DIVISÃO 3 - USO E MANEJO DO SOLO

Comissão 3.1 - Fertilidade do solo e nutrição de plantas

FERTILIZATION WITH FILTER CAKE AND MICRONUTRIENTS IN PLANT CANE[1]

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SUMMARY

The response of sugarcane to application of micronutrients is still not very well known. In view of the need for this information, the aim of this study was to evaluate the application of the micronutrients Zn, Cu, Mn, Fe, B, and Mo to plant cane in three soils, with and without application of filter cake. This study consisted of three experiments performed in the State of São Paulo, Brazil, (in Igaraçu do Tiete, on an Oxisol; in Santa Maria da Serra, on an Entisol, both in the 2008/2009 growing season; and in Mirassol, on an Ultisol, in the 2009/2010 growing season) in a randomized block design with four replications with a 8 x 2 factorial combination of micronutrients (1 - no application/control, 2 - addition of Zn, 3 - addition of Cu, 4 - addition of Mn 5 - addition of Fe, 6 - addition of B, 7 - addition of Mo, 8 - Addition of Zn, Cu, Mn, Fe, B, and Mo) and filter cake (0 and 30 t ha^{-1} of filter cake) in the furrow at planting. The application of filter cake was more efficient than of Borax in raising leaf B concentration to sufficiency levels for sugarcane in the Entisol, and it increased mean stalk yield in the Oxisol. In areas without filter cake application, leaf concentrations were not affected by the application of Zn, Cu, Mn, Fe, B, and Mo in the furrow at planting; however, Zn and B induced an increase in stalk and sugar yield in micronutrient-poor sandy soil.

Index terms: Zn, Cu, B, Mn, Fe, Mo, filter cake, *Sacharum spp*.

RESUMO: *ADUBAÇÃO COM TORTA DE FILTRO E MICRONUTRIENTES NO PLANTIO DA CANA-DE-AÇÚCAR*

A resposta da cultura da cana-de-açúcar à aplicação de micronutrientes ainda é pouco conhecida. Diante da necessidade dessas informações, o objetivo deste trabalho foi avaliar a aplicação de micronutrientes, Zn, Cu, Mn, Fe, B e Mo, em três solos com e sem aplicação de

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torta de filtro, na cultura da cana-de-açúcar. Este trabalho foi constituído de três experimentos conduzidos em condições de cana planta. Os experimentos foram instalados em Igaraçu do Tietê, SP, em Latossolo Vermelho; em Santa Maria da Serra, SP, em Neossolo Quartzarênico, ambos na safra 2008/2009; e em Mirassol, SP, em Argissolo Vermelho, conduzido na safra 2009/2010. O delineamento experimental foi em blocos casualizados, com quatro repetições, no esquema fatorial 8 x 2, sendo a combinação de micronutrientes (testemunha, Zn, Cu,Mn, Fe, B, Mo e todos os micros) com torta de filtro (0 e 30 t ha^{-1} de torta de filtro) no sulco de plantio. A aplicação de torta de filtro foi mais eficiente que o Bórax em elevar os teores foliares de B em níveis de suficiência para cana-de-açúcar no Neossolo Quartzarênico e em aumentar a produtividade média de colmos no Latossolo Vermelho. Em áreas que não receberam aplicação de torta de filtro, os teores foliares não foram afetados pela aplicação de Zn, Cu, Mn, Fe, B e Mo no sulco de plantio; porém, a aplicação de Zn e B propiciou aumento na produtividade de colmos e açúcar em solo arenoso e com baixos teores no solo.

Termos de indexação: Zn, Cu, B, Mn, Fe, Mo, torta de filtro, Sacharum spp.

INTRODUCTION

The technological evolution of the sugarcane agribusiness in recent years has led to significant increases in sugarcane production. In the 2010/2011 growing season, sugarcane processing reached 624 million tons, produced on 8.06 million hectares, i.e., a mean cane yield of 77 Mg ha^{-1} on the sugarcane fields and a production of 38.7 million tons of sugar and of 27.7 million liters of ethanol (CONAB, 2011). In spite of these achievements, the yield is still below the genetic potential of the cultivars (Albuquerque & Silva, 2008). One of the main factors that limit the yield of sugarcane fields in Brazil is the plant nutrient supply.

According to Fageria et al. (2002), micronutrient deficiency is a general problem around the world, due to the increased demand for micronutrients induced by more intensive management practices and highly productive, more micronutrient-demanding cultivars; by the increase in crop production on marginal soils with low levels of essential nutrients; the greater use of concentrated fertilizers at a lower concentration of micronutrients; reduction in the use of animal manure, composts and crop residues; the use of soils with low natural reserves; and by the involvement of natural and anthropogenic factors that limit adequate nutrient availability and induce nutrient imbalances for plants.

In the central-southern region of Brazil, the difficulty of identification of micronutrient deficiency symptoms in sugarcane, together with the low response to application, contribute to the low use of these nutrients. According to Rosseto & Dias (2005), the low response to the application of micronutrients is related to the root system, which exploits large volumes of soil with high extraction capacity, bringing nutrients from dry leaves and rhizomes from deeper layers to the surface. In addition, micronutrients are recycled from residues from agribusiness industries, in applications of vinasse and filter cake, for example.

In the State of São Paulo, fertilization recommendations of micronutrients for sugarcane include only zinc (Zn) and copper (Cu) when the soil concentrations extracted with DPTA are below 0.5 and 0.2 mg dm^{-3}, respectively (Spironello et al., 1996). Due to the absence of yield response to the other micronutrients, these were not included in the official fertilization recommendations. However, most of the studies were carried out in the 1960s, 1970s and 1980s (Spironello, 1972; IAA/Planalsucar, 1976; Alvarez et al., 1979; Azeredo & Bolsanello, 1981) with older cultivars with lower production potential.

In addition, in recent years, some factors have raised questions about the need of supplying these nutrients, such as the increase in stalk yield and consequent export of micronutrients, together with the use of phosphate fertilizers, mainly, which are more concentrated and therefore contain lower concentrations of "contaminant" micronutrients, as well as crop planting on sandy soils, poor in organic matter and micronutrients.

Filter cake is a residue composed of the mixture of ground bagasse and mud/sludge from decantation, resulting from the sugar clarification process. For each ton of ground sugarcane, between 30 and 40 kg of cake are produced. Filter cake has been mainly applied as fertilizer in the furrow at planting of sugarcane. However, there is still little information about the supply capacity of this residue in response to the micronutrient demands arising from plant extraction.

This lack of information regarding micronutrients and filter cake in sugarcane is evident, especially in view of the few publications in scientific journals.

The aim of this study was to evaluate the application of the micronutrients Zn, Cu, Mn, Fe, B, and Mo along with filter cake, in plant cane in three soils.

MATERIAL AND METHODS

All experiments were performed in the State of São Paulo, Brazil, namely in Igaraçu do Tietê (latitude

22^o 34' S, longitude 48^o 30' W), on an Oxisol (Soil Survey Staff, 2010), in Santa Maria da Serra (latitude 22^o 31' S, longitude 48^o 20' W), on an Entisol (Soil Survey Staff, 2010), both in the 2008/2009 growing season, in areas with several years of sugarcane cultivation, and in Mirassol (latitude 20^o 47' S, longitude 49^o 30' W), on an Ultisol (Soil Survey Staff, 2010), in the 2009/2010 growing season, in a former pasture area.

Prior to the experiments, the soil chemical characteristics were determined (Table 1), according to Raij et al. (2001).

The experiment was set up in a randomized block design, in a factorial scheme (8 x 2) with four replications. Treatments consisted of seven treatments with micronutrient applications plus a control (control, Zn, Cu, Mn, Fe, B, Mo, and complete (all micronutrients)) and with and without filter cake application (0 and 30 t ha^{-1} wet basis) in the furrow at planting. In all experiments, the plots consisted of eight rows of 10 m length, at a spacing of 1.5 m between rows.

The experiments were initiated in May 2008, August 2008 and February 2009, on Oxisol, Entisol, and Ultisol, respectively. Dolomitic limestone (1.5 t ha^{-1}), with effective calcium carbonate equivalence (ECCE) of 85 %, was applied only on Ultisol. In the experiment on Oxisol, fertilization consisted of 500 kg ha^{-1} of N-P_2O_5-K_2O fertilizer at percentages of 10, 25 and 25 %, respectively (10-25-25). On the Entisol, 370 kg ha^{-1} NPK fertilizer (at 00-18-36) was used where filter cake was applied, and 500 kg ha^{-1} NPK fertilizer (10-25-25) on the plots without filter cake application. On the Ultisol, 1000 L ha^{-1} NPK 04-12-10 was applied. The micronutrient sources were Zn - Zinc sulfate (20 % Zn), Cu - Copper sulfate (13 % Cu), Mn - Manganese sulfate (26 % Mn), Fe - Iron chelate (11 % Fe), B - Sodium tetraborate - Borax (11 % B), and Mo - Sodium molybdate (39 % Mo). The following quantities applied of each micronutrient source were applied: 25 kg ha^{-1} zinc sulfate (5 kg ha^{-1} of Zn), 30.8 kg ha^{-1} copper sulfate (4 kg ha^{-1} of Cu), 20 kg ha^{-1} manganese sulfate (5.2 kg ha^{-1} Mn), 21 kg ha^{-1} iron chelate (4 kg ha^{-1} Fe), 10 kg ha^{-1} sodium tetraborate - Borax (1.1 kg ha^{-1} B) and 0.5 kg ha^{-1} sodium molybdate (0.195 kg ha^{-1} Mo).

The micronutrient sources were diluted in water to ensure a regular application, and distributed in the plant row at a depth of 0.25-0.30 m. The sugarcane variety to be used was defined according to the respective production environment and criteria of the sugar mills, as varieties SP80-3280, SP81-3250 and RB 92-5211 on the Oxisol, Ultisol and Entisol, respectively. Other management practices were applied according to the crop requirements. Samples were taken of limestone, fertilizers and filter cake for chemical and physical characterization, according to LANARV (1988). The total micronutrient

Table 1. Chemical properties of the three soils in three layers prior to the experiments

Soil	Layer	pH ($CaCl_2$)	MO	P_{resin}	Al^{3+}	H+Al	K	Ca	Mg	CTC
	m		g dm^{-3}	mg dm^{-3}	mmol$_c$ dm^{-3}					
Oxisol	0.0-0.2	5.3	31	17	0	32	1.1	36	14	83
	0.2-0.4	4.8	23	9	1	39	0.5	25	10	75
	0.4-0.6	4.6	20	5	2	44	0.4	15	6	65
Ultisol	0.0-0.2	5.2	10	22	0	18	1.8	13	7	40
	0.2-0.4	4.7	9	19	2	21	1.4	8	5	35
	0.4-0.6	4.6	7	17	2	21	1.5	6	3	32
Entisol	0.0-0.2	5.7	6	6	0	12	2.7	9	4	28
	0.2-0.4	5.5	4	4	0	12	3.0	9	3	27
	0.4-0.6	5.7	5	4	0	12	3.5	8	3	27
		V	Sand	Silt	Clay	Zn	Cu	Fe	Mn	B
		%	g dm^{-3}			mg dm^{-3}				
Oxisol	0.0-0.2	61	166	269	565	0.3	2.4	6	13.6	0.24
	0.2-0.4	48	-	-	-	0.2	1.6	3	7.2	0.30
	0.4-0.6	33	-	-	-	0.1	0.6	5	3.2	0.21
Ultisol	0.0-0.2	55	815	52	133	1.2	0.8	23	20.2	0.20
	0.2-0.4	41	-		-	1.6	0.7	21	21.4	0.22
	0.4-0.6	33	-		-	0.5	0.6	20	25.6	0.13
Entisol	0.0-0.2	57	928	18	54	0.4	0.6	40	2.9	0.09
	0.2-0.4	56	-	-	-	0.1	0.5	33	4.2	0.07
	0.4-0.6	55	-	-	-	0.1	0.5	33	3.2	0.07

concentrations of the limestone and fertilizers applied in the experiments are shown in table 2.

Filter cake samples (10 subsamples) were taken at application and the results of physicochemical characterization are shown in table 3.

At sampling, the top-visible dewlaps of 30 plants per plot were collected for evaluation of the nutritional state (leaf +1), in the stage of greatest vegetation, disregarding the midrib and collecting the middle third of the leaf (Spironello et al., 1996). The collected material was dried in a forced-air oven at 60 ^{o}C for 72 h and weighed. The material was ground and the Cu, Fe, Mn, Zn, B, and Mo concentrations were determined as described by Malavolta et al. (1997).

Stalk yield at harvest was determined in the five central rows, while two rows of plants were used for the technological measurements (sugar concentration, purity, fiber, and reducing sugar). One meter was randomly detremined in both plant rows; 20 stalks were collected, cut at apical bud height, defoliated and then sent to the sugar cane laboratory of a sugar mill, for the technological evaluations described by Fernandes (2003), based on the parameter of total reducing sugars. Using the results of stalk yield and sugar concentration, the sugar yields were calculated. The experiment was harvested on August 4, 2009 (15 months after planting), September 16, 2009 (13 months after planting) and July 13, 2010 (17 months after planting) from the Oxisol, Entisol and Ultisol, respectively.

Data were subjected to analysis of variance; the mean micronutrient values were compared by the Scott-Knott test, and the mean filter cake values by the LSD test, both at 0.05 probability.

RESULTS AND DISCUSSION

No effect of interaction between the filter cake and micronutrient factors was observed on the leaf concentrations of Zn, Cu, Mn and Fe (Table 4). The leaf concentrations of Zn, Cu, Mn, Fe, B, and Mo in the three soils did not increase when Zn, Cu and Mn sulfates, Fe chelate, borax and sodium molybdate, respectively, were applied in the furrow of the plant row. Other authors also found no increase in leaf concentrations when Zn sulfate (Andrade et al., 1995), Cu sulfate, Mn sulfate and Borax (Andrade et al., 1995; Becari, 2010) were applied in the row at planting. Contrary to the results found, other authors such as Spironello (1972) and Pedras (1982) found increases in the leaf concentrations for B application, Cambria et al. (1989) for Zn application, and Alvarez-Vicente (1984) for applications of B, Cu and Zn to sugarcane.

Table 2. Total micronutrient concentrations in fertilizers and limestone applied to sugarcane on three types of soil

Fertilizer and amendment	Zn	Cu	Fe	Mn	B
	mg kg^{-1}				
10-25-25[(1)]	319.00	34.00	2,235.00	136.00	189.00
00-18-36[(2)]	292.00	33.00	5,475.00	235.00	189.00
04-12-10[(3)]	3.00	1.00	38.00	4.00	76.00
Limestone	60.00	29.00	3,760.00	635.00	189.00

NPK formulation applied to [(1)] Oxisol, [(2)] Entisol and [(3)] Ultisol.

Table 3. Physicochemical characterization of the filter cake applied in the planting furrow of sugarcane of three types of soil

Soil	N	P_2O_5	K_2O	Ca	Mg	S	Moisture
	g kg^{-1} of dry matter						
Oxisol	9.2	13.4	3.8	7.3	3.4	6.0	604
Ultisol	4.9	8.4	4.5	8.7	1.5	2.6	620
Entisol	8.5	12.0	4.0	8.0	2.5	6.2	624
	C	C/N	Zn	Cu	Fe	Mn	B
	g kg^{-1}		mg kg^{-1} of dry matter				
Oxisol	10.6	13/1	82	68	28,500	594	215
Ultisol	7.2	12/1	64	54	25,050	606	137
Entisol	9.8	12/1	72	50	24,500	574	200

However, for these micronutrients, the leaf concentrations, even in the control, were within the sufficiency range suggested for sugarcane (Spironello et al., 1996), except for B in the Entisol, which may explain the small effect of the micronutrients applied to the soil.

Only in the Entisol without filter cake application the leaf concentrations of B were below the sufficiency range suggested (10-30 mg kg^{-1}) for sugarcane (Spironello et al., 1996) for all treatments, except when iron sulfate was applied, which was at the lower limit of the range considered adequate. Confirming these results, Becari (2010) evaluated the leaf concentrations of B at eight sugarcane production sites in the State of São Paulo and observed that at five locations, the concentrations of this micronutrient were below the sufficiency level. Vitti & Mazza (2002) found micronutrient concentrations, especially of B and Zn, below the adequate levels in leaf samples in the regions of Piracicaba and Araçatuba. Vale et al. (2008) evaluated the concentrations of B, Cu, Fe, Mn, and Zn in 890 sugarcane fields in the regions of Ribeirão Preto and Catanduva, two important production regions of the State of São Paulo, and observed that most samples had leaf concentrations of B, Cu and Zn below the critical level. Even when B was applied in the planting furrow, no significant increase was observed in the leaf concentrations; these data corroborate those found by Becari (2010), who applied 3 kg ha^{-1} of B at eight sites of the State of São Paulo and observed no increase in leaf concentrations. This may have occurred because, according to Byers et al. (2001), B is extremely susceptible to leaching, especially in sandy soils subjected to high rainfall amounts, as was the case in this experiment. Franco et al. (2009) studied recovery of ^{10}B in plant cane, at a dose of 4 kg ha^{-1} B and found a recovery of 2 % by the plant.

The filter cake application in the planting furrow reduced leaf concentrations of Zn, Cu and Mn in the Oxisol and Mn in the Ultisol. These results can be explained by the application of organic residues to the soil, reducing the availability of micronutrients through complexation of the metals by the chelating agents in the organic material (Stevenson, 1994), but as this residue is decomposed, micronutrients are released. Therefore, this result is observed especially in the Oxisol because the high quantity of clay prevents mineralization of the soil organic matter, possibly through physical protection (Oades, 1988). This leads to lower decomposition of this organic residue and, consequently, the complexation of these metals lasts longer, reducing the availability and uptake of these nutrients.

For the leaf concentrations of Cu and Zn in the Ultisol, and Cu and B in the Entisol, the opposite occurred; in other words, the leaf concentrations increased after filter cake application, which may be explained by the faster mineralization of filter cake in these soils with low clay concentration. For the leaf concentrations of B, the filter cake was able to raise the concentrations to levels considered adequate for sugarcane (Spironello et al., 1996). These data indicate that filter cake was more efficient than Borax in supplying sugarcane with B. In addition, it was observed that the combination of filter cake and Borax induced the highest concentrations of B in sugarcane leaves. This probably occurred because filter cake forms organic complexes with B, reducing leaching and making this nutrient more available throughout the crop cycle.

Although the concentrations of Fe applied by the addition of filter cake are high (Table 3), no effect was observed on the leaf concentrations of Fe in the three soil types after filter cake and micronutrients were applied. Fe is widely distributed in the profiles of most of the soils, in some cases reaching high quantities in the arable layer (Bataglia, 1991), a fact which contributed to the lack of alteration in the leaf concentrations.

The filter cake application led to a reduction in the leaf concentrations of B and Mo in the Ultisol; however, even with this reduction, the concentrations remained within the sufficiency range for sugarcane (Spironello et al., 1996). The combination of filter cake with molybdenum and the complete treatment (all micronutrients), in the Entisol increased the Mo leaf concentrations in relation to the treatments without filter cake application. In the treatment without filter cake and the complete treatment, the Mo leaf concentrations decreased. This effect may have occurred, according to Reisenauer (1963), because of a competitive effect with the SO_2^{-4} present in the sulfates applied in the planting furrow, reducing Mo uptake.

The sugarcane stalk yield (Table 5) in the Oxisol increased with the filter cake application, regardless of the micronutrient factor, whereas sugar yield only increased significantly in the treatments with Cu and the complete treatment. In an Oxisol with a clayey texture, Fravet et al. (2010) also found an increase in stalk and sugar yield with the application of increasing doses of filter cake. This increase may be attributed to the diverse benefits resulting from filter cake in terms of nutrient and water availability to sugarcane (Nunes Júnior et al., 1988; Cardozo et al., 1988), leading to higher stalk and sugar yields.

According to the recommendations proposed by Spironello et al. (1996), the micronutrient concentration present in the Oxisol prior to the experiment (Table 1) indicated the need for application of Zn. Despite the need for application, no increase in stalk yield was observed when this micronutrient was supplied. These data corroborate those found by Becari, (2010) in an Oxisol with 30 % clay and Zn concentrations of 0.1 mg dm^{-3}, who observed no significant increase in stalk and sugar yield either. This result indicates that in plant cane, in this type

Table 4. Concentrations of zinc (Zn), copper (Cu), manganese (Mn), iron (Fe), boron (B), and molybdenum (Mo) in the sugarcane diagnostic leaf (+1) of three soil types as affected by filter cake and micronutrient application to plant cane

Micronutrient	Oxisol			Ultisol			Entisol		
	WFC	FC	Mean	WFC	FC	Mean	WFC	FC	Mean
Zn ($mg\ kg^{-1}$)									
Control	28^{ns}	26	27 a	22^{ns}	30	26 a	20^{ns}	22	21
Zn	33	21	27 a	25	37	31 a	20	21	21
Cu	30	23	27 a	22	30	26 a	24	19	22
Fe	31	22	26 a	21	29	25 a	20	22	21
Mn	33	22	28 a	22	33	28 a	18	20	19
B	29	22	25 a	20	35	27 a	22	22	22
Mo	29	22	25 a	23	31	27 a	21	20	21
Complete	30	26	28 a	27	29	28 a	20	23	21
Mean	30 A	23 B		23 B	32 A		21	21	
CV (%)		22.39			14.43			53.41	
Cu ($mg\ kg^{-1}$)									
Control	14^{ns}	13	14	9^{ns}	11	10	11^{ns}	14	12
Zn	15	13	14	10	11	10	11	15	13
Cu	15	15	15	10	11	10	11	14	13
Fe	14	13	14	10	12	11	11	14	13
Mn	15	13	14	10	12	11	11	14	13
B	15	13	14	9	11	10	12	14	13
Mo	15	13	14	10	11	10	11	13	12
Complete	15	13	14	9	11	10	11	15	13
Mean	15 A	13 B		10 B	11 A		11 B	14 A	
CV (%)		8.30			8.39			12.12	
Fe ($mg\ kg^{-1}$)									
Control	129^{ns}	138	134	91^{ns}	92	91	94^{ns}	104	99
Zn	127	131	129	98	87	93	95	93	94
Cu	146	135	141	88	96	92	102	97	99
Fe	135	132	134	86	99	93	107	107	107
Mn	142	125	134	89	96	93	101	106	104
B	117	136	127	88	91	90	104	98	101
Mo	118	149	134	86	95	91	105	91	101
Complete	121	140	131	82	95	89	105	94	100
Mean	130	136		89	94		102	100	
CV (%)		14.30			11.50			8.3	
Mn ($mg\ kg^{-1}$)									
Control	218^{ns}	181	199 a	98^{ns}	84	91 a	67^{ns}	62	65
Zn	212	178	195 a	106	82	94 a	66	64	65
Cu	202	193	198 a	108	90	99 a	68	75	72
Fe	202	175	189 a	93	89	91 a	69	68	69
Mn	206	187	197 a	98	99	99 a	74	67	70
B	185	203	194 a	101	90	95 a	77	76	77
Mo	205	196	200 a	105	83	94 a	71	72	71
Complete	208	209	209 a	94	93	93 a	66	73	70
Mean	205 A	190 B		100 A	89 B		70	70	
CV (%)		13.96			13.21			12.25	
B ($mg\ kg^{-1}$)									
Control	13^{ns}	16	15	24^{ns}	20	22 a	8 Ba	13 Ac	10
Zn	14	13	13	27	19	23 a	8 Ba	17 Ab	13
Cu	12	12	12	25	22	24 a	8 Ba	17 Ab	12
Fe	12	16	14	23	19	21 a	10 Ba	15 Ac	12
Mn	18	14	16	20	20	20 a	7 Ba	18 Ab	12
B	12	14	13	26	17	22 a	7 Ba	22 Aa	15
Mo	14	13	13	23	20	22 a	8 Ba	13 Ac	10
Complete	15	15	15	23	21	22	7 Ba	15 Ac	11
Mean	14	14		24 A	20 B		8	16	
CV (%)		20.35			18.15			20.94	
Mo ($mg\ kg^{-1}$)									
Control	0.36^{ns}	0.43	0.40	0.45^{ns}	0.17	0.31	0.37 Aa	0.39 Aa	0.38
Zn	0.37	0.38	0.38	0.38	0.38	0.38	0.35 Aa	0.40 Aa	0.37
Cu	0.40	0.40	0.40	0.42	0.33	0.37	0.39 Aa	0.40 Aa	0.40
Fe	0.37	0.24	0.31	0.33	017	0.25	0.37 Aa	0.41 Aa	0.39
Mn	0.39	0.33	0.36	0.41	0.33	0.37	0.40 Aa	0.41 Aa	0.40
B	0.38	0.34	0.36	0.45	0.35	0.40	0.39 Aa	0.41 Aa	0.40
Mo	0.42	0.37	0.40	0.31	0.30	0.31	0.28 Ba	0.43 Aa	0.35
Complete	0.43	0.36	0.40	0.39	0.24	0.32	0.13 Bb	0.36 Aa	0.24
Mean	0.39	0.36		0.39 A	0.29 B		0.33	0.40	
CV (%)		22.69			29.47			18.38	

^{ns}: not significant at 5 % and refers to the interaction between filter cake and micronutrients; the same small letters in the column do not differ from each other by the Scott-Knott test (p<0.05) and the same capital letters in the row by the LSD test (p<0.05). WFC: Without Filter Cake; FC: With Filter Cake.

Table 5. Stalk yield and sugar yield of sugarcane from three types of soil as affected by filter cake and micronutrient application to plant cane

Micronutrient	Oxisol			Ultisol			Entisol		
	WFC	FC	Mean	WFC	FC	Mean	WFC	FC	Mean
				Stalk yield (Mg ha^{-1})					
Control	114	115	114 a	234^{ns}	234	234 a	142 Ab	144 Aa	143
Zn	105	118	111 a	235	228	232 a	151 Aa	143 Aa	147
Cu	107	121	114 a	222	217	219 a	142 Ab	140 Aa	141
Fe	113	121	117 a	227	224	225 a	138 Ab	141 Aa	139
Mn	113	116	115 a	230	223	227 a	138 Ab	141 Aa	140
B	111	110	110 a	231	226	228 a	150 Aa	146 Aa	148
Mo	103	108	106 a	242	221	231 a	141 Ab	143 Aa	142
Complete	96	119	108 a	233	231	232 a	136 Ab	144 Aa	140
Mean	108 B	116 A	-	232 A	225 A	-	142	143	-
CV (%)		10.17			7.05			4.50	
				Sugar yield (Mg ha^{-1})					
Control	19.5 Aa	20.9 Aa	20.2	48.0	48.8	48.4 a	24.2 Ab	25.1 Aa	24.7
Zn	19.8 Aa	21.0 Aa	20.0	48.3	46.8	47.5 a	25.6 Aa	24.0 Aa	24.8
Cu	19.4 Ba	21.9 Aa	20.7	45.6	45.0	45.3 a	23.5 Ab	23.2 Aa	23.3
Fe	20.2 Aa	21.9 Aa	21.1	46.9	46.0	46.4 a	24.2 Ab	23.5 Aa	23.9
Mn	20.3Aa	19.8 Aa	20.1	46.9	45.3	46.1 a	23.5 Ab	23.7 Aa	23.7
B	20.5 Aa	19.7 Aa	20.1	48.0	45.3	46.7 a	25.3 Aa	24.7 Aa	25.1
Mo	18.4 Aa	18.8 Aa	18.6	50.3	45.6	47.9 a	23.9 Ab	23.2 Aa	23.6
Complete	16.7 Ba	21.7 Aa	19.2	49.3	45.1	47.2 a	23.3 Ab	24.1 Aa	23.7
Mean	19.2	20.7	-	47.9 A	46.0 A	-	24.2	23.9	-
CV (%)		8.93			6.73			4.74	

^{ns}: interaction between filter cake and micronutrients not significant at 5 %; the same lowercase letters in the column do not differ from each other by the Scott-Knott test (p<0.05) and the same capital letters in the row by the LSD test (p<0.05). WFC: Without Filter Cake; FC: With Filter Cake.

of soil, the critical concentration in the soil may be less than that suggested by the recommendation or the Zinc sulfate dose applied is insufficient. Couto (1985) suggested that other properties, such as clay concentration, soil water and remaining P could be used as auxiliary criteria to evaluate the availability and establish fertilization recommendations for Zn. In addition, the absence of yield increases in some crops after micronutrient application is not uncommon. This result may be explained by diverse factors, e.g., for sugarcane, the presence of micronutrients as “contaminants” in fertilizers and soil amendments may be highlighted, since they may supply a considerable part of plant needs (Table 2). In addition, the long crop cycle of sugarcane enables the roots to exploit deeper soil layers, obtaining micronutrients for their development. Another factor is the soil tillage before sugarcane planting, since this operation favors mineralization and availability of micronutrients to plants. The sugarcane setts used for planting can also supply the micronutrients required for the crop development in the initial phases.

In the Ultisol, the stalk and sugar yield were not affected by the application of micronutrients and filter cake, probably because the concentrations of Zn, Cu, Mn, Fe and B in the soil (Table 1) were in a range requiring no additional supply of these nutrients, according to the recommendations of Raij et al. (1996). In addition, since sugarcane was planted after pasture, the mineral fertilization together with the large quantity of organic material mineralized at soil tillage were sufficient to achieve the same yield as the plots treated with filter cake and/or micronutrients.

The combined application of all micronutrients (complete treatment) did not lead to yield gains. Probably, the interaction between the different sources of micronutrients applied reduced the availability of Zn and B to the plants, whereas yield responses were observed after separate applications. Alvarez & Wutke (1963) and Andrade et al. (1995) observed no significant yield responses either after the application of micronutrient mixtures.

In an Entisol, according to Spironello et al. (1996), in spite of filter cake applications having increased the B leaf concentration (Table 4) to adequate levels, no increase was observed in stalk and sugar yield (Table 5), compared to locations that did not receive this organic residue. Becari (2010) observed no correlation between the leaf concentrations and sugarcane yield either. Boaretto et al. (1997) warned that the lack of correlation between the B concentrations in the leaves and yield may often be explained by the difficulty in removing the B retained in the leaf cuticle or that bound to the pectic layer of the cell wall, without achieving its metabolic function, resulting in an overestimation of the B leaf level.

An interaction of the factors was observed in the Entisol, where the application of Zn and B in the areas without filter cake application increased stalk yield to the order of 9 and 8 Mg ha^{-1}, and sugar yield to the order of 1.4 and 1.1 Mg ha^{-1}, respectively. In agreement with our observations, Alvarez-Vicente (1984) and Cambria et al. (1989), both in sandy Oxisols, observed an increase in stalk yield after Zn application. In studies of Becari (2010) with the same soil type, Zn sulfate applied in the planting furrow led to an increase in stalk yield of 23 Mg ha^{-1} and 3.2 Mg ha^{-1} in sugar yield. This same author observed that Zn was the micronutrient that induced the greatest gains in stalk yield (20 t ha^{-1}) in plant cane, in the average of eight sugarcane production sites in the State of São Paulo. The application of B, despite not increasing the leaf concentrations (Table 4), raised the stalk and sugar yield (Table 5). Becari (2010) applied 3 kg ha^{-1} B at eight locations in the State of São Paulo and observed no increase in leaf concentrations; however, the accumulated yield of stalks and sugar increased by 8 and 1.06 Mg ha^{-1}, respectively. The increase in stalk and sugar yield on the Entisol confirmed the importance of monitoring the soil micronutrient concentrations, since the Zn and B concentrations prior to the experiment (Table 1) indicated the need for application, according to the recommendations proposed by Raij et al. (1996).

CONCLUSIONS

1. The leaf concentrations of Zn, Cu, Mn, Fe, B, and Mo were not affected by separate applications of the micronutrients.

2. In sandy soil with low Zn and B concentrations, the application of these micronutrients led to an increase in stalk and sugar yields.

3. For the Entisol, the application of filter cake was more efficient than of Borax to raise the leaf concentrations of B to sufficiency levels for sugarcane.

4. The filter cake application increased stalk yield in the Oxisol.

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