

Biomass and concentration of nutrients and silicon in sugarcane grown on soil fertilized with diatomite

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ABSTRACT: Silicon (Si) plays an important role in sugarcane, but there is a gap of information regarding the potential of diatomite as a Si fertilizer to this crop. Here, we assessed the effects of five rates (equivalents to 75; 150; 225; 300 and 375 kg ha⁻¹ Si) of a diatomite-based fertilizer on the biomass yield and concentration of nutrients and Si in sugarcane plants grown on a sandy soil. The efficiency of the extractants acetic acid and calcium chloride in predicting Si uptake was also assessed. Results showed that diatomite was efficient in supplying available Si in the soil and increased Si concentration in the plant. The addition of diatomite significantly increased the available contents of P, K, Mn, Cu, and the cationic exchangeable capacity of the soil. The concentrations of N, P, Mn, Cu, and Zn in shoots were elevated, suggesting that the fertilizer can play a role in the efficient use of nutrients by sugarcane. The extractant 0.01 mol L⁻¹ CaCl₂ was better correlated with Si concentration in plants than 0.5 mol L⁻¹ acetic acid. Therefore, CaCl₂ is the recommended extractant to estimate Si availability because of its higher efficiency and lower cost.

Key words: amorphous silicate; diatomite; mineral nutrition; sandy soils; soil fertility

Biomassa e concentração de nutrientes e silício em cana-de-açúcar cultivada em solo adubado com diatomita

RESUMO: O silício (Si) desempenha um papel importante na cana-de-açúcar, mas há pouca informação sobre o potencial da diatomita como fertilizante de Si para esta cultura. No presente estudo, avaliamos os efeitos de cinco doses (75; 150; 225; 300 e 375 kg ha⁻¹ Si) de um fertilizante à base de diatomita na produção de biomassa e na concentração de nutrientes e Si em plantas de cana-de-açúcar cultivadas em um solo arenoso. A eficiência dos extratores ácido acético e cloreto de cálcio na previsão da absorção de Si também foi avaliada. Os resultados mostraram que o fertilizante foi eficiente em fornecer Si disponível no solo e aumentar a concentração de Si na planta. A adição de diatomita aumentou significativamente os teores disponíveis de P, K, Mn, Cu e a capacidade de troca catiônica do solo. As concentrações de N, P, Mn, Cu e Zn na parte aérea foram aumentadas, sugerindo que o fertilizante pode desempenhar um papel no uso eficiente dos nutrientes pela cana-de-açúcar. O extrator CaCl₂ 0,01 mol L⁻¹ foi mais eficiente em estimar a concentração de Si nas plantas do que ácido acético 0,5 mol L⁻¹. Portanto, o CaCl₂ deve ser o extrator recomendado para estimar a disponibilidade de Si devido a sua maior eficiência e menor custo.

Palavras-chave: silicato amorfo; diatomita; nutrição mineral; solos arenoso; fertilidade do solo

Introduction

Silicon (Si) is an abundant metalloid in the earth's crust and beneficial to plants, alleviating stresses caused by drought (Amin et al., 2018), salinity (Wang et al., 2015), metals (Nascimento & Cunha, 2015), pests and diseases (Liang et al., 2015). Si-supplied plants, especially graminaceous species such as maize, rice, and sugarcane, may show higher yields and better nutritional status and quality when fertilized with Si (Keeping, 2017).

The total Si concentration in most soils is over 50%, but it is mainly found as SiO_2 in a wide variety of Si-bearing minerals in crystalline, poorly crystalline, and amorphous phases (Tubana et al., 2016), therefore not available for plant uptake. Silicon bioavailability is very low because of the slow release of Si from mineral weathering and low contribution of organic matter decomposition. Besides, the Si exportation by crops and soil desilication process continuously depletes the Si available concentration in the soil (Liang et al., 2015). Yield responses to Si take place especially in soils containing a low concentration of available silicon. Studies in Si-deficient soils ($< 10 \text{ mg kg}^{-1}$ Si) have shown that silicate fertilization promotes a significant increase in the yield of sugarcane and improvement in parameters such as fiber and total reducing sugar (Camargo et al., 2013).

Silicon fertilizers can increase nutrient uptake by optimizing soil fertility, plant water use, and soil physical and chemical characteristics (Eneji et al., 2008; Greger et al., 2018; Nascimento et al., 2020). For instance, Si fertilizers can contribute to the retention of water and cations in the soil (Pati et al., 2016). Eneji et al. (2008) found that Si improved the biomass yield and K uptake in four graminaceous plants under drought stress. Higher N accumulation in plants fertilized with Si has been shown to cowpea (Mali & Aery, 2008), rice (Pati et al., 2016), melon (Nascimento et al., 2020), and wheat (White et al., 2017). Increased efficiency of the use of P by Si was also obtained for agricultural crops (Abdalla, 2010).

Brazil is the largest world producer of sugarcane, but the national mean sugarcane yield (75 t ha^{-1}) is relatively low; the average yield in northeast Brazil is even lower, i.e., 56 t ha^{-1} (Conab, 2020). Sugarcane in this part of the country is grown mainly on sandy soils. These soils are characterized by low cation exchange capacity (CEC), water retention, natural fertility, and organic matter, and deficient soil soluble Si contents (Crusciol et al., 2018). Thus, sugarcane cultivated on these depleted-Si soils can benefit from Si fertilization.

The plant-available Si concentrations in soil vary widely. A range of extractants, including unbuffered salts, acids, and acetic acids have been used to estimate the Si availability to crops. There is no universally adopted method (Haynes, 2014) so that extractants must be tested for several soil conditions. Diluted salt solutions such as CaCl_2 10 mmol L^{-1} have ionic strength similar to soil solution; therefore, they prevent soil dispersion and facilitates soil analyses (Miles et al., 2014). Acetic acid has also been intensively used as a Si extractant (Liang et al., 2015). This extractant partially dissolves

amorphous Fe and Al oxides and amorphous aluminosilicates hence releasing the adsorbed Si (Haynes, 2014).

Several Si sources varying in total Si contents and solubility are used in Brazil. Most studies use calcium silicate (CaSiO_3) and slags (Camargo et al., 2017; Liang et al., 2015), and only a few studies tested diatomites as a Si source to crops (Nascimento et al., 2020). Diatomite is a sedimentary rock formed by the accumulation of diatom algal fossils and composed predominantly of amorphous silica ($\text{SiO}_2 \cdot n\text{H}_2\text{O}$) (Sandhya & Prakash, 2019). This study aimed to evaluate the effects of a diatomite-based fertilizer on the biomass yield and concentration of nutrients (N, P, K, Fe, Mn, Cu, and Zn) and Si in sugarcane plants grown on a sandy soil typical of the producing sugarcane region of NE Brazil. The soil Si availability by two extractants (acetic acid and calcium chloride) and the changes in soil chemical characteristics driven by diatomite were also assessed.

Materials and Methods

Pot experiment

The soil used in the experiment was collected at a depth of 0.0–0.2 m in Santa Rita - PB ($6^\circ 56' 43.4'' \text{ S}$ and $35^\circ 07' 57.7'' \text{ W}$) and is representative of many areas of sugarcane cultivation in NE Brazil. The soil was dried, sieved (2 mm mesh), and three subsamples were chemically and physically analyzed using standard methods (Embrapa, 2011). The pH was determined in the water at a 1:2.5 soil/water ratio. The determination of soil organic carbon used the Walkley-Black oxidation method. The Ca^{2+} and Mg^{2+} exchangeable contents were obtained with 1 mol L^{-1} KCl solution and determined by titration. The available contents of K^+ , Na^+ and P were extracted by Mehlich-1 and analyzed by flame photometry (K^+ , Na^+) and colorimetry (P). The exchangeable Al^{3+} was measured by titration in the extract of the 1 mol L^{-1} KCl solution. The potential acidity ($\text{H}^+ + \text{Al}^{3+}$) was determined by extraction with 0.5 mol L^{-1} calcium acetate at pH 7.0 and titration with 0.025 mol L^{-1} NaOH. The sum of bases - SB (Ca^{2+} , Mg^{2+} , K^+ , Na^+) was summed up to $\text{H}^+ + \text{Al}^{3+}$ to obtain the cation exchange capacity (CEC). Soil particle-size distribution was determined using the Bouyoucos hydrometer method.

Soluble Si contents in the soil were evaluated by two extraction solutions: CaCl_2 (0.01 mol L^{-1}) and acetic acid (0.5 mol L^{-1}) (Korndörfer et al., 1999). For Si analyses, 10 grams of soil were agitated for 1 hour with 100 mL of either acetic acid or CaCl_2 . Then, the supernatant was decanted and filtrated. Silicon concentration in the soil extracts was measured in a spectrophotometer at a wavelength of 660 nm through the molybdosilicic complex formation.

The results of soil analyses are shown in Table 1. The soil had a slightly alkaline pH, low contents of organic matter and a general low natural fertility. Soil texture was sand. The soil was classified as an Arenosol (IUSS Working Group WRB, 2015). It was highly depleted in Si, with Si available concentrations $< 3.0 \text{ mg kg}^{-1}$.

Table 1. Chemical and physical characteristics of the soil used in the experiment.

pH	water (1:2,5)	7.6
Ca ²⁺	mmol _c kg ⁻¹	10.0
Mg ²⁺	mmol _c kg ⁻¹	7.0
K ⁺	mmol _c kg ⁻¹	0.5
Na ⁺	mmol _c kg ⁻¹	0.0
Al ³⁺	mmol _c kg ⁻¹	0.0
H ⁺ + Al ³⁺	mmol _c kg ⁻¹	7.0
SB	mmol _c kg ⁻¹	17.0
CEC	mmol _c kg ⁻¹	7.4
P	mg kg ⁻¹	12.2
SOC	g kg ⁻¹	2.7
SOM	g kg ⁻¹	4.7
Si _a	mg kg ⁻¹	2.7
Si _c	mg kg ⁻¹	1.1
Sand	g kg ⁻¹	965.0
Silt	g kg ⁻¹	11.0
Clay	g kg ⁻¹	24.0
Soil density	g cm ⁻³	1.5

SB sum of bases; CEC cation exchange capacity; SOC soil organic carbon; SOM soil organic matter; Si_a silicon available in the soil extracted with acetic acid 0,5 mol L⁻¹; Si_c silicon available in the soil extracted with CaCl₂ 0,01 mol L⁻¹.

Prior do to the experiment set up, the soil was fertilized with macro and micronutrients at the following rates and sources based on Alvarez (1974) and Nascimento et al. (2006): 50 mg dm⁻³ N (Urea), 150 mg dm⁻³ K (KCl), 400 mg dm⁻³ P (MAP), 40 mg S dm⁻³ (K₂SO₄), 3.664 mg Mn dm⁻³ (MnCl₂·4H₂O), 4 mg Zn dm⁻³ (ZnSO₄·7 H₂O), 1.329 mg Cu dm⁻³ (CuSO₄), 1.556 mg dm⁻³ Fe (FeSO₄·7H₂O) and 0.15 mg dm⁻³ Mo (Na₂MoO₄·2H₂O). Two three-months-old sugarcane seedlings, variety RB 06-1675 (developed by RIDESA - Rede Interuniversitária para o Desenvolvimento do Setor Sucoalcooleiro), were transplanted to each 15 L pot; the soil was maintained at 80% of the water holding capacity throughout the experiment by weighting the soil and adding the required amount of water previously defined by the pot capacity method (Casaroli & Jong van Lier, 2008). The pot experiment was carried out between and February and May 2018.

The treatments comprised five Si rates equivalents to 75, 150, 225, 300, 375 kg ha⁻¹ plus a control (without Si addition) applied as a diatomite fertilizer to pots containing 10 dm⁻³ of soil (dry base). These rates were based on previous studies and economic feasibility for fertilizer use. Diatomite belongs to the group of silica-bearing rocks. It is originated from sedimentary materials consisting mainly of the fossilized skeletal remains of diatom, a unicellular aquatic plant related to the algae, during the tertiary and quaternary periods (Akin et al., 2000)

The source used was a granulated fertilizer (2 - 5 mm) produced from diatomite (Agrisilica@), which contains the following guarantees provided by the manufacturer: 29, 1.4, and 1.1% of total Si, Ca and Mg, respectively, cation exchange capacity > 50.0 cmol_c dm⁻³, and trace concentrations of heavy metals (0.021; 0.004; 0.003; 0.002; 0.002; 0.0003 and < 0.0001% for Mn, Cr, Zn, Cu, Pb, As and Cd, respectively).

Chemical analysis of plants and soil samples

The plant shoot was collected at 70 days after transplanting, then washed with distilled water, and dried at 65°C. The biomass was recorded, and plant tissue was ground in a Willey-type knife mill. The Si concentration of shoots was determined according to the methodology proposed by Elliot & Snyder (1991). Nitrogen was extracted by digesting 0.2 g of the plant material in concentrated sulfuric acid at 350° C, according to the Kjeldahl method. Potassium, P, Cu, Fe, Mn, and Zn were determined in the digestion extract of 0.5 g of the samples in nitroperchloric solution at 200°C.

Soil samples were collected at the end of the experiment for chemical analysis to assess the effect of diatomite on soil characteristics. The following analyses were performed: pH; exchangeable Ca and Mg; available concentrations of Cu, Fe, Mn, Zn, K, and P extracted by Mehlich-1; cation exchange capacity (CEC) by the sodium/ammonium acetate method. Phosphorus concentration was obtained by colorimetry, while K was measured by flame spectrometry. Calcium and Mg in soil were determined by titration. The micronutrients Cu, Fe, Mn, and Zn were measured by atomic absorption spectrometry. Silicon was determined by UV spectrometer through the formation of silicon-molybdate complexes.

Analytical quality control used blanks and a certified reference material SRM 1570a (Spinach Leaves) by the National Institute of Standards and Technology (NIST). All analyzes were performed in duplicate and element recoveries in the reference material ranged from 93 to 107%.

Statistical analyses

The experiment was carried out in a greenhouse using a randomized complete block design and four replicates. The data were analyzed by applying ANOVA (F test). Regression analyses ($p \leq 0.05$) were used to investigate the relationship of Si rates applied to the soil with biomass yield and concentration and content of Si in plants. The Si effect on soil characteristics and nutrients in plants were tested by Tukey ($p \leq 0.05$). Pearson's correlation was used to assess Si soil extractants' efficiency in estimating Si concentration in plants. All statistical analyses were accomplished with the software Statistica 10.1.

Results and Discussion

Diatomite effects on the soil chemical characteristics

There was no significant effect ($p > 0.05$) on the pH and available Mg and Fe concentrations in the soil (Table 2). On the other hand, diatomite promoted a significant increase in the CEC and availability of K and Mn contents. The increase in CEC may be due to the high porosity (35 - 65%), high permeability, low density, small particle size, and high specific surface area of diatomite (Bakr, 2010). Therefore, it is capable of retaining water and cationic ions owing to its CEC > 50 cmol_c kg⁻¹ (Pati et al., 2016). Increasing CEC in sandy soils is of great importance for soil fertility management, as it minimizes the leaching losses of K⁺, NH₄⁺ and Ca²⁺ and increases the availability of

Table 2. Mean values (\pm standard deviation) of chemical and physical characteristics of the Arenosol fertilized with diatomite and cultivated with sugarcane for 70 days.

Si (kg ha ⁻¹)	CEC	K ⁺ _{exchangeable} (mmolc dm ⁻³)	Ca ²⁺ _{exchangeable}	P _{available}	Mn _{available}	Cu _{available}	Zn _{available}
					(mg dm ⁻³)		
0.0	7.9 \pm 1.6b	0.4 \pm 0.1b	19.0 \pm 1.0a	9.2 \pm 2.1b	4.8 \pm 0.4b	0.9 \pm 0.1b	11.9 \pm 2.9a
75.0	12.3 \pm 1.2ab	0.6 \pm 0.1ab	18.0 \pm 2.0ab	12.0 \pm 1.5ab	8.2 \pm 1.6ab	1.3 \pm 0.2ab	9.2 \pm 1.2ab
150.0	15.6 \pm 1.0a	0.8 \pm 0.2a	17.0 \pm 2.0ab	14.7 \pm 1.4ab	11.4 \pm 3.0a	1.5 \pm 0.2ab	7.2 \pm 0.5b
225.0	18.1 \pm 2.1a	0.7 \pm 0.1ab	15.0 \pm 1.0b	16.2 \pm 0.3ab	11.8 \pm 2.5a	1.6 \pm 0.1ab	6.7 \pm 0.4b
300.0	16.2 \pm 0.5a	0.7 \pm 0.2ab	15.0 \pm 1.0b	18.5 \pm 5.8a	8.4 \pm 0.8ab	1.9 \pm 0.3ab	6.3 \pm 0.4b
375.0	16.7 \pm 0.2a	0.6 \pm 0.1ab	14.0 \pm 0.1b	19.8 \pm 1.2a	5.8 \pm 0.3b	2.7 \pm 0.4a	5.3 \pm 0.6b

Values followed by the same letter in the column do not differ statistically by the Tukey test ($p > 0.05$). CEC cation exchange capacity.

these nutrients to the plant, as observed for K⁺ in the present study.

Available soil Ca and Zn concentrations decreased with increasing silicate rates applied to the soil (Table 2). The availability decrease of these nutrients was probably due to the sugarcane nutrient removal. Other soil reactions can also contribute to this finding. For example, precipitation of Ca and Zn with phosphate [Ca₃(PO₄)₂; Zn(OH)H₂PO₄] and forms of silicic acid [H₃SiO₄⁻; H₂SiO₄²⁻; HSiO₄³⁻ and SiO₄⁴⁻] in the soil solution (Liang et al., 2015). Probably, the precipitation reactions of Ca and Zn ions with phosphate and silicate groups in the soil were more evident because of the soil pH value near neutrality, which geochemically favors the reaction of Ca⁺² and Zn⁺² with anionic groups (Matichenkov & Bocharnikova, 2001). However, the reduction of these nutrients in the soil did not damage the plant growth, and the plants did not show deficiency symptoms.

The availability of P and Cu increased with the addition of diatomite to the soil. The rate of 375 kg ha⁻¹ Si significantly increased by 115 and 300 % the P and Cu concentrations compared to the control, respectively. The increase in P availability may be due to the higher activity of H₃SiO₄⁻ in soil solution promoting the exchange of ligands with the chemo-absorbed H₃PO₄⁻ ion in soil Fe and Al oxyhydroxides; to solubilization of the stable phase of Ca-bound phosphate (Matichenkov & Bocharnikova, 2001). The increase in Cu was probably because phosphate and silicate anions have been sorbed into the soil organic groups, thus blocking the adsorption sites of the organic matter to the Cu and increasing its content in the exchangeable fraction of the soil.

Correlation between Si concentration in plants and soil Si extractants

The soil Si available concentrations in soil depended on the extractant used. 0.5 mol L⁻¹ Acetic acid extracted 139% more Si than 0.01 mol L⁻¹ CaCl₂ (Figure 1). Previous studies have reported a higher Si extraction capacity of acetic acid compared to CaCl₂ (Camargo et al., 2013). However, acetic acid can lead to misinterpretation of Si availability. The extraction of Si with the acetic acid solution occurs at very low pH values (1.0 - 2.0), which can super estimate Si availability by dissolving unavailable Si forms in the soil (Crusciol et al., 2018). In the present study, CaCl₂ had a higher correlation with Si concentration in plants (0.97, $p < 0.01$) than acetic acid (0.91, $p < 0.05$) (Figure 2). Therefore, CaCl₂ is the most recommend extractant for the sandy

soils tested here. It is a neutral salt used at low molarity, which operationally provides the readily available Si concentrations in the soil solution (Liang et al., 2015).

Biomass yield and Si accumulation in shoots

The biomass and Si concentration in shoots of sugarcane were highly correlated and increased linearly with the increasing rates of diatomite applied to the soil (Figure 2). At the highest Si rate applied to the soil, biomass yield, and Si concentration in shoots increased 34 and 31 %, respectively, compared to the control, which demonstrates the potential of the fertilizer to supply Si and hence boost biomass yield.

Previous study has confirmed that silicate fertilization using CaSiO₃ increases sugarcane biomass (Camargo et al., 2017). The Si effects on plant development are related to several ultrastructural, biochemical, and physiological changes. Among them, we can point out (i) increased root growth through cell wall extensibility, which results in the higher acquisition of water and nutrients; and, (ii) higher water use efficiency due to higher stomatal conductance, leaf water content, root hydraulic conductance for the whole plant and reduced transpiratory rate (Wang et al., 2015).

Effects of diatomite on the plant nutrition

Silicon can play an important role in the uptake, transport, and distribution of plant nutrients (Liang et al., 2015). Studies have confirmed that silicate fertilization significantly increases macro and micronutrient concentrations in plants (Garbanzo et al., 2018). Soil fertilization with diatomite induced greater nutrient uptake and translocation to the sugarcane shoots, except for K and Fe (Table 3). The N and P contents in the sugarcane shoot treated with 225 kg ha⁻¹ Si were significantly higher than the control (34 and 52%, respectively). Manganese, Cu and Zn, on the other, had their concentrations increased in shoots only for the Si rates of 300 and 375 kg ha⁻¹ Si. The sandy soil studied here is impoverished in micronutrients (Silva et al., 2019); therefore, such an effect likely occurred due to the input of micronutrients as impurities in the fertilizer.

Silicon fertilization has been shown to increase the N accumulation of cowpea (Mali & Aery, 2008) and rice plants (Pati et al., 2016). Diatomite also improved the efficient use of N by rice through alterations in the metabolism of nitrogen compounds and their distribution in the plant (Detmann et al., 2012).

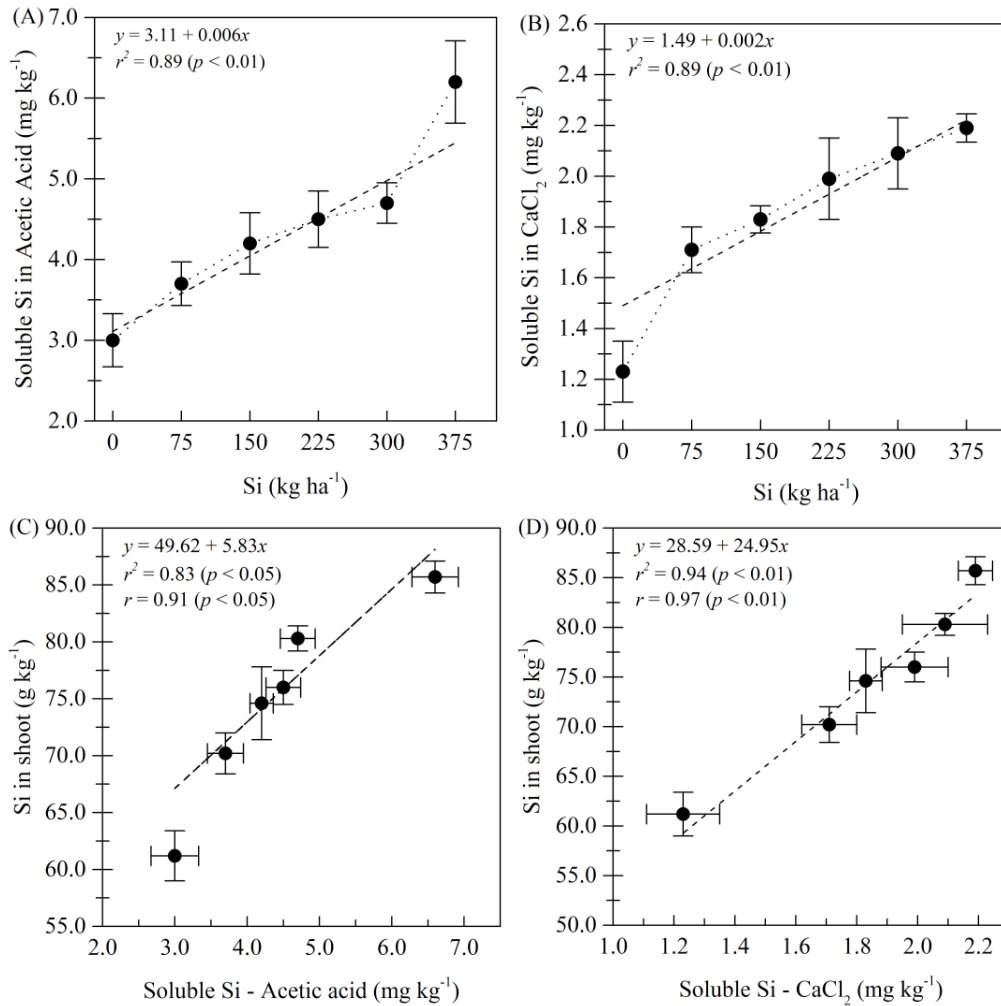


Figure 1. Mean contents (\pm standard deviation) of soluble silicon extracted with acetic acid (0.5 mol L^{-1}) and CaCl_2 (0.01 mol L^{-1}) in Arenosol fertilized with diatomite (A - B). Relationship between the Si contents in shoot of sugarcane and the soluble content in the soil (C - D). $p < 0.01$ or 0.05 significant at 1 and 5 % probability by ANOVA, respectively.

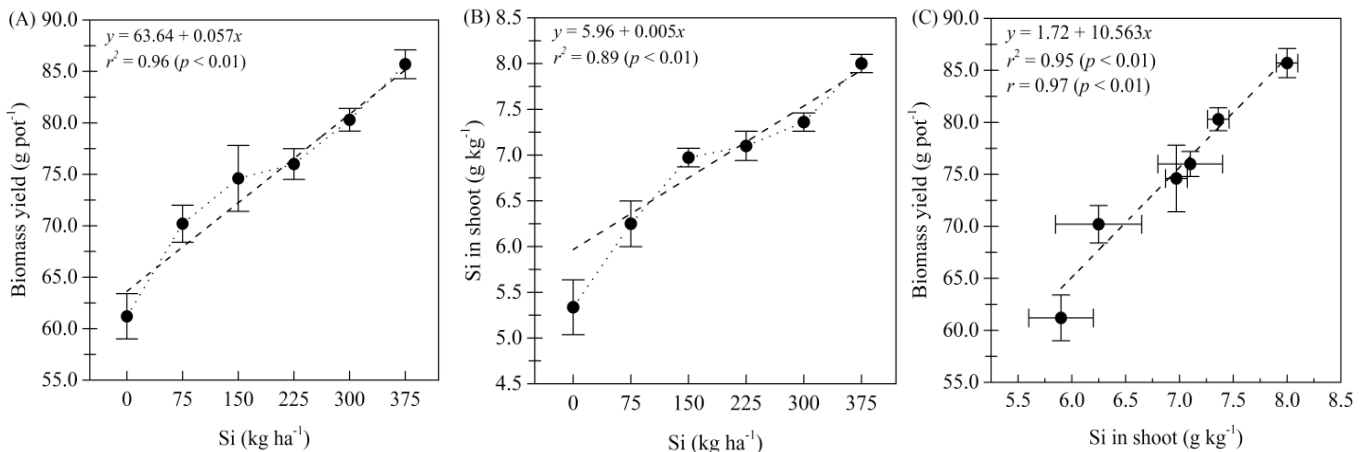


Figure 2. Mean values (\pm standard deviation) of biomass (A) and silicon concentration (B) in shoot of sugarcane plants grown in Arenosol fertilized with diatomite. Relationship between biomass production and Si content in shoot (C). $p < 0.01$ significant at 1% probability by ANOVA.

The increased P concentration in the shoots as a function of the fertilizer supply to soils are in agreement with the role of Si in the P accumulation by Graminae species (Eneji et al., 2008). The main beneficial effect of Si on plant P uptake is to increased soil

P availability, especially in tropical regions with highly weathered soils and high P adsorption capacity (Eneji et al., 2008). Competition between soluble silicates ($\text{H}_3\text{O}_4\text{Si}$) and phosphates (as H_2PO_4^-) for binding sites on soil colloids can enhance the P

Table 3. Mean concentrations (\pm standard deviation) of nutrients in the shoots of sugarcane cultivated in an Arenosol amended with diatomite.

Si (kg ha ⁻¹)	Nitrogen	Phosphorus	Potassium	Iron	Manganese	Copper	Zinc
	(g kg ⁻¹)						
0.0	15.4 \pm 0.1d	4.4 \pm 0.0b	14.0 \pm 1.5ns	77.5 \pm 0.6ns	110.0 \pm 12.0b	15.3 \pm 1.2a	48.8 \pm 8.1b
75.0	18.6 \pm 0.3b	5.2 \pm 0.8ab	15.2 \pm 0.0ns	81.4 \pm 5.1ns	135.0 \pm 15.0ab	13.6 \pm 0.2ab	53.3 \pm 6.7ab
150.0	18.8 \pm 0.2b	5.8 \pm 0.4ab	15.8 \pm 1.5ns	85.4 \pm 2.3ns	141.0 \pm 28.0ab	12.9 \pm 1.3ab	55.3 \pm 6.7ab
225.0	20.6 \pm 2.1a	6.7 \pm 0.1a	16.3 \pm 5.0ns	88.1 \pm 0.1ns	168.0 \pm 31.0ab	12.2 \pm 1.0b	61.7 \pm 9.8ab
300.0	17.9 \pm 0.5c	6.2 \pm 0.1a	16.8 \pm 0.0ns	85.5 \pm 3.5ns	175.0 \pm 9.0a	11.7 \pm 0.9b	62.3 \pm 4.6ab
375.0	17.9 \pm 0.1c	5.8 \pm 0.1ab	18.3 \pm 0.0ns	78.7 \pm 7.6ns	197.0 \pm 7.0a	10.1 \pm 1.0b	64.0 \pm 4.9a

Values followed by the same letter in the column do not differ statistically by the Tukey test ($p > 0.05$). CEC cation exchange capacity.

absorption by plants (Schaller et al., 2019). Additionally, studies have shown that Si can also improve the nutritional status of P in the plant by increasing photosynthetic phosphorylation; reducing the unnecessary absorption of Fe and Mn (Ma et al., 2004) and increasing P translocation in the plant (Greger et al., 2018). However, Si rates higher than 400 kg ha⁻¹ can diminished P uptake owing to antagonistic effects (Nascimento et al., 2020).

In general, the results showed that sugarcane cultivated in the sandy soils of NE Brazil could significantly benefit from the application of diatomite. The Si fertilizer increased plant biomass and improved the use of nutrient. These effects were directly related to the accumulation of Si by the crop, but effects on the soil, such as increased nutrient availability and water retention, probably played a role (Abdalla, 2010). Field experiments are warranted to confirm the diatomite potential to increase sugarcane yields and nutritional status.

Conclusions

Sugarcane responded positively to fertilization with diatomite in the soil studied here. The fertilizer was efficient in supplying available Si in the soil and increased Si concentration in the plant. Silicon accumulation was related to higher biomass and improved plant nutritional status.

The addition of diatomite altered the chemistry of the studied soil, significantly increasing P, K, Mn, Cu available contents, and the cationic exchangeable capacity. The diatomite application increased the concentrations of N, P, Mn, Cu, and Zn in shoots, suggesting that the fertilizer can play a role in the efficient use of nutrients by sugarcane grown on Si-depleted soils.

The extractant 0.01 mol L⁻¹ CaCl₂ was better correlated with Si concentration in plants than 0.5 mol L⁻¹ acetic acid, although both extractants posed a good correlation with Si concentration in shoots. Therefore, CaCl₂ is the recommended extractant to estimate Si availability in sandy soil because of its higher efficiency and lower cost.

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