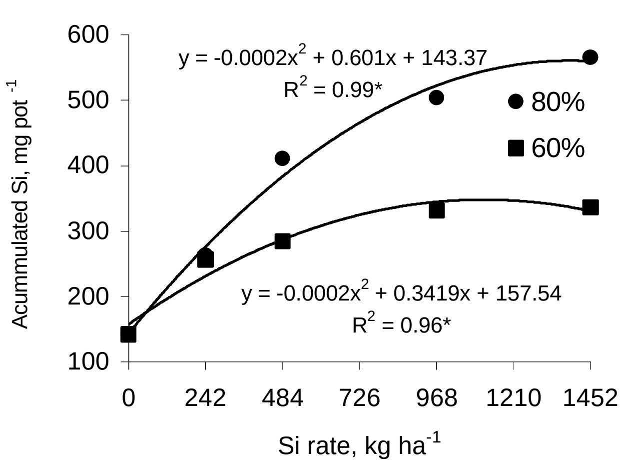

Figure 2 - Silicon accumulation in the aerial part of grasses on 80 and 60% field capacity. Sum of the three cuts over the mean of two brachiaria species. *(P = 0.05)

Table 1 - Accumulated Si in the aerial part of grasses in each of three cuts and in the sum of the three cuts.

Causes of Variation	Accumulated Si - aerial part of grasses			
	1º Cut	2º Cut	3º Cut	Σ Cuts
Soil Water Tension	------------- mg pot^{-1} -------------			
80% FC	96.3	112.4	122.6	377.0
60% FC	71.0	162.9	86.9	270.4
F test	*	*	*	*
Si rates (kg ha^{-1})	------------- mg pot^{-1} -------------			
0	48.9	44.1	49.1	142.6
242	77.4	114.7	81.6	259.7
484	82.3	156.9	108.3	347.6
968	101.4	180.1	136.1	417.6
1452	108.2	192.5	148.1	450.9
F test	*	*	*	*
Species	------------- mg pot^{-1} -------------			
Brachiaria decumbens	83.1	137.0	115.8	336.8
Brachiaria brizantha	84.1	138.3	93.7	310.6
F test	ns	ns	*	*
Interactions	-------------- F test --------------			
Tension x Rates	*	*	*	*
Tension x Species	*	ns	ns	ns
Rates x Species	ns	ns	*	ns
Rates x Species x Tension	ns	ns	ns	ns
C.V. (%)	12.4	32.4	16.6	16.6

*Significant by the F test (P < 0.05) or n.s.= not significant (P > 0.05).

Table 2 - Dry matter yield for each cut and for the sum of the three cuts

Causes of Variation	Dry Matter			
	1º Cut	2º Cut	3º Cut	Σ Cuts
Soil Water Tension	------------- g pot^{-1} -------------			
80% FC	10.4	17.2	11.8	39.4
60% FC	7.9	12.7	9.9	30.5
F test	*	*	*	*
Si rates (kg ha^{-1})	------------- g pot^{-1} -------------			
0	9.2	15.8	10.7	35.7
242	9.8	14.1	11.1	35.0
484	8.7	14.7	11.2	34.6
968	9.1	16.3	11.1	36.5
1452	9.1	14.1	9.9	33.1
F test	*	*	*	*
Species	------------- g pot^{-1} -------------			
Brachiaria decumbens	8.9	14.2	11.8	34.8
Brachiaria brizantha	9.4	15.8	9.8	35.0
F test	ns	ns	*	*
Interactions	-------------- F test --------------			
Tension x Rates	*	*	*	*
Tension x Species	*	ns	ns	ns
Rates x Species	ns	ns	*	ns
Rates x Species x Tension	ns	ns	ns	ns
C.V. (%)	10.9	25.3	18.0	15.5

*Significant by the F test ($P < 0.05$) or n.s.= not significant ($P > 0.05$).

which a 17% increase in *B. decumbens* dry matter yield as observed with the surface application of 2,000 kg ha^{-1} calcium silicate.

The lack of dry matter yield response to Si application can be related, for the most part, to the fact that the experiment was conducted in a greenhouse, where the biotic stress was controlled. In other words, the fact that no type of attack by pests or diseases during the experimental period occurred, that could affect the vegetative development of the two grasses, inhibited the positive response of Si. However, this can be observed in the field, where plants are more susceptible to pests, such as frog hoper. In addition, no visual differences were observed in leaf architecture between treatments, suggesting that there was no difference in the photosynthetic rate that could increase dry matter yield, as observed by Marschner (1995).

B. brizantha yielded more dry matter in relation to *B. decumbens* in the first and second cuts. However, *B. decumbens* had a higher yield in the third cut. No difference was observed in the sum of the three cuts between the two brachiaria species with regard to dry matter yield. Some pasture evaluations conducted with *B. decumbens* and *B. brizantha* had similar dry matter yield for both species (Euclides et al., 1993).

For the tested species, Si did not regulate transpiration, as anticipated by Faria (2000), i.e., it did not improve the ability of the species to tolerate higher water stress. Two possible reasons for the lack of response to Si in the soil with less available water (60% FC) could have been the species that were selected for the tests (brachiaria) and the water tension in the soil. On one hand, brachiaria are acknowledgedly very tolerant species to water deficit. On the other hand, it was not possible to detect visual differences between plants submitted to the two soil water regimes. This suggests that the 60% FC treatment was not sufficient to express the role Si plays on soil water deficit tolerance, contradicting results reported Agarie et al., (1998), Faria, (2000), and Ma et al., (2001).

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