UTILISATION OF SILICON FROM METALLURGY SLAG BY SUGARCANE

By

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Abstract

SUGARCANE is a species that accumulates silicon (Si) and has the ability to respond to silicon fertilisation, especially in soils where this element is scarce. Metallurgy slags constitute a source of Si in soils where this crop is grown. The objective of this paper was to study the value of metallurgy slag as a source of Si for sugarcane. A randomised block experimental design was adopted, in a 2×4 factorial combination represented by two sugarcane cultivars (SP81-3250 and RB86-7515) and four Si rates of slag providing 0, 100, 200, and 400 kg/ha. The application of metallurgy slag (silicate) increased the available soil Si content as well as the status of available Si and the Si content in sugarcane leaves. The amount of Si from the applied silicate accumulated by the above-ground part of sugarcane ranged between 23 and 56% in varieties RB86-7515 and SP81-3250, respectively. On average, 39% of the Si absorbed by the above-ground part of sugarcane came from the applied fertiliser (silicate).

Introduction

At present, the importance of sugarcane has been highlighted as a source material for the production of sugar and more particularly because it constitutes a basic input for the production of ethanol. Brazil stands out in the world scenario as the largest producer of sugarcane (Brazil. Ministério da Agricultura e Pecuária, 2007). However, many sugarcane areas in the country are characterised by significantly weathered soils, and therefore have small amounts of soluble or available silicon (Si) available to crops.

Sugarcane is considered a Si-accumulating crop. Several studies (Pereira *et al*., 2004; Carvalho-Pupatto *et al*, 2003; Berni and Prabhu, 2003) have demonstrated that grasses respond favourably to silicon fertilisation, especially when grown in soils deficient in 'available' Si.

Si provides many benefits to sugarcane including increased photosynthetic efficiency and resistance to the attack of pests and diseases, higher tolerance to water stress during periods of low soil moisture (Korndörfer and Datnoff, 1995), relief from damage caused by frosts and improved plant architecture (Savant *et al*., 1999), among others.

Such benefits result in improved sugarcane quality and increased sugarcane productivity. According to Kingston *et al*. (2005), the beneficial effects of Si in sugarcane clearly indicate that this element should be treated as an integral part of the fertilisation practices associated with sugarcane cultivation.

The metallurgy slags from iron steel production are basically composed of calcium and magnesium silicates. So long as they do not contain heavy metals in their composition, they can satisfactorily meet the requirements of a good Si source for agricultural use, such as: high soluble Si content, easy mechanised application, balanced ratios and amounts of calcium (Ca) and magnesium (Mg), low cost, and low soil contamination potential with heavy metals (Korndorfer *et al*., 2004a).

Although the agricultural use of industrial residues such as metallurgy slags is not very common in Brazil in spite of the high quantities available, their use as a source of Si for plants has been studied and in many parts of the world (Prado and Fernandes, 2001).

Considering that part of Si absorbed/accumulated by plants comes from the soil and another part comes from Si applied in the form of fertiliser, our aim in this study was to evaluate varietal differences with regard to Si absorption and the amount of accumulated Si in the above-ground part that is derived from metallurgy slag.

Material and methods

The experiment was conducted in an experimental area of Universidade Federal de Uberlândia, in Uberlândia city, Brazil, simulating a field situation, during the period from August 15, 2007 to May 2, 2008.

A randomised block experimental design was adopted, in a 2×4 factorial combination represented by two sugarcane cultivars (SP81-3250 and RB86-7515) and four rates of Si (0, 100, 200, and 400 kg/ha), with four replicates (Table 1).

The metallurgy slag ($CaSiO_3$) employed had the following physical and chemical characteristics: powder formulation, CaO: 42%, MgO: 12%, SiO_2: 23%, total Si 11.2% (determined by colorimetry after extraction with hydrochloric acid and hydrofluoric acid, according to methodology described by Korndorfer *et al* (2004b), P_2O_5: 0.4%, K_2O: 0.2%, SO_4: 4.4%, Fe: 8.5%, Mn: 1.4%, Mo: 0.4 mg/kg; and Zn: 0.1 mg/kg. Each experimental plot consisted of a plastic tank (200 L capacity), filled with 200 kg of soil where three sugarcane stools were planted.

The soil used in the pots was taken from the 0–20cm of a soil classified as typic Dark Red Dystrophic Latosol with the following chemical characteristics: organic matter = 13 g/dm; pH in $CaCl_2$ 0.01 mol/L (1:2.5) = 5.2; P mehlich = 2.7 mg/dm; K = 1; Ca = 7.0; Mg = 3.0; H + Al = 31.0 all exchangeable in $mmol_c$/dm; and V (base saturation) = 27%, (Embrapa, 1999). The amount of soil soluble Si, 4.3 mg/dm, was determined according to a methodology described by Korndorfer *et al* (2004b), using $CaCl_2$ 0.01 mol/L as extractant.

Before the sugarcane seedlings were transplanted to the tanks (permanent site), pre established quantities of limestone were applied (Table 1), with physical and chemical characteristics similar to those found in the slag used (TNP 85%, CaO = 42%, and MgO = 12%). Both Ca and Mg were balanced, that is, all pots received identical quantities of Ca and Mg.

All treatments received 100 kg N/ha as ammonium sulfate, 300 kg P_2O_5/ha as single superphosphate, 300 kg K_2O/ha as potassium chloride, 80 kg/ha of a cocktail (FTE – BR12) containing 9% Zn, 1.8% B, 2% Mn, 0.8% Cu, 0.1% Mo, and 3% Fe, as recommended by Boletim Técnico N° 100 (1996).

Table 1—Treatments and amount of slag and lime used in the experiment.

Treatments	Slag rates	Lime rates
	kg/ha	
1. 0 kg/ha of Si, cultivar RB86-7515	0	3559
2. 100 kg/ha of Si, cultivar RB86-7515	890	2669
3. 200 kg kg/ha of Si, cultivar RB86-7515	1779	1779
4. 400 kg/ha of Si, cultivar RB86-7515	3559	0
5. 0 kg/ha of Si, cultivar SP81-3250	0	3559
6. 100 kg/ha of Si, cultivar SP81-3250	890	2669
7. 200 kg/ha of Si, cultivar SP81-3250	1779	1779
8. 400 kg/ha of Si, cultivar SP81-3250	3559	0

The amount of soil used in each tank was divided into two portions of 100 kg each. The nutrients (both macro and micro) were incorporated in to one of those parts. Next, the soil was placed in the bottom of the tank. The treatments, the limestone and the slag were incorporated into the second portion of soil, which was then placed in the pot, over the first portion. This procedure was adopted to achieve a uniform distribution of nutrients in the entire tank, leaving the limestone and the silicate in the first soil layer only. Water was added in the next step, with about 32 L applied per pot; this is the quantity required to reach approximately 70% of field capacity. The amounts of slag and limestone used in each treatment are presented in Table 1.

Three pre-germinated (one month old) cuttings of sugarcane were planted in each tank on September 13. Two kg/ha boric acid were applied per pot on December 10, 2007 (87 days after transplanting). On December 17, 2007, after nitrogen deficiency was detected, we applied 200 kg/ha N in the form of ammonium sulfate (20% N). On December 21, 2007 we again applied 2 kg/ha boric acid. Leaves (first leaf from the apex to the base at the TVD or Top Visible Dewlap) were collected in January 2008 for Si analysis according to methodology described by Korndorfer and Ramos (2008). Soil samples were taken on the same day for determination of available or soluble Si.

Since a high infestation of sugarcane spittlebugs was observed in the overall experiment, the insecticide thiamethoxan 250WG was applied on March 13, 2008 at a rate of 2.5g of active ingredient per 4 L water. The sugarcane was harvested eight months after planting. At harvest, the plants were divided into leader shoot (heart + leaves) and stalks and then weighed.

The plant material was ground separately and dried in a forced air circulation oven at 65ºC to constant weight. After drying, the material was placed in properly identified plastic bags. Si accumulation by the plants was determined as a function of dry matter yield and on Si content in the tissues of the various plant parts.

Si determinations were made according to analytical procedures described by Korndorfer *et al.* (2004a). After harvest, soil samples were taken from each pot for determination of soluble Si analysis according to Korndorfer *et al.* (2004a) and for determination of pH and exchangeable Ca and Mg analysis according to Embrapa (1999). The qualitative results were submitted to analysis of variance and means were compared using Tukey's test at 5% significance. The quantitative results were submitted to polynomial regression analysis. The SISVAR software was used in the statistical analysis (Ferreira, 2000).

Results and discussion

Si content in the soil showed an increasing trend with increasing rates of slag at 120 and 260 days after application (Figure 1).

The data showed that, at 120 days, indicated Si content increased by 18, 56, and 72% relative to the control, for doses of 100, 200, and 400 kg Si/ha, respectively. At 260 days, soil Si contents in the treatments that received 100, 200, and 400 kg/ha Si were 2, 8, and 50% higher than the control, indicating that nine months after application, the slag continued to supply Si to the soil although at smaller quantities with the lower rates of 100 and 200 kg Si/ha.

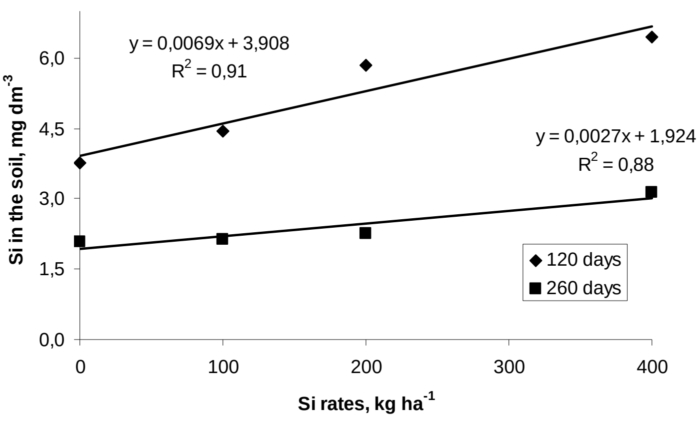

Fig. 1—Soil Si content at 120 and 260 days after slag (silicate) application to the soil.

By comparing the soil Si results at 120 and 260 days after slag application, a significant reduction can be noted in available Si contents in the soil (Figure 1). Such difference can be explained in part by Si extraction by the sugarcane (Table 2). Si contents in the plants increased from 12.31 to 17.46 g per pot when the Si dose applied was 400 kg/ha, corresponding to an increase of approximately 70% in the amount of Si extracted by the above-ground part of sugarcane (Table 2).

The increased Si contents in the soil caused by the application of slag resulted in increased amounts of Si accumulated in the above-ground part of sugarcane (Table 2).

The silicon mean recovery from slag (mean of two sugarcane cultivars) was 39.4%, varying from 25.8 to 56.6% depending on the Si rate used (Table 2). Considering the fact that the soil under study had low clay (sandy soil), low organic matter and low water retention capacity, the interaction of the slag particles with the soil solid phase was smaller, which can explain the low reactivity of the slag (silicate) applied. This result agrees with those reported by Korndörfer *et al.* (1999), who studied the effect of calcium silicate as a source of Si on upland rice crop in four soils representative of the savanna region and found greater recovery of this element in soils with higher clay contents.

Table 2—Soil available Si, Si accumulated in the above-ground part of plant, Si uptake from the fertiliser, and Recovery Index as a function of Si doses applied (mean of 2 varieties).

Si applied	Soil available Si	Si accumulated above-ground part of the plant	Si uptake from the fertiliser*	Recovery index**	Mean
g per pot				%	
0	0.42	12.31	–	–	
5	0.43	15.14	2.83	56.6	39.4
10	0.45	15.89	3.8	35.8	
20	0.63	17.46	5.15	25.8	

* Absorbed Si from the fertiliser = Si accumulated in the above-ground part – Si accumulated by the control;
** Recovery Index (%) = (absorbed Si from the fertiliser/applied Si) × 100

Cultivar SP81-3250 had the highest Si recovery capacity (Recovery Index equal to 55.8%), which means that of all absorbed Si more than one half came from the fertiliser. The difference between recovered Si amounts was approximately 60%, which gives variety SP81-3250 a greater capacity of utilising Si from the fertiliser (slag) when compared with variety RB86-7515 (Figure 2).

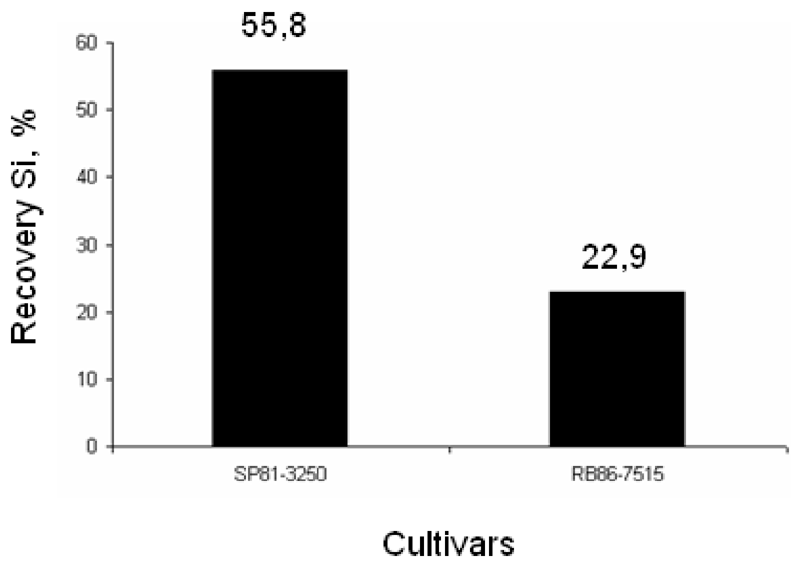

Fig. 2—Silicon recovered from the fertiliser by two sugarcane cultivars.

In general, cultivar SP81-3250 proved superior to RB86-7515 for its capacity to accumulate Si in the top leaves, lower leaves, and stalks, which resulted in greater accumulation of this element in the whole above-ground part of the plant (Table 3).

The mean contents of Si accumulated in the top leaves, lower leaves, stalks, and the whole above-ground part of cultivar SP81-3250 were 80%, 29%, 23%, and 24% higher, respectively, than the values accumulated by variety RB86-7515 (Table 3).

The mean Si contents accumulated in the leaves, stalk, and the whole above-ground part increased linearly with Si doses applied (Figures 3a, 3b, and 3c).

This fact reinforces the importance of Si use in sugarcane fertilisation to obtain greater resistance against pests, diseases and drought susceptibility.

The foliar diagnosis performed at 87 days after planting the seedlings showed that variety RB86-7515 had a higher incidence of B deficiency symptoms when compared with variety SP81-3250 (Table 4).

Table 3—Effect of slag on accumulation of Si in different plant parts in two sugarcane cultivars.

Si rates	Si accumulated top leaves		Si accumulated lower leaves		Si accumulated stalks		Si accumulated above-ground part	
	SP81-3250	RB86- 7515	SP81-3250	RB86-7515	SP81-3250	RB86-7515	SP81-3250	RB86-7515
kg/ha	g/pot							
0	2.49 a	1.20 b	8.62 a	7.76 a	2.54 a	2.02 a	13.65 a	10.97 a
100	2.59 a	1.30 b	12.01 a	8.06 b	3.67 a	2.64 b	18.27 a	12.00 b
200	2.28 a	1.57 b	13.00 a	8.90 b	3.31 a	2.73 a	18.58 a	13.19 b
400	2.75 a	1.47 b	11.84 a	11.63 a	4.17 a	3.07 b	18.75 a	16.17 b
Average	2.53 a	1.39 b	11.37 a	9.09 b	3.42 a	2.62 b	17.31 a	13.08 b
CV: 20%	LSD (cultivar): 0.59 LSD** (mean): 0.29		LSD (cultivar): 3.51 LSD (mean) : 1.76		LSD (cultivar): 0.86 LSD (mean): 0.43		LSD (cultivar): 4.24 LSD (mean): 2.12	

*Means followed by the same letter in the line are not significant by the Tukey test at 5% significance.
***LSD = least significant difference.

Table 4—Effect of slag on Si content in different plant parts and number of leaves with B deficiency in two sugarcane cultivars.

Si rates	Si content top leaves		Si content lower leaves		Si content stalks		Number of leaves B deficiency***	
	SP81-3250	RB86-7515	SP81-3250	RB86-7515	SP81-3250	RB86-7515	SP81-3250	RB86-7515
kg/ha	%							
0	0.32 a	0.33 a	0.93 a	0.96 a	0.10 a	0.10 a	8 a	12 a
100	0.34 a	0.33 a	1.16 a	0.92 a	0.13 a	0.12 a	4 a	13 b
200	0.36 a	0.35 a	1.22 a	0.98 a	0.13 a	0.11 b	3 a	15 b
400	0.37 a	037 a	1.21 a	1.35 a	0.18 a	0.14 b	6 a	13 b
Average	0.35 a	0.35 a	1.13 a	1.05 a	0.14 a	0.12 b	5 a	13 b
CV: 10%	LSD (cultivar): 0.05 LSD** (mean): 0.03		LSD (cultivar): 0.29 LSD (mean): 0.14		LSD (cultivar): 0.02 LSD (mean): 0.009		LSD (cultivar): 4.41 LSD (mean): 2.20	

*Means followed by the same letter in the line are not significant by the Tukey test at 5% significance.
**LSD = least significant difference.
*** Report made 87 days after seed transplanting.

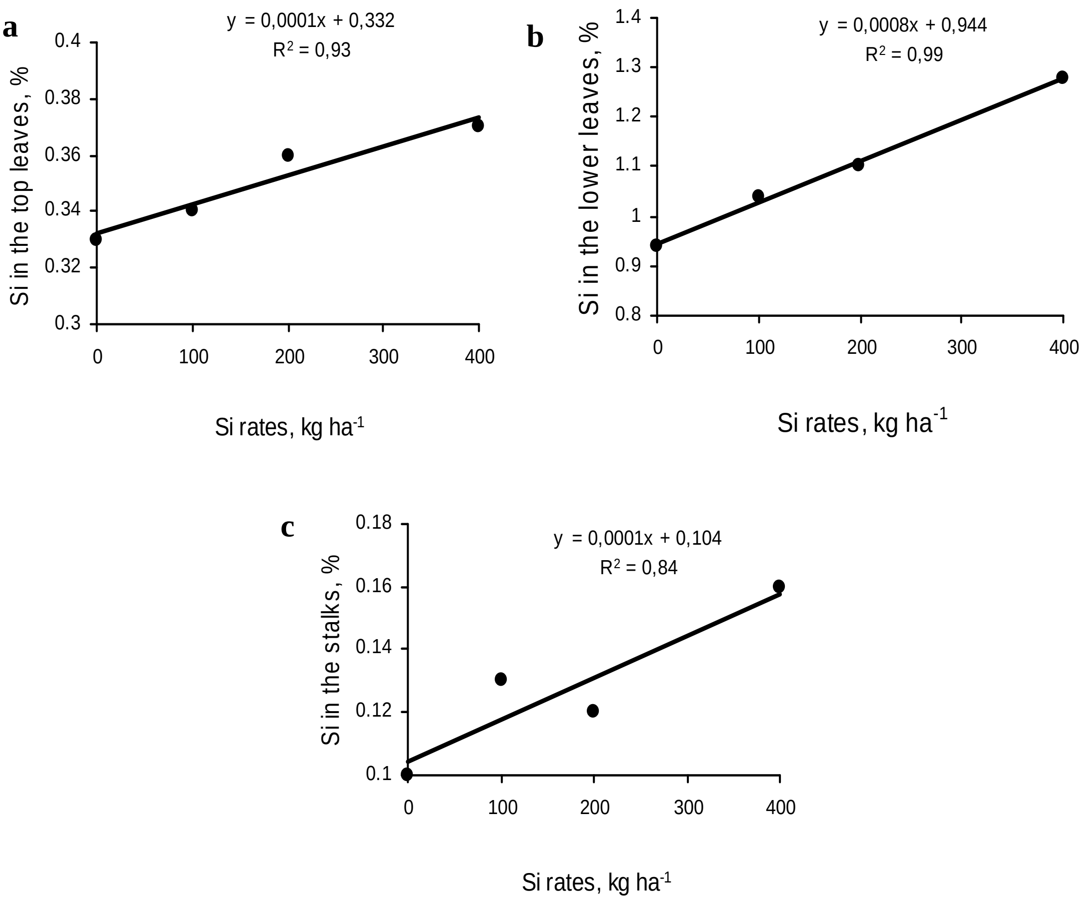

Fig 3—Si contents in sugarcane top leaves (a), lower leaves (b), and stalks (c) as a function of Si rates applied to the soil (means of two cultivars).

The two sugarcane cultivars did not differ from each other for Si content in the top leaves and lower leaves in any of the doses applied (Table 4). However, the mean Si concentrations increased from 0.33 to 0.37% in the top leaves and from 0.94% to 1.28% with the highest rate of 400 kg/ha.

Regardless of cultivars, Si concentration in the top leaves and the lower leaves increased linearly with doses of this element (Figures 4a and 4b). When the control is compared against the highest Si dose (400 kg/ha), the mean values of increase in Si concentration in the top leaves and lower leaves were 36 and 12%, respectively.

Variety SP81-3250 had a significantly higher (14% higher, on average) Si content in stalks compared to variety RB86-7515 (Table 4). Considering only the two highest Si doses (200 and 400 kg/ha), cultivar SP81-3250 concentrated 15 and 22% more Si in stalks, respectively, than RB86-7515 (Table 4).

Silicon deposition in stalks may increase sugarcane resistance to lodging (Ma and Takahashi, 2002). This trait is particularly important in mechanised green cane harvest. The selection of varieties with high Si uptake potential could minimise damping-off problems in mechanised harvest.

The mean Si content in stalks of both sugarcane varieties increased linearly with Si doses applied to the soil (Figure 4c). Plants grown in the presence of 400 kg/ha Si had 60% more Si in stalks than control plants.

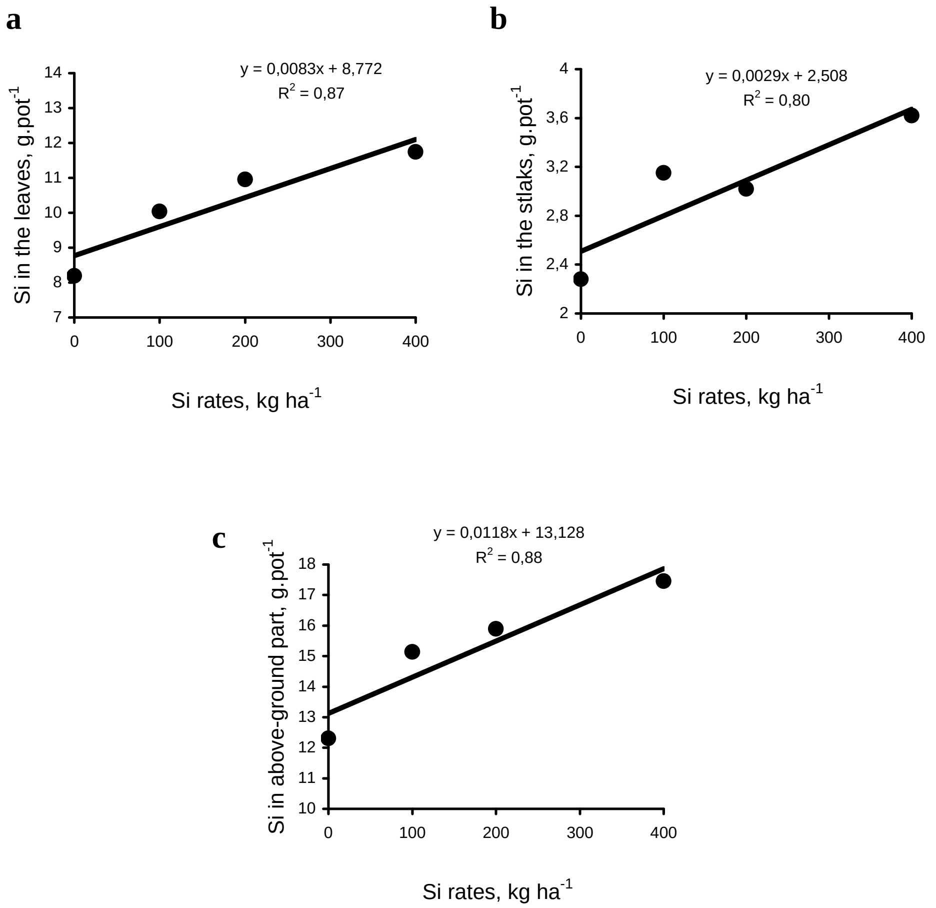

Fig. 4—Si accumulated in the leaves (a), stalks (b), and the whole above-ground part (c) as a function of Si rates applied (mean of varieties RB86-7515 and SP81-3250).

Si deposition in stalks could also increase sugarcane resistance to the attack of pests such as the stalk borer, *Eldana saccharina* (Lepidoptera: Piralidae) (Keeping and Meyer, 2005).

Conclusions

a) The silicate application increased the soil content of available Si and the Si content in sugarcane leaves.

b) The amount of Si from the applied silicate accumulated by the above-ground part of sugarcane ranged between 23 and 56% in varieties SP81-3250 and RB86-7515, respectively.

c) On average, 39% of the Si absorbed by the above-ground part of sugarcane came from the applied fertiliser (silicate).

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UTILISATION PAR LA CANNE A SUCRE DU SILICIUM PROVENANT DE SCORIES DE METALLURGIE

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MOTS-CLÉS: Silicate, Si soluble, Contribution du Silicium, Silicium Accumulé.

Résumé

LA CANNE à sucre est une espèce qui accumule le Silicium (Si) et a la capacité de répondre à de la fertilisation à base de Silicium, spécialement dans les sols où cet élément est rare. Les scories de métallurgie constituent une source de Si pour les sols où la canne à sucre est cultivée. L'objectif de ce papier est d'étudier la valeur des scories de métallurgie comme source de Si pour la canne à sucre. Un essai factoriel 2×4 en blocs randomisés fut réalisé. Cet essai comprenait 2 variétés (SP81-3250 et RB86-7515) et 4 doses (0, 100, 200, et 400 kg/ha) de Si provenant de scories. L'épandage des scories de métallurgie (silicate) augmenta la teneur en Si assimilable du sol aussi bien que le statut en Si assimilable et la teneur en en Si des feuilles. La quantité de Si accumulée par les parties aériennes de la canne à sucre variait respectivement de 23 à 56% dans les variétés RB86-7515 et SP81-3250. En moyenne, 39% du Si absorbé par les parties aériennes provenait de l'engrais appliqué (silicate).

UTILIZACIÓN DE SILICIO PROVENIENTE DEL DESECHO DE LA METALURGIA, POR LA CAÑA DE AZÚCAR

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PALABRAS CLAVE: Silicato, Si soluble, Recuperación de Silicio, Si Acumulado.

Resumen

LA CAÑA de azúcar es una especie que acumula silicio (Si) y tiene la habilidad de responder a la fertilización con silicio, especialmente en suelos donde este elemento es escaso. Los desechos de la metalurgia constituyen una fuente de Si en suelos donde se planta este cultivo. El objetivo de este trabajo era estudiar el valor del desecho de la metalurgia como fuente de Si para la caña de azúcar. Se empleó un diseño experimental de bloques al azar, en una combinación factorial 2×4, representada por dos variedades de caña de azúcar (SP81-3250 y RB86-7515) y cuatro dosis de Si proveniente del desecho, que proporcionaran 0, 100, 200 y 400 kg/ha. La aplicación del desecho de la metalurgia (silicato) incrementó el contenido de Si disponible en el suelo, así como el estado de disponibilidad de Si y el contenido de Si en las hojas de la caña de azúcar. La cantidad de Si del silicato aplicado acumulada en la parte aérea de la planta osciló entre 23 y 56% en las variedades SP81-3250 y RB86-7515, respectivamente. En promedio, 39% del Si absorbido por la parte aérea de la planta provino del fertilizante aplicado (silicato).