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Ways of applying zinc to maize plants growing in Oxisol: effects on the soil, on plant nutrition and on yield

Formas de aplicación de zinc para las plantas de maíz que crecen en Oxisol: efectos sobre el suelo, la nutrición de las plantas y la productividad

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SUMMARY

The way of applying zinc can influence the zinc uptake and productivity of crops, especially cereals that have high demand for this nutrient. The aim of this study is to evaluate methods of Zn application on soil, nutritional status and productivity of maize. For this, an experiment was undertaken at FCAV/UNESP, Jaboticabal-SP, in Oxisol clay (DTPA on Zn: 0.5 mg dm^{-3}) with maize (hybrid Simple Impact), from December through May 2009. Nine treatments with three doses of Zn in soil banded application (in furrows) and three doses of Zn by incorporation in soil (0-20 cm depth), foliar application, seed application and control (no Zn). The treatments were arranged in a randomized block design with four replications. Regardless of the method, Zn application promoted higher contents of this micronutrient in soil and higher accumulation in the shoots as well as increasing Zn in the maize grain. However, it did not affect the nutritional status and yield of the maize. The Zn application in the soil resulted in a greater Zn uptake by plants and maize yield, compared to Zn application in the plant by seed or foliar.

Key word: Zn, *Zea mays* L., micronutrient, application methods.

RESUMEN

La manera de aplicar zinc puede influir en la absorción de zinc y productividad de los cultivos, especialmente los cereales que tienen alta demanda de este nutriente. El objetivo de este estudio es evaluar los métodos de aplicación de Zn en el suelo, el estado nutricional y el rendimiento de maíz. Para ello, se realizó un experimento en FCAV/UNESP, Jaboticabal en Oxisol arcilloso (Zn-DTPA: 0,5 mg dm-3), el maíz (híbrido de impacto simple) de diciembre a mayo de 2009. Se aplicaron nueve tratamientos con tres dosis de Zn en forma localizada (en las crestas) y tres dosis de Zn mediante la incorporación en el suelo (0-20 cm), foliar, las semillas y el control de la aplicación (sin Zn). Los tratamientos se dispusieron en un diseño de bloques al azar con cuatro repeticiones. Independientemente del método, la aplicación de Zn promovió mayores niveles de zinc mayor acumulación en el suelo y en el aire, así como aumento de Zn en el grano. Sin embargo, no afectó el estado nutricional y el rendimiento de maíz. La aplicación de Zn resultó en un incremento de la absorción de zinc por las plantas y el rendimiento de maíz en comparación con la aplicación de Zn a la semilla de la planta o forma de hoja.

Palabra clave: *Zn,* Zea mays *L., micronutrientes, los métodos de aplicación.*

Introduction

Tropical soils, in general, present low zinc (Zn) concentration (Lopes, 1983), be it with the original material or by planting practices with the use of intensive crops without necessary fertilization. In literature many causes of Zn deficiency is presented in crops as: low levels of Zn in the soil, excessive lime, low levels of organic matter and temperature, high levels of P in the soil or in the fertilizer, excessive applications of N and restriction of root development (Lucas and Knezek, 1972).

Among the micronutrients, the importance of this element in the crops in Brazilian soils is

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unquestionable for its frequent deficiency, mainly in soils that are not from basic rocks (Abreu *et al.*, 2001). According to Galrão (1994) Zn is one of the micronutrients whose deficiency has limited crop production in Brazil.

This way, the Zn deficiency is recognized as a worldwide nutritional problem in the crop production (Fageria, 2001), especially, as *poaceae* which are demanded in this nutrient. According to Malavolta (1980) for obtaining high yield in maize it is indispensable the supply of micronutrients, mainly boron and Zn.

The Zn activity is effective for determined relevant process in the physiological and nutritional homeostasis of the plant, acting as an activator or enzyme component, it participates of the photosynthesis in the C4 plants, it is necessary for the production of tryptophan and for the maintenance of the biomembrane integrity (Malavolta, 2006) and still participate in the protein metabolism (Bowen, 1979) and acting as structural component of the ribosomes (Marschner, 1995). With Zn deficiency, the plant may present symptoms of strong chlorosis along the main nervure and purple shades on the leaves, shortening of the internodes and decrease of the leaf production, besides the reduction of growth and production (Malavolta, 1980).

Zn is a micronutrient which enhances the grain productivity in the maize production (Melarato, 2000) and for the soils in the São Paulo state the recommended doses are of 2 to 4kg ha^{-1}, according to the element content of the soil (Raij and Cantarella, 1997). However, according to Fageria *et al.* (2002), the quantity of fertilizer to be applied to correct the Zn deficiency in the crops depend on the content of this micronutrient in the soil, climate conditions and vegetal specie.

The supply of Zn in the crops can be done directly on the soil, as fertilizers, via foliar fertilization or seed treatments (Gonçalves Júnior *et al.*, 2007). In concordance to Galrão (1996), for maize applications on leaves or seeds are rarely recommended due to lack of research data. Consequently, complete researches involving all the forms of Zn application are necessary and the study of the effects in the soil-plant systems, and its effects in the grain quality and productivity.

Therefore, the aim of this study is to evaluate the methods of applying Zn on the soil, the nutritional state and the productivity of the maize crop.

Material and Methods

The experiment was done at the farm school belonging to FCAV/UNESP, Jaboticabal campus in São Paulo state, at 21° 15' 22'' S to 48° 18' 58'' W and the altitude of 575 m, in an Oxisol dystrophic classified by EMBRAPA (2006), clay texture. The soil chemical analyses (0–20 cm soil layer) the method used was written by Raij *et al.* (2001), having the following properties: pH in $CaCl_2$ = 4.3; O.M. = 21 g dm^{-3}; P(resin) = 19 mg dm^{-3}; K = 1.5 $mmol_c$ dm^{-3}; Ca = 7 $mmol_c$ dm^{-3}; Mg = 4 $mmol_c$ dm^{-3}; H + Al = 42 $mmol_c$ dm^{-3}; base sum (SB) = 12.5 $mmol_c$ dm^{-3}; CEC = 54.5 $mmol_c$ dm^{-3} e V% = 23; B = 0.18 mg dm^{-3}, Cu = 0.8 mg dm^{-3}, Fe = 19.0 mg dm^{-3}, Mn = 16.1 mg dm^{-3} and Zn = 0.5 mg dm^{-3}.

The plots were composed by four rows, 5 m long, the two middle rows are considered useful and the others are margins, with a spacing between rows of 0,9 m. The simple hybrid maize, Impacto, was used. The average rain in the experimental period was of 996 mm.

The following nine treatments were applied: three doses of Zn (2, 4 and 8 kg of Zn per ha) applied locally (in furrows); three doses of Zn (6, 12 and 24 kg of Zn per ha) applied by incorporation (layers of 0-20 cm deep); foliar application (0.4 kg of Zn per ha); seed application (40g of Zn kg^{-1} of seeds) and control (no Zn application). The treatments with micronutrient via soil and foliar, received Zn in the form of Zn sulfate (79% Zn), and, via seeds in the form of Zn oxide (22.7% Zn). The treatments were arranged in a randomized block design with four replications.

To evaluate the nutritional state, leaf samples were collected, one third of the center of the leaf is removed from the base of the maize ear, when the crop is in flower, according to Cantarella et. al (1997). During harvest, the maize plants were separated in leaves, stems, ear husks, cobs and grains. The preparation of the samples were realized (washing and drying), determining the dry matter and the Zn content, and, calculating the accumulation of this nutrient on the shoot. In each plot, were determined: the number of grains per maize ear, 1.000 grain mass and grain productivity (13% moisture base).

Soil sampling was done after harvest (0-20 cm layer) in the fertilizing area. The Zn content was determined by extractors DTPA (Raij *et al.*, 2001) and Mehlich-1 (Nelson; Mehlich, 1953).

The data from the studied variable were subjected to variance analysis by the F-test and using the degrees of freedom from treatments and orthogonal contrasts. Moreover, a polynomial regression was performed for doses pertaining to the Zn application methods via soil.

Results and Discussion

1. Effects of the treatments in the chemical attributes of the soil

In all the comparisons there were no differences in the chemical attributes of the evaluated soils, except for the Zn content, as expected (Table 1).

For the Zn content, it can be verified by the first comparison group tested (control vs. other treatments) is that the Zn application independently of the manner, it provoked a higher content of this nutrient, for the extractor DTPA as for Mehlich-1, in the soil of maize crop, corroborating Galrão (1994) in the study of Zn application methods in soil, where the control presented a minor content of this micronutrient (0.3 mg dm^{-3}). However, Galrão (1996) in similar study of Zn in maize, observed differences only in some treatment doses in which Zn was applied by incorporating it in the soil, the dose being of 7.2 kg ha^{-1} provided a higher content of this micronutrient in soil (1.6 mg kg^{-1}), however this effect was expected due to the high Zn doses in soil (2 to 24 kg ha^{-1}) compared to the application on the plant (up to 0.4 kg ha^{-1}). Jamami *et al.* (2006), maize field study, verified that the dose of 2 kg ha^{-1} produced soil contents considered average, while a double dose resulted in content values considered high for the annual crops.

The Zn content from the soil in this experiment was classified according to Raij *et al.* (1997), average content (0.6 - 1.2 mg dm^{-3}) in treatments where the micronutrient was applied into the soil, the content was low (0 - 0.5 mg dm^{-3}) in the control and in foliar application and seeds.

In the Zn content extracted by DTPA method there was a variation of 0.5 to 1.1 mg dm^{-3} and for Mehlich-1 extractor, 0.3 to 1.0 mg dm^{-3}. However, Abreu and Raij (1996) in a study on the effect of the soil on the Zn extracted by different methods, have shown that Oxisol presents an amplitude of 0.9 to 1.2 mg dm^{-3} (DTPA) and 2.1 to 2.6 mg dm^{-3} (Mehlich-1). These differences can be explained by the content of the organic matter presented in the soils. In the citied work the content of the organic matter of the soil was approximately 37 g dm^{-3}, while in the current study the content is 16 g dm^{-3}, and, DTPA solution extracts, preferentially, the micronutrient is present in the organic matter.

The Zn application in soil compare to the one in the plant (foliar and seeds) (Table 1), stood out reaching higher contents of this nutrient in the soil (1.1mg dm^{-3} – DTPA and 1.1mg dm^{-3} – Mehlich-1), compared to the plant (0.5 to 0.7mg dm^{-3} – DTPA and 0.3mg dm^{-3} – Mehlich-1), the same effect was obtained by Galrão (1996), who obtained the highest value of 2.4 mg dm^{-3} (the average from three crops), with the nutrient application in the soil.

It has been observed that the treatment where Zn was applied to the soil and incorporated provides an increased content of this micronutrient in soil for the two extractors, when compared to the banded application (Table 1), corroborating Galrão (1994) in the study of application methods of Zn in soil, in which applications of this nutrient, in incorporated manner, provided an elevated content in soil. Possibly this occurred by the usage of higher doses of Zn in the incorporated treatment, and also, a lower adsorption of this micronutrient in soil.

The application of Zn on the soil provided a rise in linear adjustment in the Zn content, banded manner ($y = 0.179x + 0.55$; $R^2 = 0.89^*$) or incorporated ($y = 0.0274x + 0.35$; $R^2 = 0.99^{**}$), only by Mehlich-1 extractor, demonstrating increased sensibility and capacity of extracting the nutrient from the soil. Similar results have been verified by other authors, that the usage of acid solutions, as Mehlich-1 compare to DTPA , has a larger capacity of extracting Zn from soil, in studies involving two soils (Adônis *et al.*, 2009), three soils (Consolini and Coutinho, 2004) and seven soils (Menezes *et al.*, 2010). Other authors have mentioned that in general DTPA solution is better in relation to acid solutions in the evaluation availability of Zn in soils that have or not received the application of this element (Abreu and Raij, 1996). DTPA solution can be similar to the acid solutions due to the existence of a good correlation to the Zn content in the soil between the Mehlich-1 and DTPA methodology (Silva *et al.*, 2009). In this way, Gonçalves Jr. *et al.* (2006) have observed that the complexant extractors, as DTPA, extract less Zn from the soil, having greater effectiveness in the acid soil.

These differences in the capacity of extraction highlight the problems in defining an adequate

Table 1. Summary of the variance analysis regarding the chemical attributes in cultivated soil with maize crop according to different Zn application methods.

Zinc application	pH $CaCl_2$	OM	P	K^+	Ca^{2+}	Mg^{2+}	H+Al	SB	CEC	V	Zn DTPA	Zn Mehlich-1
		g dm^{-3}	mg dm^{-3}			mmol$_c$ dm^{-3}				%	mg dm^{-3}	
Soil, banded, 2 kg ha^{-1}	5.6	15	16	1.0	32	12	18	45.0	33	72	0.7	0.6
Soil, banded, 4 kg ha^{-1}	5.8	16	20	0.9	24	11	16	35.9	28	68	0.8	0.6
Soil, banded, 8 kg ha^{-1}	5.2	16	22	0.9	26	10	25	36.9	37	59	0.8	0.7
Soil, incorporated, 6 kg ha^{-1}	5.3	16	18	0.9	26	11	24	37.9	36	59	0.8	0.5
Soil, incorporated, 12 kg ha^{-1}	5.4	16	15	0.8	29	12	21	41.8	34	67	0.8	0.7
Soil, incorporated, 24 kg ha^{-1}	5.3	16	18	1.0	26	10	23	37.0	35	62	1.1	1.0
Foliar, 0.4 kg ha^{-1}	5.4	16	17	0.9	28	12	21	40.9	35	63	0.5	0.3
Seed, 40 g kg^{-1}	5.3	16	15	0.9	24	11	23	35.9	35	58	0.7	0.3
Control	5.6	16	20	0.9	24	10	21	34.9	33	64	0.3	0.3
							F-test					
Control vs. Others	2.428^{NS}	0.053^{NS}	1.756^{NS}	0.117^{NS}	3.308^{NS}	0.394^{NS}	0.024^{NS}	3.221^{NS}	0.813^{NS}	0.017^{NS}	38.735**	47.103**
Soil vs. (Foliar + Seed)	0.562^{NS}	0.443^{NS}	1.959^{NS}	0.039^{NS}	0.659^{NS}	0.603^{NS}	0.489^{NS}	0.256^{NS}	0.313^{NS}	2.454^{NS}	18.593**	149.364**
Foliar vs. Seed	0.826^{NS}	0.850^{NS}	0.761^{NS}	0.052^{NS}	3.241^{NS}	1.576^{NS}	0.703^{NS}	3.073^{NS}	0.042^{NS}	1.152^{NS}	1.779^{NS}	0.233^{NS}
Soil, incorporated vs. Soil banded	3.512^{NS}	3.472^{NS}	3.413^{NS}	0.277^{NS}	0.004^{NS}	0.043^{NS}	2.781^{NS}	0.000^{NS}	3.337^{NS}	3.083^{NS}	4.008*	6.278**
Doses in Banded	4.254^{NS}	3.545^{NS}	4.308^{NS}	0.75^{NS}	3.677^{NS}	0.874^{NS}	3.214^{NS}	3.729^{NS}	4.448^{NS}	2.378^{NS}	0.208^{NS}	7.518*
Doses in Incorporated	0.840^{NS}	0.000^{NS}	1.081^{NS}	2.33^{3NS}	1.754^{NS}	0.925^{NS}	1.881^{NS}	1.387^{NS}	1.437^{NS}	2.291^{NS}	4.154^{NS}	26.561**
CV%	5.0	4.8	20.3	17.7	11.9	18.2	17.8	11.1	10.2	9.3	18.6	13.4

According to the F-test, ** and * denote significance at 1 and 5% probability, and ns denotes not significant.

Table 2. Summary of the variance analysis regarding the foliar content of macro and micronutrients of maize plants and the content of Zn in maize grains according to different Zn application methods.

Zinc application	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn (foliar)	Zn (grain)
				g kg^{-1}						mg kg^{-1}		
Soil, banded, 2 kg ha^{-1}	26.6	2.5	21.6	5.9	2.5	1.7	12.0	9	90	35	16	25
Soil, banded, 4 kg ha^{-1}	25.3	2.7	21.5	6.1	2.5	1.9	8.8	10	83	37	18	24
Soil, banded, 8 kg ha^{-1}	26.5	2.5	21.5	6.1	2.5	1.7	10.8	9	89	37	18	26
Soil, incorporated, 6 kg ha^{-1}	25.6	2.4	19.8	6.5	2.6	1.7	10.3	9	85	37	16	26
Soil, incorporated, 12 kg ha^{-1}	26.2	2.6	21.4	6.0	2.4	1.4	8.7	10	85	36	17	26
Soil, incorporated, 24 kg ha^{-1}	26.1	2.5	20.8	6.5	2.5	1.7	11.5	10	90	40	22	28
Foliar, 0.4 kg ha^{-1}	25.4	2.5	21.4	6.2	2.5	1.7	10.8	9	88	40	17	24
Seed, 40 g kg^{-1}	26.2	2.5	19.9	6.2	2.3	1.6	11.3	9	84	40	15	24
Control	26.2	2.6	21.2	5.9	2.5	1.8	10.0	9	85	37	17	19
							F-test					
Control vs. Others	0.199^{NS}	0.202^{NS}	0.184^{NS}	0.768^{NS}	0.210^{NS}	0.917^{NS}	0.172^{NS}	0.197^{NS}	0.769^{NS}	0.003^{NS}	2.799^{NS}	21.051**
Soil vs. (Foliar + Seed)	0.522^{NS}	0.269^{NS}	0.853^{NS}	0.001^{NS}	1.317^{NS}	0.120^{NS}	0.516^{NS}	0.591^{NS}	0.633^{NS}	3.244^{NS}	19.302**	2.767^{NS}
Foliar vs. Seed	1.906^{NS}	0.454^{NS}	3.310^{NS}	0.011^{NS}	1.145^{NS}	0.018^{NS}	0.097^{NS}	0.579^{NS}	1.004^{NS}	0.027^{NS}	3.775^{NS}	0.000^{NS}
Soil, incorporated vs. Soil banded	0.300^{NS}	0.824^{NS}	3.280^{NS}	1.279^{NS}	0.070^{NS}	2.379^{NS}	0.129^{NS}	3.909^{NS}	0.633^{NS}	1.519^{NS}	4.229^{NS}	3.416^{NS}
Doses in Banded	3.091^{NS}	0.871^{NS}	0.015^{NS}	0.383^{NS}	0.009^{NS}	1.000^{NS}	0.818^{NS}	1.000^{NS}	0.490^{NS}	0.504^{NS}	5.949*	1.280^{NS}
Doses in Incorporated	0.460^{NS}	2.440^{NS}	1.522^{NS}	0.524^{NS}	1.547^{NS}	0.714^{NS}	0.861^{NS}	1.235^{NS}	0.446^{NS}	2.600^{NS}	18.176**	0.843^{NS}
CV%	3.2	6.3	5.4	11.1	9.3	15.8	21.8	10.1	6.5	11.5	6.2	8.9

According to the F-test, ** and * denote significance at 1 and 5% probability, and ns denotes not significant.

micronutrient extractor for the local conditions and distinct soil characteristics.

2. Effects of the treatments on the content of the leaves of macro and micronutrients and Zn content in grains

In all tested comparisons there were no differences in the foliar content of macro and micronutrients evaluated in the maize crop, except Zn (Table 2). For the Zn foliar content there was no differences between control and the other Zn treatments. However, there were differences in the following treatments: with Zn in soil, via foliar and seeds, and banded doses and incorporated doses (Table 2).

Decaro *et al.* (1983) in a study with doses and sources of Zn in maize crop, it was observed that the foliar content increased with the Zn doses applied to soil, corroborating current work. Although, the other studies with Zn application in soil, did not verify effects of this micronutrient in the foliar content of maize crop (Igue *et al.*, 1962; Domingues *et al.*, 2004).

The banded doses of applied Zn as well as the incorporated doses affected the foliar content of this micronutrient in maize plants (Table 2). It was noticed that this effect of the Zn applied in the banded manner promoted increment with quadratic adjustment ($P < 0.05$) (Figure 1a) in the Zn foliar content, reaching the maximum dose of 6.0 kg ha^{-1}. On the other hand, Zn applied in the incorporated manner promoted increment with linear adjustment ($P < 0.01$) (Figure 1b) in the Zn foliar content. These gains in the foliar content occurred due to the effect of Zn application in soil, that is, with the high availability of this micronutrient in soil, higher the uptake of the plants.

Even though Zn application has increased the foliar content of the said nutrient in plants, it was observed that the values were in the intervals of 15-100 mg kg^{-1} considered adequate by Cantarella and Raij (1997). Korndörfer *et al.* (1995) observed that Zn content in the maize leaf increased with doses of Zn applied to soil and the average content of Zn on the leaf varied from 13 mg kg^{-1} in the control to 23 mg kg^{-1} in the micronutrient treatment (4 kg of Zn ha^{-1}), and, in the present experiment, Zn content between 15 to 22 mg kg^{-1} was found.

As for the Zn content in grains, it was observed that Zn application promoted a higher content of Zn (24 to 28 mg kg^{-1}) compared to control (19 mg kg^{-1}) (Table 2). Galrão (1994), in the study of the deficiency correction of Zn in maize, it was observed that the micronutrient content in grains varied little between the treatments (Zn application methods) as in the present study. Ferreira *et al.* (2001) said that the Zn content in grains increased in 7% due to its application in the furrows, while in the present study this increase reached 32%. In this sense, Kanwal *et al.* (2010) in a study with doses of Zn applied to soil in maize crop, verified a significant raise in the content of this micronutrient in maize grains (21.8 to 30.7 mg kg^{-1}).

According to Welch (2002), the increase of the Zn application in soil significantly raises its concentration in parts of edible plants. Relatively higher content of Zn in maize grains is vital for human nutrition, that is, for the biofortification of basic food plantation (Graham *et al.*, 1992). However, Zn in grains or seeds is a complex process that has a series of steps from its translocation by the roots to the shoots and, finally, phloem flush in the grain development (Welch, 1986).

By the Brazilian Food Composition Table, the content of Zn in green maize grains in natura is of 5mg kg^{-1} (TACO, 2006), while in the present work the content of Zn in the grains obtained was of 19 to 28mg kg^{-1}. This fact is probably due to the differences of the grain development and distinct varieties.

3. Effects of the treatments in the accumulation of Zn in the shoot and yield

As to the dry material of the shoot, the Zn application independently of the manner, there was no difference when compared to the control (Table 3).

A confrontation of these results with field work using Zn in maize in literature (Galrão, 1994; Galrão, 1996; Gonçalves Júnior *et al.*, 2007) was affected, because in these works the dry material of the plants were not evaluated, only the yield. However, there are some works with maize cultivated in pots (young plants), where the authors observed beneficial effects of Zn in the production of dry material of the shoot [Fageria (2000); Coutinho *et al.* (2001); Leite *et al.*, 2003; Jamami *et al.*, 2006; Prado *et al.*(2008)], and the other one observed, there was no effect of this micronutrient in the production of dry material in maize plants (Leal *et al.*, 2007).

Table 3. Summary of the variance analysis regarding the dry shoot material, grains per maize ear, 1000 grain mass and the maize crop yield according to different Zn application methods.

Zinc application	Dry matter on the aerial part	Accumulation on the aerial part	Grains per maize ear	1000 grain mass	Yield
	kg ha^{-1}	g ha^{-1}		g	kg ha^{-1}
Soil, banded, 2 kg ha^{-1}	9974	101	474	355.1	10795
Soil, banded, 4 kg ha^{-1}	10238	111	431	357.8	9681
Soil, banded, 8 kg ha^{-1}	9723	121	470	376.4	10275
Soil, incorporated, 6 kg ha^{-1}	7588	101	460	356.2	11228
Soil, incorporated, 12 kg ha^{-1}	8149	115	453	353.3	10113
Soil, incorporated, 24 kg ha^{-1}	8314	145	473	350.0	11085
Foliar, 0.4 kg ha^{-1}	8107	104	443	346.0	9467
Seed, 40 g kg^{-1}	8436	95	476	360.7	10126
Control	8285	70	452	350.7	9965
			F-test		
Control vs. Others	2.561^{NS}	50.844**	0.239^{NS}	0.352^{NS}	0.198^{NS}
Soil vs. (Foliar + Seed)	8.070**	19.899**	0.004^{NS}	0.352^{NS}	8.193**
Foliar vs. Seed	0.550^{NS}	1.824^{NS}	2.220^{NS}	1.112^{NS}	2.205^{NS}
Soil, incorporated vs. Soil banded	58.864**	5.580*	0.082^{NS}	1.521^{NS}	4.756*
Doses in Banded	0.584^{NS}	14.993**	1.279^{NS}	1.151^{NS}	2.426^{NS}
Doses in Incorporated	2.392^{NS}	22.186**	0.650^{NS}	0.058^{NS}	3.368^{NS}
CV%	7.2	8.1	6.6	5.5	6.0

According to the F-test, ** and * denote significance at 1 and 5% probability.

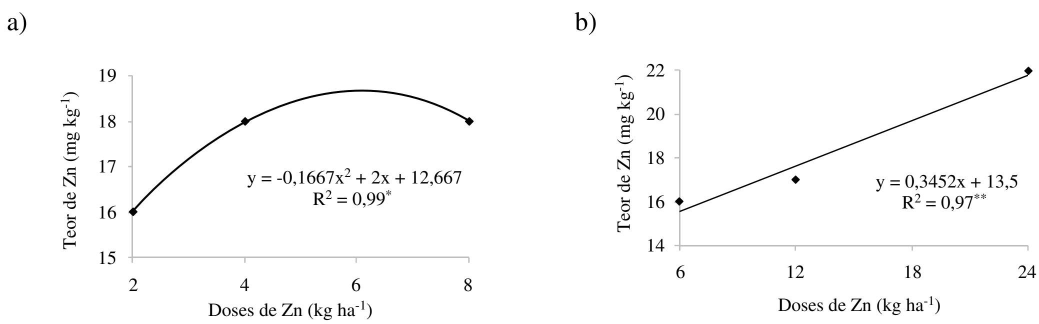

Figure 1. Contents of Zn in the maize plants leaves according to the banded application of Zn in soil.

When compared to the application in soil with the plant (seed and foliar), it was observed that added Zn to the soil induced a higher quantity of dry material in the maize plants (Table 3).

Studying the Zn banded application and the incorporated one, it was noticed that the Zn banded application induced a higher quantity of dry material when compared to the incorporated micronutrient application. Nonetheless, when studying the doses in the banded and incorporated treatment of the micronutrient, no differences were found between the treatments (Table 3).

Observing the comparison between the control *vs* the other treatments, it was seen that the Zn application induced a higher accumulation of Zn in the shoot compared to the control (Table 3). In spite of Prado *et al.* (2008) studying the Zn application manners in maize cv. BRS 1001, in a greenhouse, it was verified that differences between the treatments and control, with the exception of the banded and seed treatment, in the accumulation of Zn in the shoots.

Even so comparing the application in the soil with the plant application, it was noted that the application in the soil did not cause a higher accumulation of this micronutrient in the plants. Observing the comparison of the application in the soil, the banded and incorporated method, differences were established, in which the Zn application by incorporation in the soil provided higher accumulation of micronutrient (Table 3).

It was noticed that the banded Zn application in soil promoted increment with quadratic adjustment ($P<0.01$) (Figura 2a), and, in the incorporated application with the linear adjustment ($P<0.01$) (Figura 2b) in the accumulation of Zn in the shoot. Similar results were obtained by other authors, whereas the Zn application incremented the accumulation of this nutrient in the leaves (Leite *et al.*, 2009) and in the maize crop shoot (Coutinho *et al.*, 2001).

As to the maize crop grains, it can be observed in Table 4, that there were no differences between the treatments for the number of grains per maize ear and the 1.000 grain mass, corroborating Galrão (1994), in experiment with correction methods of Zn deficiency in maize in the field, where the numbers of grains in the ear did not present significant variations between treatments (Zn application in soil, seed and leaves). Decaro *et al.* (1983) in study with doses (5, 10 and 15 kg ha^{-1}) and Zn source in the maize crop, differences were not found as to the weight of a hundred seeds. Ferreira *et al.* (2001) in field experiment with maize fertilized with Zn, it was reported that the weight of a thousand grains was not influenced by the Zn application. Whilst Ávila *et al.* (2006), in micronutrients application study in maize seeds in Ultisol, it was observed that the seed treatment did not affect the number of seeds on the ear.

As the yield of the maize plants, it was noticed that there were no differences when compared to the Zn application and the control (Table 3). The absence of Zn treatment effects, in the maize crop yield can be explained by the fact that there were no differences in the nutritional state of the plants (Table 2) and in the production of dry material of the shoot (Table 3). Besides that, the average yield of this experiment (10.304 kg ha^{-1}) was higher than the average Brazilian production, harvest crop 2012/2013 (4.972 kg ha^{-1}) (CONAB, 2013).

The absence of Zn effect in the maize crop yield corroborates Jamami *et al.* (2006), in study of how to apply Zn in maize crop, it was verified that the application of this micronutrient in the soil has not increased the production. As Korndörfer (1995) who tested manners of adding Zn to NPK formula on maize crop, it was noticed that there was no effect on the maize production, independently of the dose or the manner used. However, Galrão (1994) in a study of methods of applying Zn in maize, in the field, it was observed that there was crop yield increase due to the treatments (Zn application in the soil, seeds and leaves), except the treatment with 0.4 kg ha^{-1} of Zn in the furrows. In the same way, other studies have indicated that the Zn banded application or incorporated using 5 kg ha^{-1} Zn (Domingues *et al.*, 2004) and higher doses (5 to 15 kg ha^{-1}) (Decaro *et al.*, 1983), provided significant increases in the maize production.

When compared to the application in soil vs application on the plant (foliar and seeds), it was seen that the Zn application in soil promoted a higher maize plant yield. Nevertheless, Igue *et al.* (1962) studying the influence of Zn in the maize production, in the field, differences were not observed in the production when Zn was applied to the soil and foliar. However, Ávila *et al.* (2006) in a field study where micronutrients were applied to the maize seed in a Ultisol clay texture, the treated seeds did not present satisfactory results in increasing the seed yield in five evaluated hybrids. Yet, Potarzycki

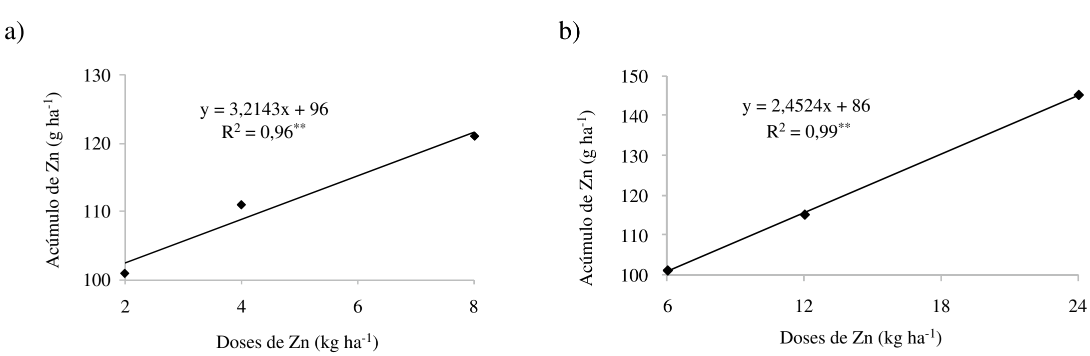

Figure 2. the accumulation of Zn in the maize plant shoot according to the Zn application in the soil by the banded manner (a) and incorporated (b).

and Grzebisz (2006) in the study with Zn applied via foliar (oxisulphate) in maize in Alfisol in three consecutives years, there was an increase in grains (three year average) with doses of 1.0 to 1.5 kg of Zn ha^{-1}, compared to the treatment that had not received micronutrient.

The applied Zn by soil incorporation resulted in a higher maize yield when compared to the banded application (Table 3). This occurred due to the incorporated application having received a higher dose of Zn, with greater availability of this micronutrient in soil (Table 1), as well as this nutrient in the leaves (Table 2) and consequently in the yield. However, Souza *et al.* (1998) in experiment with doses of applied Zn in furrows in Oxisol (Zn: 0.39 mg dm^{-3}), it was found that the addition of Zn promoted an increase in the maize production and in the concentration of this micronutrient in leaves, even though there were no advantages in applying superior doses of 5 kg ha^{-1} of Zn. Notwithstanding, Ferreira *et al.* (2001) in the field study of maize crop fertilized with Zn, it was reported that there was no increase in the production with the application of 3 kg ha^{-1} of Zn in the furrow. Though, Kanwal *et al.* (2010) in study with Zn doses applied to soil, it was verified the maximum yield of the cultivated hydride maize (FHY-421) when applying 18 kg ha^{-1} of Zn, while the used variety (Golden) reached the maximum yield of 9 kg ha^{-1} of Zn.

As there were no significant differences of the treatment doses incorporated to the soil (Table 4), hence the lower dose (6 kg ha^{-1}), could represent an economy in micronutrient.

Conclusions

1. The Zn application independently of the manner, provided a higher content of this micronutrient in the soil and higher accumulation in the shoot which reflected in the maize grain, however, it did not affected the nutritional state and the maize yield.

2. The Zn application in the soil promoted a higher Zn uptake by the plants and maize yield, compared to the application of this micronutrient on the plant via seeds or foliar. In the soil, incorporated manner, in the dose of 6 kg $ha^{-1}$of Zn, the banded application stood out.

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