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Silicate fertilization of sugarcane cultivated in tropical soils

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ABSTRACT

Although the benefits of silicon (Si) fertilization for sugarcane yields have already been demonstrated, few studies have examined the effects of silicate fertilization applied at less than 200 kg ha^{-1} Si in the furrow at planting on the soluble Si concentration in the soils, plant uptake in sugarcane (a Si-accumulating crop) and damage caused by the stalk borer (*Diatraea saccharalis*) under field conditions. The objective of this study was to evaluate the effects of a Ca–Mg silicate that was applied in the furrow at planting on the available Si in the soil, sugarcane yields and stalk borer damage of two sugarcane cultivars under field conditions. Two experiments were conducted on two soil types with a low silicon content (a Typic Quartzipsamment-Q and a Rhodic Hapludox-RH) using a completely randomized factorial scheme design with four replicates, four Si application rates (0, 55, 110 and 165 kg ha^{-1} Si) and two cultivars (IAC 86-3396 and SP 89 1115). Ca–Mg silicate was applied during furrow planting such that all plots received the same quantity of Ca and Mg. On both of the soil types, silicate fertilization increased the Si concentrations in the soil and the leaves of the plants at 8 months for both the plant cane and the first ratoon, thereby showing residual effects. Additionally, the potential for silicon fertilization applied in the furrow at planting to reduce stalk borer (*D. saccharalis*) damage was confirmed for stalk Si concentrations that were greater than 3 g kg^{-1} Si as shown in the RH soil experiment. Therefore, the practice of silicate placement at low rates (<200 kg ha^{-1} Si) in the furrow at planting should be considered an alternative method of nutritional management for sugarcane in sandy and loam sandy soils with additional benefits of increased soluble Si in the soil, Si uptake and sugarcane yield and may help reduce the stalk borer damage of *D. saccharalis*.

1. Introduction

Silicon (Si) is the second most abundant element in the Earth's crust, but low soluble Si contents are observed in highly weathered soils in humid tropical areas, especially sandy and sandy loam soils (Savant et al., 1999). Sugarcane is an Si accumulator (Epstein, 2009), and the Si contents in the aboveground biomass can reach between 307 and 500 kg ha^{-1} Si (Samuels, 1969; Ross et al., 1974; Savant et al., 1999) in only one harvest, surpassing the levels of some macronutrients, such as nitrogen. Intensive management and the planting of monocultures for sugarcane cultivation could decrease the Si availability in these areas (Berthelsen et al., 1999), resulting in a need for Si fertilization (Epstein, 2009).

Beneficial responses to silicon fertilization, including increased photosynthetic activity (Cheng, 1982; Elawad et al., 1982), increased tolerance to salinity (Ashraf et al., 2010a,b) and reduced levels of damage by disease and insects (Savant et al., 1999; Raid et al., 1992; Keeping et al., 2009), have been demonstrated in sugarcane. Most of these effects result from increasing levels of Si deposited in the leaves and stems (Kvedaras and Keeping, 2007). Positive effects on increasing yield and sugar content have been observed in sugarcane crops in several countries, including Mauritius, the USA (Hawaii and Florida), Australia and Brazil. These effects have been observed in crops that are grown on soils with high contents of oxides (Ayres, 1966; Fox et al., 1967; Ross et al., 1974; Berthelsen et al., 2001a,b; Gurgel, 1979) and organic matter (Elawad et al., 1982; McCray and Ji, 2012), as well as sandy and loamy soils (Korndörfer et al., 2000, 2002; Brassioli et al., 2009).

The most commonly used Si source in sugarcane crop is silicate or basic slag, which could lead to increased pH, Ca and Mg concentrations in the soil (Alcarde, 1992). Despite a long history of research on the silicon fertilization of sugarcane that extends back to 1960, few studies have isolated the effects of Ca, Mg and pH when different rates of silicate are used (Ayres, 1966; Keeping and Meyer, 2006; Keeping et al., 2013; Berthelsen et al.,

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2001b; McCray and Ji, 2012). In addition, it is essential to evaluate the soluble Si in soils to predict the Si requirement for sugarcane, as performed by Berthelsen et al. (2001b) in Australia. These authors cultivated sugarcane into four groups based on the level of soluble Si (extracted with $CaCl_2$ 0.01 mol L^{-1}) in the soil: very low (0–5 mg kg^{-1}), low (5–10 mg kg^{-1}), limited (10–20 mg kg^{-1}) and sufficient (20–>50 mg kg^{-1}). Another study was conducted in Florida by McCray and Ji (2012), who observed positive responses to Si fertilization when the soil Si levels were less than 15 mg m^{-3} Si (0.5 mol L^{-1} acetic acid extraction). Although the Si extractants have been previously evaluated in soils that were cultivated with sugarcane, this is the first study that compares both of the common (0.5 mol L^{-1} acetic acid and 0.01 mol L^{-1} $CaCl_2$) without the influence of Ca, Mg and pH in soil provided by silicate application. An analysis of the soluble Si concentration in soils, especially with the pH, Ca and Mg concentrations being held constant, and the Si uptake by sugarcane could confirm whether the yield obtained with silicate fertilization is due exclusively to increasing levels of soluble silicon in the soil.

Furthermore, most of the positive effects of the published experiments were observed with the application of silicate at rates that are similar to the application of agricultural lime (>2 or 3 t ha^{-1}) applied across the entire cultivated area (Ayres, 1966; Berthelsen et al., 2001a,b; Elawad et al., 1982; McCray and Ji, 2012; Brassioli et al., 2009). In contrast, silicate fertilization at these high rates can be costly for the sugarcane crop if Si deficiency is all that is required for correction rather than when used as an acidity correction or as with lime application (Anderson et al., 1991). Si fertilization in planting furrows could be a useful method in order to provide Si to sugarcane plants at a reduced cost, as shown by Keeping et al. (2013), but this method was not studied using rates that were less than 200 kg ha^{-1} Si.

Another potential advantage of the silicon fertilization of sugarcane is a reduction in the level of damage inflicted by insects. Studies conducted in greenhouses and under field conditions have demonstrated that Si positively affects the control of the stalk borer *Eldana saccharina*. Keeping and Meyer (2002) studied six cultivars and found reductions of 19 and 33% in pest damage with the application of 425 and 850 kg ha^{-1} Si, respectively. In pots studies, Meyer and Keeping (2005) also observed that Si application (200 kg ha^{-1} Si) decreased the damage caused by the stalk borer by 70 and 35% when N was applied to soils with low and high levels of Si, respectively. In addition, Keeping and Meyer (2006) demonstrated that Si application increased the Si uptake in plant stalks and reduced stalk borer damage by 26 and 34% in the two cultivars. Recently, Keeping et al. (2013) published the first study of silicate application and *E. saccharina* herbivory under field conditions. These authors demonstrated a decreased percentage of stalk borer damage to plant canes and two ratoons that contained 394 and 1080 kg ha^{-1} Si and that had been treated with 4 and 8 t ha^{-1}, respectively, of applied silicate.

Similar damage is caused by a different stalk borer, *Diatraea saccharalis* (F.) (Lepidoptera: Crambidae), in Central and South America. Several studies have demonstrated that stalk borer damage (or the percentage of bored internodes) of 1% can resulted in losses of 0.42% of sugar or 0.21% of alcohol and a 1.14% weight loss (Parra et al., 2010). This pest is controlled by biological methods and/or using resistant cultivars. Using silicate to increase the rate of silicon uptake in sugarcane could reduce the damage caused by *D. saccharalis*, as demonstrated by Elawad et al. (1982) in a greenhouse experiment.

However, the association between Si availability, sugarcane uptake of Si and beneficial effects in sandy and loam sandy soils, which are commonly found in tropical regions, requires further study. In addition, there are few studies of sugarcane that associate Si uptake with the *D. saccharalis* damage under field conditions over time. Most of the studies investigated on stalk borer *E. saccharina* in sugarcane. Therefore, the objectives of this study were to evaluate the effects of a Ca–Mg silicate applied at less than 200 kg ha^{-1} Si in the furrow at planting on the soluble Si concentration in the soils, plant uptake in sugarcane and damage caused by the stalk borer (*D. saccharalis*) in two cultivars under field conditions.

2. Materials and methods

The experiments were conducted on the plant (March 2008 to July 2009) and ratoon crops (July 2009 to August 2010) that were grown on a Typic Quartzipsamment (Q) soil and on plant cane (March 2009 to August 2010) and ratoon crops (August 2010 to August 2011) that were grown on a Rhodic Hapludox (RH) soil. Both of the experiments were conducted in a commercial area in Piracicaba (22°42′30″S; 47°38′01″W), São Paulo, Brazil. The chemical content and texture were analyzed in soil samples that were collected in the 0–20 cm layer from both experimental areas (Table 1). These soils were selected by texture (sandy and loam sandy), which could provide differences in the soluble Si (Savant et al., 1999). The minimum and maximum temperature and rainfall were monitored monthly (Fig. 1).

A completely randomized factorial design (4 × 2) with four replications was used in the experiments. Four Si rates (0, 55, 110 and 165 kg ha^{-1} Si) were used. Two cultivars were examined: IAC87-3396 (intermediate resistance to *D. saccharalis*, Sugarcane Center, Agronomic Institute-IAC) and SP89-1115 (susceptible to *D. saccharalis*, Sugarcane Technology Center-CTC). The source of silicon was a Ca–Mg silicate (262.1 g kg^{-1} Ca; 56.8 g kg^{-1} Mg and 108.4 g kg^{-1} Si) applied in the furrow at planting. All of the treatments were adjusted to receive the same quantities of Ca and Mg by applying lime (343 g kg^{-1} Ca and 96 g kg^{-1} Mg) and/or $MgCl_2$ (11.9% Mg) as necessary. The cultivars were selected due to their high yield and high sprouting rate under sugarcane residue mulch.

During sugarcane planting (March 19, 2008, on the Q soil and March 21, 2009, on the RH soil), the silicate treatments and nitrogen, phosphorus and potassium were applied in continuous bands on both sides of the furrows (0–20 cm depth) by hands. The furrows were covered with soil by rotavator as commonly used in commercial sugarcane areas. The soil was fertilized with nitrogen, phosphorus and potassium based on the soil analyses (Raij et al., 1997). Fertilizer was applied at rates of 40 kg ha^{-1} of N, 100 kg ha^{-1} of P_2O_5 and 100 kg ha^{-1} of K_2O (10–25–25). Each plot contained five 10-m rows. Surface nitrogen (40 kg ha^{-1} N; ammonium sulfate, 20% N) and potassium (60 kg ha^{-1} of K_2O; KCl, 60% K_2O) fertilization occurred 30 days after planting. During the first ratoon stage, surface fertilization with N (100 kg ha^{-1} of N; ammonium sulfate) and K (60 kg ha^{-1} of K_2O; KCl) was performed, according to Raij et al. (1997).

The 20 youngest fully expanded leaves (top-visible dewlap-TVD) without midribs (Anderson and Bowen, 1992) were collected from each plot during the plant cane stage at 8 months after germination (Q soil, December 2008; RH soil, December 2009) and during the first ratoon stage (Q soil, March 2010; RH soil, March 2011) for the evaluation of Si content (Elliott and Snyder, 1991).

The yield (tons of sugarcane stalks per hectare) was determined for the plant cane and first ratoon by weighing the chopped cane of each plot in a truck that was equipped with a grab loader that was instrumented with a load cell. To determine the Si contents, before the harvest of both the plant cane and first ratoon, sugarcane samples were taken from 1 m of each row of sugarcane per plot and divided into straw (old and new leaves + tops) and stalks. Both the fresh and dry matters were weighed. The Si content in the straw and stalks was determined according to Elliott and Snyder (1991). The stalk borer damage was determined by calculating the percentage