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Rates and sources of zinc applied in sugarcane grown on sandy soil in Brazil

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Productivity and longevity of sugarcane plantations may currently be affected by the expanded cultivation activities in low fertility areas, which can result in micronutrient deficiencies. Zinc is important in this regard because its deficiency in sugarcane can cause reduced tillering, shorter internodes and thinner stalks. Therefore, the agronomic performance of sugarcane was evaluated (plant-sugarcane and first-ratoon-sugarcane), grown on a sandy soil with low zinc content, in response to rates and sources of zinc applications in the planting grooves. The experiment was conducted in an eutrophic Alfisol in Suzanápolis, São Paulo State, Brazil. A randomized blocks design in a factorial scheme (5x3), with five zinc rates (0, 2.5, 5.0, 7.5 and 10.0 kg ha$^{-1)}$ and three sources of zinc (sulfate, FTE (Zn silicate powder) and EDTA chelated Zinc) applied only in the planting furrow of the plant-sugarcane, with four replications, was used. The zinc sources had a similar effect on the Zn foliar and stalk contents, number of internodes per stalk, number of stalks per meter and sugarcane stalk productivity (cultivar RB867515), in two crops. Increasing zinc rates afforded a linear increase in the levels of foliar Zn and Zn in the stalks of the plant-sugarcane and first-ratoon-sugarcane, independent of the Zn source used. The zinc rates did not affect the production components and productivity of the plant-sugarcane stalks and first-ratoon sugarcane, grown on a sandy and acid soil with low zinc content.

Key words: *Saccharum* spp., fertilization with zinc, micronutrient, stalk productivity.

INTRODUCTION

The sugarcane (*Saccharum* spp.) is an important crop for the global and Brazilian agricultural economy. Brazil stands out as the world's largest producer of sugarcane. Sugarcane production is one of the major contributors of many countries economy, like the South African (Baiyegunhi and Arnold, 2011).

Historically in Brazil, the alcohol sector has received little attention to the response of sugarcane to the

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application of micronutrients. Consequently, this is not a widespread practice in the agricultural companies producing sugarcane (Franco et al., 2009). However, micronutrient deficiencies can cause serious problems to crop development, especially productivity losses, as the micronutrients play crucial roles in plant metabolism. Among the micronutrients, zinc (Zn) is quite important because it enhances the production of auxin, tryptophan synthase and tryptamine metabolism. Zn is concentrated in growth areas due to high concentrations of auxin (Taiz et al., 2004); thus its main effect is on the development and elongation of plant young parts. The deficiency of this nutrient in sugarcane can result in reduced tillering, shorter internodes, and thinner stalks. According to Malavolta et al. (1997), the Zn requirement for sugarcane production is in average 0.72 kg ha^{-1}, with a relative dispersal to the stalks of 0.50 kg Zn ha^{-1}.

In general, the soils most commonly associated with zinc deficiency problems in plants mainly due to the factors like neutral to alkaline in reaction, especially where the pH is above 7.4, high calcium carbonate content in topsoil or in subsoil exposed by removal of the topsoil during field leveling or by erosion, coarse texture (sandy soil) with a low organic matter status, permanently or intermittently waterlogged soil, high available phosphate status, high bicarbonate or magnesium concentrations in soil or irrigation water and acid soil of low zinc status developed on highly weathered parent material (Arunachalam et al., 2013).

In sugarcane grown in São Paulo State, Brazil, micronutrient deficiencies are not commonly seen. However, according to Orlando Filho et al. (2001), sugarcane frequently exhibits the so-called “hidden hunger”, a situation in which the symptoms do not appear visually, yet these levels are insufficient to the point of reducing crop yield. Moreover, this situation may be growing worse due to the expansion of sugarcane cultivation in areas with less favorable production environments (soil and climate), where zinc is generally the most lacking micronutrient due to the poor material source of these soils. In addition, the lack of a tradition of applying zinc-containing fertilizers to the crops of these regions, which are predominantly livestock pasture regions.

Korndörfer et al. (1999) indicate zinc application to sugarcane in nutrient-deficient areas, especially in sandy soils with low organic matter content, which is a common situation in the expanding areas with sugarcane in the Northwest region of São Paulo State, Brazil. Thus, zinc fertilization in sugarcane grown in soils with low content of this nutrient may be important to maintain adequate levels of zinc in the crop, thereby affording higher internodes growth, increasing top growth in the sugarcane and, consequently, increasing stalk length and yield.

Alvarez et al. (1979), in twenty-three experiments conducted in São Paulo State, Brazil, under different climate and soil conditions, found no effect of zinc application on sugarcane production. However, in a study by Cambria et al. (1989), conducted in a medium-textured red-yellow latosol (oxisol) with low initial levels of Zn in the soil, found that there was a stalk yield increase up to a rate of 10 kg Zn ha^{-1}. However Costa Filho and Prado (2008), while assessing the soil application of Zn rates (0, 5, 10 and 15 kg $ha^{-1)}$ in the form of zinc sulfate, in the third sugarcane ratoon grown in a Red-Yellow Latosol (oxisol) with a low content of this nutrient, found no significant effect on height and stalk productivity in the culture, but found increases in Zn foliar concentrations.

Another important aspect is to determine which source of micronutrient would be more efficient, both in the plant-sugarcane as well as in the ratoon-sugarcane. This is because of the solubility and physical form (powder or granules) of various micronutrient sources and soil conditions may interact, resulting in greater or lesser effect of fertilization for the correction of nutritional deficiencies (Moraes et al., 2004). Furthermore, most studies on zinc fertilization in sugarcane are outdated and were conducted only with zinc sulfate. Therefore, there is need for more studies on this subject, as new sugarcane cultivars continuously emerge, and which can be more responsive to this fertilizer. Within this context, the objective of this study was to evaluate the agronomic performance of sugarcane (plant and first-ratoon) grown on a sandy soil with low zinc content, in response to the application of zinc rates and sources in the planting furrows.

MATERIALS AND METHODS

The experiment was conducted in 2008, in an agricultural area managed by the Usina Vale do Paraná Açúcar e Álcool in Suzanápolis, São Paulo State, Brazil, within the geographical coordinates of 50° 58′ west longitude and 20° 32′ south latitude and 345 m of altitude. The soil is classified as sandy-textured eutrophic Alfisol, according to the classification by Embrapa (2006), with particle-size depth values of 0.0 to 0.20 m of 820, 56 and 124 g kg^{-1} of sand, silt and clay, respectively. At the depth of 0.20 to 0.40 m, the granulometric values were 813, 54 and 133 g kg^{-1} of sand, silt and clay, respectively.

The soil was chemically analyzed before the experiment (Table 1), according to the methodology proposed by Raij et al. (2001), which found low levels of Zn in the soil, as described in Raij et al. (1997). The region’s climate classification according to Köppen is Aw, defined as tropical humid, rainy in summer and dry in winter. Figure 1 shows the values of rain precipitation (mm), relative air humidity (%) and maximum, minimum and mean temperatures (°C) in the cultivation area during the sugarcane experiment and with a first-ratoon-sugarcane.

The treatments were at a location previously used for grazing (Brachiaria grass) for at least ten years. First, desiccation of the pasture with glyphosate was carried out (1.44 kg a.i. ha^{-1}). Soil preparation included deep plowing followed by intermediate disking to incorporate lime into the soil (0.20 m deep) and light disking with herbicide trifluralin application (2 L ha^{-1}). Next, soil furrowing was performed at a depth of 0.40 m and the insecticide fipronil was applied (200 g a.i. ha^{-1}) into the furrow. Manual planting system was adopted (conventional), in which the stalks were distributed and

Table 1. Chemical analysis of the soil from the experimental area. Suzanápolis, SP, Brazil, 2007.

Depth (m)	P (resin)	O.M.	pH	K	Ca	Mg	H+Al	SB	CTC	V
	mg dm^{-3}	g dm^{-3}	$CaCl_2$	mmol$_c$ dm^{-3}						%
0.0-0.25	3	24	4.9	3.0	10.0	8.0	20.0	21.4	41.4	52
0.25-0.50	2	12	4.6	0.3	9.0	4.0	21.0	13.3	34.3	39

Depth (m)	Cu*	Fe*	Mn*	Zn*	B**
	mg dm^{-3}				
0.0-0.25	0.8	39.0	4.8	0.4	0.61
0.25-0.50	0.9	12.0	2.5	0.1	0.50

*Determined in DTPA; **Determined in hot water.

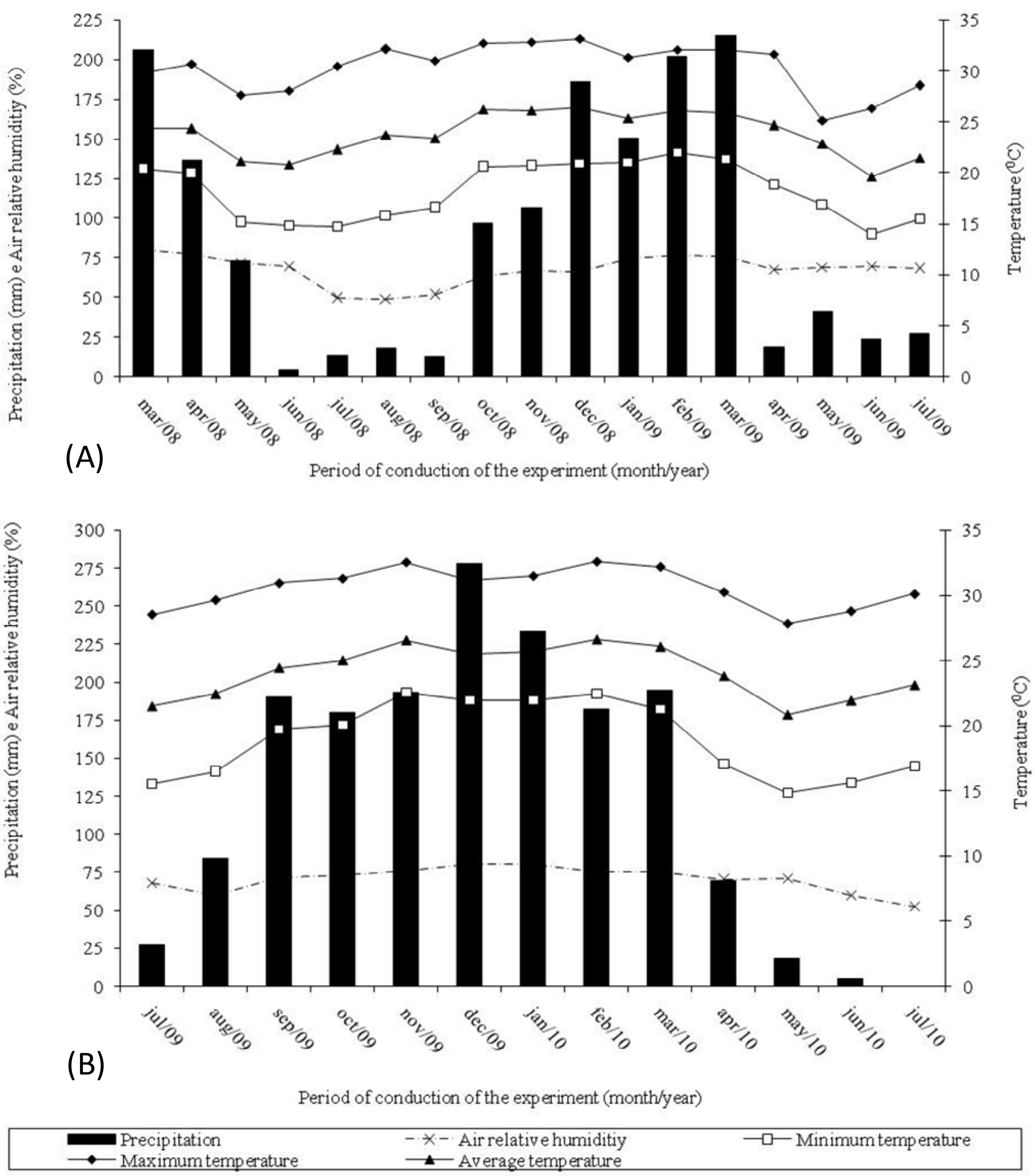

Figure 1. Monthly rainfall (mm) relative air humidity (%), monthly mean maximum, and minimum temperatures (°C) during the plant-sugarcane experiment (A) in the 2008/2009 crop and first-ratoon-sugarcane (B) in the 2009/2010 harvest in Suzanápolis – SP, Brazil.

sectioned within the planting rows, placing six seed pieces with three buds each per row meter.

The sugarcane cultivar used was RB867515, which exhibits a late-maturing cycle and is one of the most widely planted cultivars in São Paulo State. This cultivar is drought tolerant, with good sprouting stumps, even when reaped raw; tall, fast growing and with high productivity and high sucrose content (Hoffmann, 2008).

Thirty days prior to planting the crop, the soil of the experimental area received the application of 2 t ha^{-1} of lime (302.3 g CaO kg^{-1}, 108.4 g MgO kg^{-1} and 75% of PRNT) in order to obtain 60% of base saturation, as recommended by Raij et al. (1997) for sugarcane. Also, 30 kg ha^{-1} of N (urea), 150 kg ha^{-1} of P_2O_5 (simple super phosphate) and 120 kg ha^{-1} of K_2O (potassium chloride) were applied into the planting fertilizer, as well as in all treatments, based on soil analysis (Table 1), and according to the fertilizer used by the sugar mill. On 16/10/2009, fertilization in the first-ratoon-sugarcane in between the rows was performed, applying and incorporating into the soil 80 kg ha^{-1} of N (urea) and 60 kg ha^{-1} of K_2O (potassium chloride), according to the fertilizer used by the sugar mill.

Weed control was carried out in both crops with the application of diuron + hexazinone herbicides (702+264 g of i.a. ha^{-1}), in post-crop emergence, performed 45 days after planting the plant-sugarcane and 55 days after harvesting the plant-sugarcane. However, there was no need to control diseases and pests. Sugarcane flowering was observed in both crops. The sugarcane harvest (488 day cycle) and the first-ratoon-sugarcane (363 day cycle) was performed manually and individually for each experimental unit, on 7 August, 2009 and 7 July, 2010, respectively. Next, the sugarcane was harvested mechanically without any previous burning of the crop.

The following evaluations were performed: a) Zn foliar content, analyzing the middle third of 15 leaves +1 (highest leaf with top visible leaf collar -"TVP"), excluding the midrib, after collection in the highest development phase (carried out on 1 December, 2008 for the plant-sugarcane and on 21 January, 2010 for the first-ratoon-sugarcane), according to the methodology described by Raij et al. (1997); b) Zn content in the sugarcane stalk, 3 cane stalks were collected and crushed per plot during the sugarcane harvest. Then, the Zn content was determined after drying, as described in Malavolta et al. (1997); c) stalk diameter, determined using a caliper by the average diameter of the base, middle and end of three industrially usable stalks; d) number of internodes per meter was evaluated in three industrially usable stalks, by counting the number of internodes in one meter of the middle third of the stalk, and; e) for stalk height, five stalks per plot were measured during the harvest, using a graduated ruler from ground level to the first visible collar, classified as leaf +1; L) number of stalks per meter by counting the mill's industrially usable stalks, in 5 m of culture rows; g) sugarcane yield, determined based on the average mass of 10 stalks and the number of industrially usable stalks per plot, after being quantified, the data were converted into ha^{-1} (TCH). The data were subjected to analysis of variance (F test) and the means compared by Tukey test at 5% probability for Zn sources and adjusted to regression equations for the effect of Zn rates. The SISVAR program was used for the Statistical analysis (Ferreira, 2008).

RESULTS AND DISCUSSION

There was more rainfall during the first-ratoon-sugarcane cycle from July 2009 to January 2010 (Figure 1B), as compared to the same sugarcane cycle period (Figure 1A). Was observed that in the early development of the first-ratoon-sugarcane (August and September 2009), above average rainfalls were recorded for the northwest region of São Paulo (Figure 1B).

The experiment shows that there was no significant interaction between Zn sources and rates for any of the evaluations performed (Tables 2 and 3). Zn levels in leaves and stalks of the plant-sugarcane as well as of the first-ratoon-sugarcane, were not affected by Zn sources (sulfate, FTE and chelated Zn) applied to the crop (Table 2). However, it should be noted that foliar zinc contents in the sugarcane plant and in the first-ratoon-sugarcane, independent of the dose applied, are within the range considered adequate (10 to 50 mg of Zn kg^{-1} of dry matter) for the sugarcane culture, as described in Raij et al. (1997). However, Malavolta et al. (1997) indicate that the adequate range for the Zn foliar content (leaf +3) in the sugarcane is higher in the plant-sugarcane (25 to 50 mg kg^{-1} of M.S.), when compared to first-ratoon-sugarcane (25 to 30 mg kg^{-1} of M.S.). Thus, all foliar concentrations of zinc were below the range considered adequate. However, it is important to note that these authors recommend the collection of the leaf +3 (older leaves), four months after sugarcane sprouting. According to Costa Filho and Prado (2008), the fact that the knuckles present lower zinc content in the tissues, when compared to the plant-sugarcane, is indicative of a greater tolerance to reduced availability of zinc in the soil, without productivity loss.

Table 2 shows for Zn stalk contents, that these levels were higher in the stalks of the plant-sugarcane in comparison to the stalks in the first-ratoon-sugarcane. This lower zinc concentration in the sugarcane stalks may be due to the fact that in the cultivation of the first-ratoon-sugarcane there was no fertilization with zinc, but rather the residual effect of this fertilization performed on the plant-sugarcane.

The Zn rates significantly influenced the foliar Zn levels and the stalks of the plant-sugarcane and first-ratoon-sugarcane, always adjusting to the increasing linear function, independent of the Zn source (Table 2). Costa Filho and Prado (2008), evaluating the application of zinc rates in the sugarcane knuckles, also found significant linear increases in the foliar levels of zinc. However, Andrade et al. (1995), working with the application of fritted trace elements and sources of soluble boron, copper and zinc sulfate (Zn sulfate) in the planting furrow, found that the joint application (fritted), as well as the standalone application of micronutrients, did not result in increased foliar concentrations of Zn in the plant-sugarcane and in the first-ratoon-sugarcane, in a medium textured soil with low Zn (0.3 mg dm^{-3}).

The sources of Zn provided similar stalk diameters in the plant-sugarcane, but there was a significant difference in this assessment in the first-ratoon-sugarcane, as the chelated Zn yielded higher stalk diameter, when compared to the FTE and Zn sulfate (Table 2). A possible explanation is that as this treatment (chelated Zn) provided smaller stalk heights in this cultivation (Table 3), there was a compensatory effect with the increase in stalk diameter, a common feature in

Table 2. Means, coefficients of variation (CV), Tukey test and regression equations relating to the foliar Zn concentrations and stalk, stalk diameter and number of internodes per meter of plant-sugarcane stalk (2008/2009 crop) and first-ratoon-sugarcane (2009/2010 crop), according to the application of rates and sources of Zn in the planting of sugarcane, in Suzanápolis – SP, Brazil.

Variables	Foliar Zn concentration (mg kg^{-1})		Stalk Zn concentration (mg kg^{-1})		Stalk diameter (cm)		Number of internodes per meter of stalk	
	Plant-sugar cane	First-ratoon sugar cane	Plant-sugar cane	First-ratoon sugar cane	Plant- sugar cane	First-ratoon sugar cane	Plant-sugar cane	First-ratoonsugar cane
Zn sources								
FTE	15.85 a	19.60 a	36.87 a	15.73 a	2.62 a	2.74 b	9.36 a	8.65 a
Zn chelated	17.20 a	20.53 a	40.80 a	15.40 a	2.59 a	3.01 a	9.07 a	8.94 a
Zn sulfate	16.45 a	20.33 a	41.33 a	14.67 a	2.57 a	2.73 b	9.34 a	8.55 a
D.M.S. (5%)	1.72	1.52	5.72	4.29	0.22	0.26	0.99	0.46
Zn rates (kg ha^{-1})								
0	11.75(1)	19.44(3)	32.78(2)	9.67(4)	2.57ns	2.77 ns	9.02 ns	8.76 ns
2.5	13.75	19.89	37.11	14.00	2.51	2.90	9.29	8.61
5.0	17.17	20.22	40.56	15.00	2.64	2.74	9.27	8.64
7.5	19.50	20.00	45.67	17.78	2.55	2.84	9.38	8.89
10.0	20.33	21.22	42.22	19.89	2.71	2.82	9.33	8.66
Overall mean	16.50	20.16	39.67	15.27	2.60	2.83	9.26	8.71
C.V. (%)	13.56	8.35	15.96	31.08	11.04	12.12	13.84	6.88

Means followed by same letter in the column do not differ by Tukey test at 5% level of probability. nsNot significant by regression analysis. (1), (2), (3) and (4) refer to the regression equations: (1)$Y = 11.9167+0.9167X$ ($R^2 = 0.97$**); (2)$Y = 34.1778+1.0978X$ ($R^2 = 0.77$**); (3)$Y = 19.4222+0.1467X$ ($R^2 = 0.77$*); (4)$Y = 10.4222+0.9689X$ ($R^2 = 0.97$**).

Table 3. Means, coefficients of variation (CV) and Tukey's test related to stalk height, number of stalks per meter and stalk yield (t ha^{-1}) of plant sugarcane (2008/2009 crop) and a first-ratoon sugarcane (2009/2010 crop), according to the application of rates and sources of Zn in the planting of sugarcane, in Suzanápolis – SP, Brazil.

Variables	**Stalk height (m)**		**Number of stalks per meter**		**Stalk yield (t ha^{-1})**	
	Plant-sugarcane	**First-ratoon sugarcane**	**Plant-sugarcane**	**First-ratoon sugarcane**	**Plant-sugarcane**	**First-ratoon sugarcane**
Zn sources						
FTE	2.90 a	2.89 ab	8.46 a	8.74 a	87.40 a	106.46 a
Zn chelated	2.93 a	2.85 b	8.17 a	9.07 a	87.90 a	114.37 a
Zn sulfate	2.92 a	2.94 a	8.46 a	8.68 a	86.70 a	105.06 a
D.M.S. (5%)	0.18	0.08	0.76	0.90	9.50	14.61
Zn Rates (kg ha^{-1})						
0	2.91 ns	2.94 ns	8.73 ns	8.77 ns	79.58 ns	109.26 ns
2.5	2.85	2.82	8.37	9.05	89.33	106.72
5.0	2.91	2.89	8.58	8.88	89.42	108.22
7.5	2.96	2.92	7.78	8.60	88.75	103.77
10.0	2.95	2.90	8.35	8.85	89.58	115.19
Overall mean	2.91	2.89	8.36	8.83	87.33	108.63
C.V. (%)	7.91	3.79	11.80	13.19	14.15	17.50

Means followed by same letter in the column do not differ by Tukey test at 5% level of probability. nsNot significant by regression analysis.

grasses.

Regarding the number of internodes per meter of stalk, no significant difference was observed between the sources of Zn for plant-sugarcane and for the first-ratoon sugarcane. As for the rates of Zn, these did not affect stalk diameter and number of internodes per meter of stalk, for the plant-sugarcane as well as for the first-ratoon-sugarcane (Table 2). It should be noted that a typical symptom of Zn deficiency in sugarcane is the shortening of internodes, in other words, greater number of internodes per meter of stalk. Therefore, there was probably no effect of Zn levels on this evaluation, because all foliar concentrations of zinc found in plant-sugarcane and the first-ratoon-sugarcane (Table 2), independent of the dose applied, were within the range considered appropriate for this culture, as previously reported.

Table 3 shows that the height of the plant-sugarcane stalk was not affected by Zn sources. However, in the first-ratoon-sugarcane there was no significant difference between Zn sources, with zinc sulfate affording the maximum stalk height, although this did not differ significantly from the FTE. The stalk heights of the plant-sugarcane and first-ratoon-sugarcane were not influenced by increasing rates of Zn (Table 3), therefore they did not affect stalk growth. Costa Filho and Prado (2008), evaluating the application of zinc in the sugarcane knuckles, also did not see increasing stalk heights.

Regarding the number of stalks per meter, no difference was found among the sources of Zn (sulfate, FTE and chelated Zn) for the plant-sugarcane and first-ratoon-sugarcane. There was also no significant effect for the rates of Zn applied to the sugarcane sowing in both crops (Table 3). This result indicates that zinc did not affect tillering on the sugarcane cultivar RB867515. However, Cambria et al. (1989), applying Zn rates in the soil, in the form of zinc sulphate, found that the tillering of plant-sugarcane was negatively affected when the rates were higher than 15 kg Zn ha^{-1}, a higher dose than that used in this work. According to Landell and Silva (2004), tillering, stalk heights and diameters are important components for the formation of the agricultural potential of sugarcane.

Although it is usually the most productive plant-sugarcane, there was greater stalk productivity (TCH) of the first-ratoon-sugarcane (108,63 t ha^{-1}) in comparison to the plant-sugarcane (87,33 t ha^{-1}), independent of the treatment (Table 3). This unusual result occurred mainly because there was more rainfall during the vegetative growth period of the first-ratoon-sugarcane (Figure 1B), in comparison to the same period for the sugarcane plant (Figure 1A).

The Zn sources did not provide significant stalk yield differences (TCH) of the plant-cane and first-ratoon of sugarcane cultivar RB867515 (Table 3), although they have different sulphate and chelate solubilities, when compared to the FTE. According to Volkweiss (1991), it is necessary that the micronutrient sources use solubilization in the soil at least at speeds compatible with the absorption by the roots and applied in a manner they can receive it, since the micronutrients have little mobility in the soil. According to Mortvedt (2001), the FTEs are the more appropriate products for maintenance programs than for correcting severe deficiencies and provide greater efficiency in sandy soils in regions with higher rainfall rates. However, despite these soil conditions (sandy texture) and favorable climate (Figure 1), the FTE was not significant when compared to other sources of Zn.

On the other hand, based on the indicators of technological quality (sucrose concentration, brix cane and total recoverable sugar) of the first-ratoon-sugarcane, according to Teixeira Filho et al. (2013), would be interesting the application between 4.0 and 5.0 kg Zn ha^{-1} in the in the planting furrow, in the form of chelate or sulfate of Zn.

Moreover, the Zn rates did not significantly influence sugarcane stalk yields in the cane plant as well as in the first-ratoon-sugarcane (Table 3), despite having been grown on a sandy soil with a low content of the element. These results were also found for the main crop production components (Tables 2 and 3). Therefore, this explains why there was no significant increase in the productivity of sugarcane. But it is important to emphasize that there was a mean increase for plant-sugarcane in the stalk yield of 9.7 t ha^{-1} compared to the control (without zinc fertilization).

Franco et al. (2009), working with rates of Zn (0, 3 and 6 kg ha^{-1}) applied to the soil about 20 cm from the plants, in the form of zinc sulfate dissolved in water (200 L ha^{-1}) and 90 days after planting the crop, also did not observe increases in the productivity of the plant-sugarcane stalks. Costa Filho and Prado (2008), studying the application of Zn rates in the third-ratoon-sugarcane, also found no significant effect on the productivity of stalks in soils with low Zn content. Similarly, Alvarez et al. (1979), evaluating twenty-three experiments under various climate and soil conditions in the São Paulo State, found no Zn effect on the sugarcane production.

However, significant increases in sugarcane stalk productivity in response to Zn fertilization in soils with low content of this nutrient were verified by Cambria et al. (1989) in a medium-textured Red-Yellow Latosol (Oxisol), up to a dose of 10 kg Zn ha^{-1}, with soil application of zinc sulphate. Moreover, Andrade et al. (1995), studying the application of (fritted trace elements) and soluble Zn sources (zinc sulfate), applied to the planting furrow in medium-textured distrophic Red Latosol, found that the joint application (fritted), as well as the standalone application of the micronutrient, did not result in increased stalk productivity. Moreover, these authors also observed residual effect of this fertilization on the first-ratoon-sugarcane. Farias et al. (2008), evaluating the efficiency of water use in sugarcane under different irrigation and zinc rates (0, 1, 2, 3 and 4 kg ha^{-1}), on a soil in the coast of Paraíba, Brazil, observed quadratic increase in stalk productivity, estimated at 2.38 kg ha^{-1},as the dose that maximizes the crop's water use efficiency. Marinho and Albuquerque (1981) also found a significant effect of Zn application on the productivity of sugarcane, in seven experiments performed in soils in Alagoas, Brazil, when these micronutrient levels were below 5 mg dm^{-3}.

Wang et al. (2005) reported that the soil applications of 4.4 and 8.9 kg Zn ha^{-1} significantly increased sugarcane and sugar yields of LCP 85-384 by an average of more than 23% above the control for acidic and calcareous soils. Madhuri et al. (2013) recommended the application of $ZnSO_4$ to the soil 50 kg ha^{-1} for better yield and quality of sugarcane production in sandy loam soils with pH equal to 8.08. In this sense it is important to note that these recommendations are for different soil and climate conditions (such as pH, texture, organic matter content and pluvial precipitation) that was used in our research.

A hypothesis for the non-effect of zinc fertilization on the productivity of sugarcane grown on sandy soils with low zinc content, is that the plant-sugarcane experiment was conducted in an atypical year of rainfall (Figure 1A), that is, much rain during the dry period. This could have then favored a better root development, and therefore this must have explored a greater soil volume and thus absorbed more zinc from the soil. Another hypothesis reported by Tokeshi (1991), indicates that as sugarcane has a deep root system, it enables the absorption of micronutrients in the subsurface layers. However, although no significant response of the sugarcane cultivar RB867515 was found for fertilization with zinc in the first two cuts of the culture, such results may be different for other varieties of sugarcane that are more demanding in this micronutrient and/or in subsequent crops, as these Zn sources may have different residual effects. Casarin et al. (2001) report that in low fertility soils or which are exploited for many years, the occurrence of micronutrient deficiency in sugarcane becomes even more aggravated.

Conclusions

1) The sources of zinc (sulphate, FTE and chelated zinc) had a similar effect on the Zn foliar and stalk concentrations, number of internodes per meter of stalk, number of stalks per meter and stalk productivity in sugarcane, in two crops.
2) Increasing rates of zinc afforded a linear increase in the foliar Zn levels and Zn in the stalks of the plant-sugarcane and first-ratoon-sugarcane, independent of the Zn source used.
3) The zinc rates did not affect the production components and hence the stalk productivity of the plant-sugarcane and first-ratoon-sugarcane, grown on sandy and acid soil with low zinc content.

Conflict of Interest

The authors have not declared any conflict of interest.

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