Nota

LEAF APPLICATION OF SILICIC ACID TO WHITE OAT AND WHEAT[1]

Rogério Peres Soratto[2], Carlos Alexandre Costa Crusciol[3], Gustavo Spadotti Amaral Castro[4], Claudio Hideo Martins da Costa[4] & Jayme Ferrari Neto[4]

SUMMARY

Silicon (Si) is beneficial to plants in several aspects, but there are doubts about the effectiveness of leaf application. The purpose of this work was to evaluate the effects of Si, applied in a newly developed stabilized silicic acid form to the leaf, on nutrition and yield of irrigated white oat and wheat. Two experiments were performed (one per crop) in winter 2008, in Botucatu-SP, Brazil. A completely randomized block design with 14 replications was used. Treatments consisted of a control (without Si application) and Si leaf spraying, at a rate of 2.0 L ha^{-1} of the commercial product containing 0.8 % soluble Si. Silicon rate was divided in three parts, i.e. applications at tillering, floral differentiation and booting stages. Silicon leaf application increased N, P, K, and Si concentrations in white oat flag leaf, resulting in higher shoot dry matter, number of panicles per m^2, number of grains per panicle and grain yield increase of 34 %. In wheat, Si leaf application increased K and Si concentrations, shoot dry matter and number of spikes per m^2, resulting in a grain yield increase of 26.9 %.

Index terms: *Avena sativa*, *Triticum aestivum*, silicon, mineral nutrition, yield components.

---

(1) Received for publication in August 8, 2011 and approved in July 11, 2012.

(2) Associate Professor at the Department of Crop Science, College of Agricultural Sciences, São Paulo State University - FCA/UNESP. Rua José Barbosa de Barros, 1780. Fazenda Experimental Lageado CEP 18610-307 Botucatu (SP), Brazil. Research award from CNPq. E-mail: soratto@fca.unesp.br

(3) Full Professor at the Department of Crop Science, FCA/UNESP. Research award from CNPq. E-mail: crusciol@fca.unesp.br

(4) PhD student in Agronomy (Agriculture), FCA/UNESP. E-mail: gsacastro@hotmail.com, c_hideo@hotmail.com, jaymeferrari@hotmail.com

REUSMO: *APLICAÇÃO FOLIAR DE ÁCIDO SILÍCICO ESTABILIZADO NAS CULTURAS DE AVEIA-BRANCA E TRIGO*

O fornecimento de silício (Si) traz inúmeros benefícios às plantas, porém existem dúvidas acerca da eficiência do fornecimento via foliar. Objetivou-se com este trabalho avaliar o efeito da aplicação de Si via foliar, na forma de uma fonte recém-desenvolvida de ácido silícico estabilizado, sobre a nutrição e a produtividade das culturas de aveia-branca e trigo, sob irrigação. Foram conduzidos dois experimentos (um com cada cultura), na safra de inverno de 2008, no município de Botucatu-SP. O delineamento experimental foi o de blocos ao acaso, com 14 repetições. Os tratamentos foram: controle (sem aplicação de Si) e aplicação de Si via foliar, na dose de 2,0 L ha^{-1} do produto comercial contendo 0,8 % de Si solúvel. A dose de Si foi parcelada em três aplicações, nos estádios de perfilhamento, diferenciação floral e emborrachamento. A aplicação foliar de Si elevou os teores de N, P, K e Si na folha-bandeira da cultura de aveia-branca, proporcionando aumento da produção de matéria seca da parte aérea, do número de panículas por m^2, do número de grãos por panícula e da produtividade de grãos, da ordem de 34 %. Na cultura do trigo, a aplicação de Si aumentou os teores de K e Si, a produção de matéria seca da parte aérea e o número de espigas por m^2, refletindo em aumento de 26,9 % na produtividade de grãos.

Termo de indexação: Avena sativa, Triticum aestivum, *silício, nutrição mineral, componentes da produção.*

INTRODUCTION

White oat (*Avena sativa* L.) and wheat (*Triticum aestivum* L.) are important winter cereal crops in South Central Brazil. In 2010/2011, the total area of these two species was 3.0 million ha, of which 2.1 and 0.9 million ha was cultivated with wheat and oat, respectively, producing 5.9 million tons of grains (CONAB, 2011).

Several studies have shown that silicon (Si) application is beneficial to crops such as rice, sugar cane, barley, maize, sorghum, and wheat (Ma et al., 2001; Gong et al., 2005; Hattori et al., 2005), which are considered Si-accumulating species. Nevertheless, Si is still relatively unknown and applied in agriculture. In many cases, increasing Si availability has increased crop development and yield, once this nutrient can indirectly influence some photosynthetic and biochemical aspects, especially in plants under biotic or abiotic stress conditions (Ma & Yamaji, 2006; Abdalla, 2011). Stress caused by extreme temperatures, drought, heavy or toxic metals, for instance, can be attenuated by Si application (Barbosa Filho et al., 2000; Crusciol et al., 2009; Abdalla, 2011; Prabagar et al., 2011). Si fertilization can also increase plant resistance to several fungal diseases and pests (Goussain et al., 2002; Berni & Prabhu, 2003).

In Brazil, Si is mostly supplied to soil through slug materials with calcium (Ca) and magnesium (Mg) silicates, which are low-water soluble sources (Sousa et al., 2010) and, depending on the origin, can contain heavy metals. Silicon uptake can occur actively, in an energy-spending process, even when roots are exposed to high concentrations of this nutrient (Malavolta, 2006), once plants absorb Si exclusively as monosilicic acid, also known as orthosilicic acid [$Si(OH)_4$] (Elawad & Green Junior, 1979). This monomeric form of silicic acid is found in freshwater and seawater at low concentrations (< 10^{-4} mol L^{-1}) and can gelatinize into silica gel at high concentrations or when the pH is low (Calomme et al., 2000). In this way, sources containing Si as stabilized silicic acid, which form mainly orthosilicic acid after dilution, can hypothetically be an alternative to increase Si uptake by plants.

In this regard, studies have shown that supplying Si via leaf, in small amounts, can be a viable option, fully providing Si and/or stimulating its absorption, with beneficial effects (Wang & Galleta, 1998; Buck et al., 2008; Reis et al., 2008; Carré-Missio et al., 2010; Figueiredo et al., 2010; Sousa et al., 2010). Thus, leaf fertilization with soluble Si sources seems promising to supply this element to plants, for its effectiveness and feasibility, low doses and because applications can be performed with the sprayers usually used by farmers (Figueiredo et al., 2010). However, there are practically no scientific studies available in the literature on supplying Si via leaf application, as stabilized silicic acid.

The purpose of this work was to evaluate the effects of Si leaf application, in the form of stabilized silicic acid, on nutrition and yield of sprinkle-irrigated white oat and wheat.

MATERIAL AND METHODS

This study consisted of two experiments, one with white oat and the other with wheat, conducted in the winter of 2008, in Botucatu-SP, Brazil (22º 51' S, 48º 26' W, 740 m asl). According to Köppen's classification, the climate is Cwa, characterized as tropical altitude, with dry winters and hot wet summers.

The soil in the experimental area is a Typic Hapludox (Embrapa, 2006), with the following chemical properties in the arable layer (0-0.20 m depth) prior to the experiment (Raij et al., 2001): organic matter: 25.0 g dm^{-3}; pH ($CaCl_2$): 5.4; P (resin): 18.0 mg dm^{-3}; Si: 6.4 mg dm^{-3}; K, Ca, Mg, H+Al and CEC: 4.9, 47.0, 21.0, 32.0 and 104.9 mmol$_c$ dm^{-3}, respectively; base saturation: 70 %.

The experiment had a completely randomized block design with 14 replications. Treatments consisted of a control (with no Si application) and Si leaf application, at 2.0 L ha^{-1} of the commercial product (0.8 % soluble Si as stabilized concentrated silicic acid that forms orthosilicic acid [$Si(OH)_4$] and disilicic acid after dilution, 0.15 % Mo and 48 % polyethyleneglycol - PEG400). For both crops, each plot consisted of thirteen 5-m rows of plants, of which the nine central rows were evaluated, disregarding 0.5 m at the row ends.

Both crops were sown on April 24, 2008, in rows spaced 0.17 m apart and 50 seeds m^{-1}. The cultivars white oat IAC 7 and wheat Coodetec 107 were used. At sowing, both crops were fertilized with 17, 60 and 34.5 kg ha^{-1} of N, P_2O_5 and K_2O, respectively, applied as 04-14-08 NPK formula, according to soil chemical analysis and recommendations of Cantarella et al. (1997). Sowing and fertilization were carried out mechanically, in a no tillage system. Seeds were treated with fungicide carboxin+thiram (50 + 50 g of the active ingredient per 100 kg of seeds). Seedlings emerged eight days after sowing. Side dressing was applied at tillering, with 65 kg ha^{-1} N as ammonium sulphate.

Silicon was applied at the stages recommended by the fertilizer manufacturer, i.e. three applications of 0.67 L ha^{-1}, at tillering, floral differentiation and booting, with a CO_2-pressurized sprayer (volume 200 L ha^{-1}).

Plant protection products were applied to control the rose-grain aphid (*Metopolophium dirhodum* Walker 1849) and leaf rust (*Puccinia triticina* Erikss.). Crops were irrigated by a sprinkler system, whenever water tension in soil reached -0.06 MPa, in the 0.10-m layer, as recommended by Guerra et al. (1994). By these measures, it was possible to isolate the physiological effects of Si nutrition from other influences, such as pests, diseases and water stress.

At flowering, plants were harvested from 2 m of two rows to evaluate dry matter production. Also, the flag leaf of 50 plants per plot was sampled (Cantarella et al., 1997) for macronutrient (N, P, K, Ca, Mg and S) and Si analyses, according to Malavolta et al. (1997) and Korndörfer et al. (2004).

The crops were harvested on September 4, 2008. At this stage, yield components (white oat: number of panicles per m^2, number of filled spikelets per panicle and 1,000 grain weight; wheat: number of spikes per m^2, number of grains per spike and 1,000 grain mass) and total yield were determined.

Data were subjected to analysis of variance and means were compared by the t test (LSD) at a probability level of 5 %.

RESULTS AND DISCUSSION

Silicon application increased N, P, K and Si concentrations in the flag leaves of white oat (Table 1). This result can be a consequence of improved root growth, once Si application enhances root structures, as reported by Vlamis & Williams (1967) and Carvalho-Pupatto et al. (2003). Despite the effects of Si treatments, only P, K, Mg and S concentrations were within the ranges considered appropriate by Cantarella et al. (1997), which are 20-30, 2.0-5.0, 15-30, 2.5-5.0, 1.5-5.0 and 1.5-4.0 g kg^{-1}, respectively. Nitrogen and Ca concentrations were above the optimum ranges.

Although ranges of Si deficiency, sufficiency and excess have not been established for white oat in Brazil so far, both treatments resulted in higher concentrations than those reported in the literature, i.e. 10.9 g kg^{-1}, considering the total shoots (Korndörfer et al., 2004). This can be explained by the analysis of the flag leaf only, in this experiment. From these results, it was possible to infer that white oat plants were nutritionally well-balanced, being classified as Si-accumulating, with contents above 10 g kg^{-1} (Ma et al., 2001).

Shoot dry matter was increased by Si leaf application, which may be associated to better plant nutrition (Table 1). Silicon positively influences plant growth and biomass production, especially monocotyledons, as a consequence of improved tissue rigidity, better angle of leaves and light interception, improving photosynthesis (Ma & Yamaji, 2006; Abdalla, 2011; Gong & Chen, 2012). Gong et al. (2003) also found that Si fertilization in soil increased wheat growth, even under appropriate water supply, probably due to growth stimuli. According to Elawad et al. (1982a,b) and Abdalla (2011), Si is involved in cell elongation and division processes as well as in hormone balance.

Evaluations of yield components revealed that Si application increased the number of panicles per area by 22.2 % compared to the control (Table 1). This corroborates findings of Ma et al. (1989), Takahashi (1995) and Artigiani (2008), who also attributed higher number of panicles per area to a better Si nutrition in rice.

The average number of filled spikelets per panicle was also increased by Si leaf application (Table 1), which may be related to higher spikelet fertility. Takatsuka & Makihara (2001) associated low spikelet fertility with low Si concentrations in rice plants. In rice and barley, Ma (2004) reported that the yield component number of filled spikelets per panicle is most influenced by Si.

The mass of 1,000 grains was the only component not affected by the treatments (Table 1). That can be explained by the fact that this yield component is intimately related to genetic characteristics, and is little influenced by other factors (Fornasieri Filho & Fornasieri, 1993).

Silicon application increased grain yield as a consequence of significant changes in yield components compared to the control (Table 1). Yield was increased by 1,783 kg ha^{-1}, i.e. 29.7 sacks (of 60 kg) per hectare or 34 %, compared to the treatment with no Si application. This result is mainly justified by the higher number of panicles m^{-2} and filled spikelets per panicle.

Silicon leaf application increased K and Si concentrations in the wheat flag leaves (Table 2). The concentrations of the other nutrients were not influenced, possibly due to higher dry matter production causing a dilution effect despite Si uptake increase, which led to similar contents in both treatments. Studies showed that Si supplied via leaf application, at lower rates, can be a viable alternative to provide this nutrient to plants, with particular beneficial effects, meeting the Si requirements and/or stimulating Si uptake (Wang & Galleta, 1998; Buck et al., 2008; Reis et al., 2008; Carré-Missio et al., 2010; Figueiredo et al., 2010; Sousa et al., 2010). According to Rosolem (2002), leaf applications at low nutrient rates can increase nutrient concentrations above the initially applied amounts. This management is designated stimulating complementary leaf fertilization, indicated for vigorous, highly productive crops, with no nutritional deficiency. The treatments did not influence the concentrations of all other nutrients.

It is worth mentioning that, although Si application enhanced plant nutrition for the cited nutrients, concentrations were within the range considered appropriate for the wheat crop (Raij et al., 1997), both with and without Si application, as follows: 20-34, 2.1-3.3, 15-30, 2.5-10.0, 1.5-4.0 and 1.5-3.0 g kg^{-1}, respectively for N, P, K, Ca, Mg and S. Although the ranges of Si sufficiency concentrations in wheat are not determined to date, the contents observed in both treatments can be considered appropriate, according to the range of 5.1 - 16.9 g kg^{-1} established by Korndörfer et al. (2004) for leaves + stems. This shows that wheat is a Si-accumulating crop, similarly to white oat (Ma et al., 2001).

Silicon leaf application increased the wheat shoot dry matter by 47.3 %, probably as a result of better plant nutrition (Table 2). Gong et al. (2003) also reported that Si supplied in soil increased wheat development possibly due to stimulated growth, once Si may be involved in cell elongation and division processes, as well as in the hormone balance (Elawad et al., 1982a,b; Abdalla, 2011). The number of spikes per area was the only yield component affected by Si (Table 2). The other components were not influenced by the treatments. Silicon leaf application increased the number of spikes per area by 10.4 %. Ma et al. (1989), Takahashi (1995) and Artigiani (2008) had also confirmed the effects of Si on the number of rice panicles per area.

Grain yield was significantly increased by Si leaf application compared to the control (without Si application), as a result of the higher photosynthetic area, due to the higher dry matter production and higher number of spikes per m² (Table 2). Silicon leaf application increased yields by 1,377 kg ha^{-1},

Table 1. Concentration of N, P, K, Ca, Mg, S and Si in the flag leaf, shoot dry matter, number of panicles per m², number of spikelets per panicle, mass of 1,000 grains and grain yield of sprinkler-irrigated white oat under Si leaf application

Variable	Control	Si	F value	CV (%)
N (g kg^{-1})	31.3 b	33.0 a	8.15*	5.9
P (g kg^{-1})	3.1 b	3.7 a	7.11*	17.5
K (g kg^{-1})	15.2 b	16.1 a	6.26*	6.9
Ca (g kg^{-1})	5.1 a	6.2 a	6.67^{ns}	24.2
Mg (g kg^{-1})	5.1 a	5.0 a	0.55^{ns}	11.0
S (g kg^{-1})	3.2 a	3.2 a	0.01^{ns}	11.5
Si (g kg^{-1})	11.5 b	13.5 a	34.99***	7.6
Shoot dry matter (kg ha^{-1})	7.63 b	8.75 a	5.42*	16.7
Number of panicles m^{-2}	410.6 b	501.9 a	29.97***	10.3
Number of filled spikelets/panicle	58.6 b	63.1 a	5.20*	9.2
Mass of 1,000 grains (g)	31.5 a	31.6 a	0.01^{ns}	3.4
Grain yield (kg ha^{-1})	5,241 b	7,024 a	80.24***	9.2

Means followed by the same small letter in the row do not differ significantly by the t test at 5 %. * and ***: significant at 5 and 0.1 %, respectively; ^{ns}: not significant.

Table 2. Concentration of N, P, K, Ca, Mg, S and Si in the flag leaf, shoot dry matter, number of spikes per m², number of grains per spike, mass of 1,000 grains and grain yield of sprinkler-irrigated wheat under Si leaf application

Variable	Control	Si	F value	CV (%)
N (g kg^{-1})	29.4 a	30.0 a	0.78^{ns}	5.8
P (g kg^{-1})	2.6 a	2.6 a	0.01^{ns}	9.2
K (g kg^{-1})	22.4 b	26.4 a	30.37***	8.4
Ca (g kg^{-1})	9.0 a	9.0 a	1.28^{ns}	10.2
Mg (g kg^{-1})	3.1 a	3.1 a	0.21	17.8
S (g kg^{-1})	2.4 a	2.3 a	2.19^{ns}	12.8
Si (g kg^{-1})	13.8 b	15.1 a	5.31*	10.4
Shoot dry matter (kg ha^{-1})	3,562 b	5,250 a	19.02***	24.8
Number of spikes m^{-2}	456.5 b	504.2 a	21.86***	6.1
Number of grains/spike	26.2 a	28.2 a	3.16^{ns}	11.7
Mass of 1,000 grains (g)	42.5 a	42.6 a	0.01^{ns}	3.3
Grain yield (kg ha^{-1})	5,126 b	6,503 a	9.40***	15.3

Means followed by the same small letter in the row do not differ significantly by the t test at 5 %. * and ***: significant at 5 and 0.1 %, respectively; ^{ns}: not significant.

i.e. 23 sacks per hectare or 26.9 %, compared to the control.

Studies have demonstrated that Si is involved in a number of structural, physiological and biochemical aspects of the plant cycle, with diverse functions. As pests and diseases were controlled during the experiment and irrigation ensured the water supply, it is believed that Si effects may be correlated to the better crop response at the low temperatures (Liang et al., 2008) that are normal in the winter, or even related to the higher production and accumulation of total sugar and proline (Crusciol et al., 2009; Abdalla, 2011). Silicon is also beneficial to the plant metabolism, since the element can activate genes involved in phenol production and enzyme activity related to defense mechanisms (Ma & Yamaji, 2006; Buck et al., 2008; Abdalla, 2011), resulting in increased crop yields, as observed in both experiments.

CONCLUSIONS

1. Silicon leaf application as stabilized silicic acid efficiently supplied Si for white oat and wheat plants.

2. Leaf-supplied Si increased nutrient concentrations in flag leaves and yield of white oat and wheat cropped under sprinkler irrigation.

ACKNOWLEDGEMENT

The authors wish to thank the CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) for providing the first and second author with Research awards.

LITERATURE CITED

ABDALLA, M.M. Beneficial effects of diatomite on growth, the biochemical contents and polymorphic DNA in *Lupinus albus* plants grown under water stress. Agric. Biol. J. North Am., 2:207-220, 2011.

ARTIGIANI, A.C.C. Produção de arroz e feijão no sistema plantio direto em função da aplicação superficial de gesso, calcário, silicato e misturas desses produtos. Botucatu, Universidade Estadual Paulista, 2008. 128p. (Tese de Doutorado)

BARBOSA FILHO, M.P.; SNYDER, G.H.; PRABHU, A.S.; DATNOFF, L.E. & KORNDÖRFER, G.H. Importância do silício para a cultura do arroz. Inf. Agron., 89:1-8, 2000.

BERNI, R.F. & PRABHU, A.S. Eficiência relativa de fontes de silício no controle de bruzone nas folhas em arroz. Pesq. Agropec. Bras., 38:195-201, 2003.

BUCK G.B.; KORNDÖRFER, G.H.; NOLLA, A. & COELHO, L. Potassium silicate as foliar spray and rice blast control. J. Plant Nutr., 31:231-237, 2008.

CALOMME, M.; COS, P.; D'HAESE, P.; VINGERHOETS, R.; LAMBERTS, L.; DE BROE, M.; van HOOREBEKE, C. & VANDEN BERGHE, D. Silicon absorption from stabilized orthosilicic acid and other supplements in healthy subjects. Trace Elem. Man Anim., 10:1111-1114, 2000.

CANTARELLA, H.; RAIJ, B.van & CAMARGO, C.E.O. Cereais. In: RAIJ, B.van; CANTARELLA, H.; QUAGGIO, J.A. & FURLANI, A.M.C. Recomendações de adubação e calagem para o Estado de São Paulo. 2.ed. Campinas, Instituto Agronômico de Campinas, 1997. p.45-47. (Boletim Técnico, 100)

CARRÉ-MISSIO V.; RODRIGUES, F.A.; SCHURT, D.A.; REZENDE, D.C.; RIBEIRO, N.B. & ZAMBOLIM, L. Aplicação foliar de silicato de potássio, acibenzolar-S-metil e fungicidas na redução da mancha de *Pestalotia* em morango. Trop. Plant Pathol., 35:182-185, 2010.

CARVALHO-PUPATTO, J.G.; BÜLL, L.T.; CRUSCIOL, C.A.C.; MAUAD, M. & SILVA, R.H. Efeito da escória de alto forno no crescimento radicular e na produtividade de arroz. Pesq. Agropec. Bras., 38:938-943, 2003.

CONSELHO NACIONAL DE ABASTECIMENTO - CONAB. Série histórica. Brasil - por produtos. Available in: <http://www.conab.gov.br/conabweb/download/safra/BrasilProdutoSerieHist.xls> Accessed: Feb 21, 2011.

CRUSCIOL C.A.C.; PULZ, A.L.; LEMOS, L.B.; SORATTO, R.P. & LIMA, G.P.P. Effects of silicon and drought stress on tuber yield and leaf biochemical characteristics in potato. Crop Sci., 49:949-954, 2009.

ELAWAD, S.H. & GREEN JUNIOR, V.E. Silicon and the rice plant environment: A review of recent research. Il Riso, 28:235-253, 1979.

ELAWAD, S.H.; STREET, J.J. & GASCHO, G.J. Response of sugarcane to silicate source and rate. II. Leaf freckling and nutrient content. Agron. J., 74:484-487, 1982a.

ELAWAD, S.H.; STREET, J.J. & GASCHO, G.J. Response of sugarcane to silicate source and rate. I. Growth and yield. Agron. J., 74:481-484, 1982b.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA - EMBRAPA. Sistema brasileiro de pesquisa do solo. Sistema brasileiro de classificação de solos. 2.ed. Rio de Janeiro, 2006. 306p.

FIGUEIREDO F.C.; BOTREL, P.P.; TEIXEIRA, C.P.; PETRAZZINI, L.L.; LOCARNO, M. & CARVALHO, J.G. Pulverização foliar e fertirrigação com silício nos atributos físico-químicos de qualidade e índices de coloração do morango. Ci. Agrotec., 34:1306-1311, 2010.

FORNASIERI, FILHO D. & FORNASIERI, J.L. Manual da cultura do arroz. Jaboticabal, FUNEP, 1993. 221p.

GONG H.; ZHU, X.; CHEN, K.; WANG, S. & ZHANG, C. Silicon alleviates oxidative damage of wheat plants in pots under drought. Plant Sci., 169:313-321, 2005.

GONG, H.; CHEN, K.; CHEN, G.; WANG, S. & ZHANG, C. Effects of silicon on growth of wheat under drought, J. Plant Nutr., 26:1055-1063, 2003.

GONG, H. & CHEN, K. The regulatory role of silicon on water relations, photosynthetic gas exchange, and carboxylation activities of wheat leaves in field drought conditions. Acta Physiol. Plant., 34:1-6, 2012.

GOUSSAIN, M.M.; MORAES, J.C.; CARVALHO, J.G.; NOGUEIRA, N.L. & ROSSI, M.L. Efeito da aplicação de silício em plantas de milho no desenvolvimento biológico da lagarta do cartucho *Spodoptera frugiperda* (J.E. Smith) (Lepdoptera: Noctuidae). Neotrop. Entomol., 31:305-310, 2002.

GUERRA, A.F.; SILVA, E.M. & AZEVEDO, J.A. Tensão de água no solo: um critério viável para a irrigação do trigo na região do cerrado. Pesq. Agropec. Bras., 29:631-636, 1994.

HATTORI, T.; INANAGA, S.; ARAKI, H.; PING, A.; MORITA, S.; LUXOVA, M. & LUX, A. Application of silicon enhanced drought tolerance in *Sorghum bicolor*. Physiol. Plant., 123:459-466, 2005.

KORNDÖRFER, G.H.; PEREIRA, H.S. & NOLLA, A. Análise de silício: Solo, planta e fertilizante. Uberlândia, GPSi-ICIAG-UFU, 2004. 34p. (Boletim Técnico, 2)

LIANG, Y.; ZHU, J.; LI, Z.; CHU, G.; DING, Y.; ZHANG, J. & SUN, W. Role of silicon in enhancing resistance to freezing stress in two contrasting winter wheat cultivars. Environ. Exper. Bot., 64:286-294, 2008.

MA, J.F. Role of silicon in enhancing the resistance of plants to biotic and abiotic stresses. Soil Sci. Plant Nutr., 50:11-18, 2004.

MA, J.; NISHIMRA, K. & TAKAHASHI, E. Effect of silicon on the growth of rice plant at different growth stages. Soil Sci. Plant Nutr., 35:347-356, 1989.

MA, J.F.; MIYAKE, Y. & TAKAHASHI, E. Silicon as a beneficial element for crop plants. In: DATNOFLF, L.E.; SNYDER, G.H. & KORNDÖRFER, G.H., eds. Silicon in agriculture. The Netherland, Elsevier Science, 2001. p.17-39.

MA, J.F. & YAMAJI, N. Silicon uptake and accumulation in higher plants. Trends Plant Sci., 11:392-397, 2006.

MALAVOLTA, E. Elementos de nutrição de plantas. São Paulo, Agronômica Ceres, 2006. 638p.

MALAVOLTA, E.; VITTI, G.C. & OLIVEIRA, S.A. Avaliação do estado nutricional das plantas: princípios e aplicações. 2.ed. Piracicaba, Associação Brasileira para Pesquisa da Potassa e do Fosfato, 1997. 319p.

PRABAGAR, S.; HODSON, M.J. & EVANS, D.E. Silicon amelioration of aluminium toxicity and cell death in suspension cultures of Norway spruce (*Picea abies* (L.) Karst.), Environ. Exper. Bot., 70:266-276, 2011.

RAIJ, B.van; ANDRADE, J.C.; CANTARELLA, H. & QUAGGIO, J.A. Análise química para avaliação da fertilidade de solos tropicais. Campinas, Instituto Agronômico de Campinas, 2001. 284p.

REIS, T.H.P. Efeito da associação silício líquido solúvel com fungicida no controle fitossanitário do cafeeiro. Coffee Sci., 3:78-80, 2008.

ROSOLEM, C.A. Recomendação e aplicação de nutrientes via foliar. Lavras, UFLA/FAEPE, 2002. 99p.

SOUSA, J.V.; RODRIGUES, C.R.; LUZ, J.M.Q.; SOUSA, V.B.F.; CARVALHO, P.C.; RODRIGUES, T.M. & BRITO, C.H. Silicato de potássio via foliar no milho: Fotossíntese, crescimento e produtividade. Biosci. J., 26:502-513, 2010.

TAKAHASHI, E. Uptake mode and physiological functions of silica. In: MATUSUO, T. & HOSHIKAWA, K., eds. Science of rice plant physiology. Tokio, Nobunkyo, 1995. v.2. p.420-433.

TAKATSUKA, M. & MAKIHARA, D. Plant water relation and silicon concentration in two rice varieties differing in salinity tolerance. Japan J. Trop. Agric., 45:259-265, 2001.

VLAMIS, J. & WILLIAMS, D.E. Manganese and silicon interaction in the gramineae. Plant Soil, 27:131-140, 1967.

WANG, S.Y. & GALLETA, G.J. Foliar application of potassium silicate induces metabolic changes in strawberry plants. J. Plant Nutr., 21:157-167, 1998.