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Micronutrient application and residual effect on corn production in a no-tillage system

Aplicação de micronutrientes e seu efeito residual na cultura do milho em sistema plantio direto

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Abstract

Applying micronutrients to the soilhas a residual effect, reducing the fertilizer applications that are needed under a no-tillage system. The present study determined the residual effect of applying micronutrient-containing fertilizer to soil used for corn production under a no-tillage system. The field study was conducted in Red Latosol in Goiânia, Goiás, Brazil. The experiment was a conducted in a randomized block design with five treatments and four replicates. The fertilizer used in the study contained the micronutrients Mn, Zn, Fe, Cu, and B in powder form and was applied atfour doses (33.33 kg ha^{-1}, 66.66 kg ha^{-1}, 133.32 kg ha^{-1}, and 66.66 kgha^{-1} plus 1.4 t ha^{-1} of calcium oxide); a control to which this fertilizer was not applied was used as a reference.The grain yield was measured, and leaf analysis and soil chemical analysis were conducted to evaluate the fertilizer efficiency and residual effect. The soil Zn content remained higherthan pre-experiment levels. Leaf analysis indicatedhigher absorption at the sites with high soil Zn content. The highest yield was obtained when applying 69.08 kg ha^{-1}of micronutrient-containing fertilizer. The micronutrients Mn, Fe, Cu, and B exhibited no significant effect on corn yield, leaf nutrition, or soil residue.

Key words: *Zea mays*, cerrado, mineral nutrition

Resumo

A utilização de micronutrientes via solo favorece o seu efeito residual diminuindo as aplicações no sistema plantio direto. O objetivo desse estudo foi determinar o efeito residual da aplicação, via solo, de fertilizantes contendo micronutrientes para cultura do milho cultivado em sistema plantio direto. O trabalho foi realizado a campo em Latossolo Vermelho, em Goiânia, Goiás. O experimento foi conduzido em blocos casualizados com cinco tratamentos e quatro repetições. O fertilizante utilizado na pesquisa contém os micronutrientes Mn, Zn, Fe, Cu e B na forma de pó e foram aplicados em quatro doses (66,66 kg ha^{-1} mais 1,4 t ha^{-1} de óxido de cálcio, 33,33 kg ha^{-1}, 66,66 kg ha^{-1}, 133,32 kg ha^{-1}) e tomou-se como referência a testemunha sem a aplicação desse fertilizante. A produtividade de grãos, a análise foliar e a análise química do solo foram realizadas para avaliar a eficiência e o residual do fertilizante. Os teores de Zn se mantiveram elevados no solo em relação aos teores antes da instalação do experimento. Com a análise foliar observou-se uma maior absorção nas parcelas com altos teores de Zn no solo. A maior produtividade foi obtida com a aplicação de 69,08 kg ha^{-1} do fertilizante contendo micronutrientes em relação à testemunha. Os micronutrientes Mn, Fe, Cu e B não mostraram efeito significativo na produtividade do milho, nutrição foliar e residual no solo.

Palavras-chave: *Zea mays*, cerrado, nutrição mineral

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Introduction

No-tillage (NT) systems involve planting crops in soil without tillage, protecting them with mulch, i.e., plant biomass on the soil surface from crop residues or from a cover crop sown for this purpose, and controlling weeds by combined chemical methods (ANGHINONI, 2007). Several studies have shown that NT systems in the Cerrado (Brazilian savanna) present challenges. Producers within the Cerrado region have had difficulties producing and maintaining plant biomass on the soil surface due to the high temperature and microbial activity of these decomposing residues, which hinder the accumulation of soil organic matter (OM) (SÁ et al., 2004).

Decomposition of soil OM may favor increased micronutrient availability in the soil. However, soils with a high OM content are often deficient in one or more micronutrients. This deficiency occurs due to OM mineralization, which depends on several factors related to soil microorganisms, such as soil temperature, moisture, and density (DECHEN; NACHTIGALL, 2006). Due to these factors, the need to achieve high yields has led to a growing interest in fertilization with micronutrients (CANTARELLA; DUARTE, 2004).

Micronutrients are closely associated with limited yield in Cerrado soils because these soils are originally deficient in micronutrients and are characterized by low natural fertility, high acidity, and the presence of aluminum (Al) (FAGERIA; BALIGAR, 2001; ERNANI; BAYER; MAESTRI, 2002). Micronutrients are essential elements for plant growth that are absorbed in small amounts. Boron (B), Chlorine (Cl), Copper (Cu), Iron (Fe), Manganese (Mn), Molybdenum (Mo), Nickel (Ni), and Zinc (Zn) are essential micronutrients for plants (DECHEN; NACHTIGALL, 2006).

Micronutrient availability for plants depends on, among other factors, the soil texture, OM, and especially pH, which, when increased, decreases Cu, Fe, Mn, and Zn availability (MARSCHNER, 1995). Boron is more available within a pH range of 5.0 to 7.0. Micronutrient availability varies with soil type and geographical region.

To obtain high crop yields in Cerrado soils, it is necessary to add several micronutrients, especially Zn (GALRÃO, 2004). In Brazil, Zn is the micronutrient most likely to limit plant growth, especially for demanding species, such as corn. Fertilization with Zn has achieved the best corn yield responses in Brazilian soils, due to the widespread Zn deficiency that occurs mainly in the Cerrado (BÜLL, 1993).

The choice of species or crop used under NT depends on its adaptation to each region’s climate conditions and the producer’s interest. Corn grown after soybeans under NT in central Brazil produces straw in the winter, which, due to corn’s low C:N ratio, favors soil cover, OM mineralization, and weed control (CERETTA; FRIES, 1998).

Corn is widely used in crop rotations or following soybean production because it has great yield potential. However, for that potential to be expressed, it is important to use the correct fertilizer that meets nutritional requirements. Thus, the importance of micronutrients in obtaining maximum corn yield is evident. Determining the most appropriate doses, sources, and application times, as well as identifying possible toxic effects to plants, may assist in planning the use of micronutrient-containing fertilizer.

The present study aimed to determine the residual effect of applying micronutrient-containing fertilizer to the soil used for corn production under a NT system.

Materials and Methods

The assay was conducted under field conditions in Goiânia, Goiás, Brazil at the School of Agriculture and Food Engineering, Federal University of Goiás (Escola de Agronomia e Engenharia de Alimentos da Universidade Federal de Goiás- EA/

UFG), Samambaia Campus (16°35’59”S latitude, 49°16’56”W longitude, 704.35 m altitude). Soil from the testing site was characterized as dystroferric Red Latosol (SILVA, 1999). The testing site was maintained as pasture for10 years without applying lime or any type of fertilization.

The experiment was conducted using a randomized block design with five treatments and four replicates. The total experimental area was 900 m^2, and each experimental plot measured 7 m wide by 5 m long. The plots were spaced 1 m apart. The treatments applied during the 2007/2008 crop season consisted of four doses of fertilizer as a micronutrient source (66.66 kg ha^{-1} plus 1.4 t ha^{-1} of calcium oxide (CaO), 33.33 kg ha^{-1}, 66.66 kg ha^{-1}, and 133.32 kg ha^{-1}) applied to the furrow. A control treatment with no micronutrient application was used as a reference. CaO was applied to observe the effect on its availability for plants because it is a highly soluble product.

The fertilizer used as micronutrient source was supplied by the company Stefani S/A Indústria e Comércio de Adubos e Fertilizantes (Stefani S/A Mulch and Fertilizer Industry and Commerce), which is located in the municipality of Senador Canedo, Goiás, Brazil. The product was obtained by transforming manganese ore into manganese monoxide, which was subsequently digested with sulfuric acid to produce manganese sulfates and manganese solutions. The inorganic source was mixed with other metallic salts containing sulfates and oxides (oxisulfates). The product tested was composed of 1.1 % B, 1.2 % Cu, 2.1 % Fe, 3.9 % Zn, and 6.8 % Mn.

The experimental soil was prepared with a 12 x 32 disc harrow containing 12 32-inch discs 6 months before the experiment began. In addition to the disc harrow, a leveling harrow was used to standardize the testing site. The soil was furrowed with a seeder-fertilizer equipped with a soil-type disk tillage system during the 2007/2008 crop season. The furrows were left uncapped, fertilizer with micronutrients was later applied, and the furrows were subsequently covered.

In the 2007/2008 crop season, soybeans were planted to simulate the site’s cultivation as crop rotation with corn. In the second year (2008/2009), corn was planted following the furrowed rows from the previous crop season to investigate the residual effect of micronutrient-containing fertilizer from the previous crop season. Table 1 shows the nutrient levels before planting corn.

Table 1. Soil chemical properties at the 0-20 cm depth layer before planting the corn crop in October 2008, in Goiânia, Goiás, Brazil.

O.M.	V	pH	P	K	Ca	Mg	CTC	Cu	Fe	Mn	Zn
(g dm^{-3})	(%)	(CaCl$_2$)	---(mg dm^{-3})---		–---(cmol$_c$dm^3)----			–---------(mg dm^{-3})----------			
23.0	55.8	5.3	8.3	205	3.2	0.7	7.9	0.8	12	19.4	1.6

K, P, Cu, Fe, Mn, and Zn = Mehlich 1 extractor; Ca, Mg = extraction with KClmol L^{-1}; methodologies described in Embrapa (1999). Analyses conducted in the Laboratory of Soil and Leaf Analysis (Laboratório de Análises de Solos e Foliar)at the School of Agronomy and Food Engineering (Escola de Agronomia e Engenharia de Alimentos) of UFG.
Source: Elaboration of the authors.

The site was desiccated with glyphosate using a 4.0 L ha^{-1} dose applied with a boom sprayer set for 200 L ha^{-1}flow 16 days before planting. At desiccation, the site had 80 % to 100 % weed coverage, and approximately 80% of this total consisted of *Brachiaria brizantha*, *Panicum maximum*, *Commelina benghalensis*, *Bidens pilosa*, and *Ipomoea grandifolia*. The soil was not corrected with lime, meaning that the effect of calcium carbonate in combination with fertilizer as a micronutrient source could be evaluated.

Sowing in December 2008 was performed under NT with a seeder-fertilizer equipped with a soil-type disk tillage system. Hybrid corn seeds (Pioneer 30A04 Y) were previously treated with a broad-spectrum, systemic fungicide comprising two active ingredients – fludioxonil and metalaxyl-M (one mL $kg^{-1}$of seed) – and an insecticidal compound with the systemic base active ingredient thiamethoxam, which belongs to the neonicotinoid chemical group (300 mL ha^{-1}). Additional fertilization consisted of 500 kg ha^{-1} of 08-28-18 at planting and 200 kg $ha^{-1}$of urea topdressing at 20 days after germination with doses determined according to soil analysis results and recommendations by the Commission of Soil Fertility of Goiás State (Comissão de Fertilidade do Solo do Estado de Goiás) (1988) and by Sousa and Lobato (2004).

In each plot, the soil and leaves were sampled during the crop's full flowering stage. In the sampling of soil for chemical analysis, thirteen simple samples were randomly selected per plot and homogenized to form a composite sample. For each plot, the same procedure was performed using1 sample taken from the planting row for every twelve samples taken from between the rows.

Soil samples were collected at 0-20 cm and 20-40 cm depths using a Dutch auger during the crop's flowering stage. The two chosen depths allow us to determine whether nutrient movement occurred. The samples were identified and sent to the Laboratory of Soil and Leaf Analysis (Laboratório de Análises de Solos e Foliar – LASF) at the EA/UFG, where they were air-dried and pressed through two mm mesh sieves following the methodology proposed by Silva (1999).

To assess the leaf content, thirty leaf samples per plot were collected during the onset of female inflorescence, from the central third of the opposite leaf and below the ear, discarding the midrib, as recommended by Malavolta, Vitti and Olvieira (1989). These samples were placed in paper bags, identified, and transported to LASF-EA/UFG. The material was washed with distilled water and placed in paper bags for drying in a forced-air oven at 60 °C. After reaching a constant dry weight, the leaves were ground and subjected to N, P, K, Ca, Mg, B, Cu, Fe, Mn, and Zn analyses according to methodology described by Malavolta, Vitti and Olvieira (1989).

To determine yield, corn from the 2008/2009 crop season was harvested from the center of each plot. All of the ears within four three-m rows comprising 10.2 m^2 of usable area per plot were harvested. The samples were identified, bagged, and husked. After weighing, the moisture was corrected to 13 % by extrapolating the yield calculation in hectares.

The results were subjected to analysis of variance. The data were analyzed statistically by applying the F-test analysis of variance. The significant results were compared by Tukey's test ($\alpha = 0.05$). The soil Fe and Mn levels, corn leaf B and Zn levels, and corn yield were fitted to doses of micronutrient-containing fertilizer with a polynomial regression. For statistical analyses, the Statistical Analysis System software – SAS, version 9.1 was used (SAS INSTITUTE, 2003).

Results and Discussion

The application of micronutrient-containing fertilizer exhibited a significant effect on the amounts of Ca, Mg, and Zn at 0-40 cm soil depth (Tables 2 and 3). In the same context, the Cu, Mn, Zn, OM, P, and K values significantly differed between the 0-20 and 20-40 cm soil depths during the 2008/2009 crop season (Table 3). No significant interaction was found between fertilizer application and soil depth. Thus, the effect of fertilizer was restricted to 0-20 cm layer depth. Only Cu showed higher levels in the 20-40 cm layer (Table 3).

Table 2. Soil chemical properties as a function of residues from micronutrient doses applied to soil for the corn crop and analysis of variance during the 2008/2009 crop season, in Goiânia, Goiás, Brazil.

Fertilizer dose (kg ha^{-1})	Cu	Fe	Mn	Zn	O.M. (g dm^{-3})	pH (CaCl$_2$)	M (%)	V (%)
	–---------------(mg dm^{-3})--------------							
0.0	1.47	30.25	14.06	1.79	20.7	4.63	0.00	37.7
33.33	1.74	27.07	12.81	2.37	19.3	4.64	0.93	27.0
66.66	1.31	23.94	13.04	3.11	20.5	4.62	1.05	26.2
133.32	1.79	26.57	14.87	4.23	20.2	4.68	0.61	24.1
66.66 + CaO$^{(1)}$	1.67	23.41	14.17	2.93	20.8	4.72	0.00	29.1
Depth								
0-20 cm	1.36	25.72	17.58	4.05	23.7	4.60	1.04	29.6
	b	a	a	A	a	a	A	a
20-40 cm	1.83	26.77	10.02	1.72	16.9	4.71	0.00	29.8
	a	a	b	B	b	b	B	a
F Test								
Treatment	0.93	1.48	0.57	4.80**	3.8	0.08	0.84	6.08
Depth	6.37**	0.27	57.23**	39.44**	603**	0.83	4.50	0.01
Treatment x Depth	0.66	1.17	0.40	0.79	29.8	0.74	0.84	0.62
CV (%)	36.47	24.31	22.91	40.74	13.64	8.39	298.08	18.0

[1]CaO (Calcium oxide). Means followed by the same lowercase letter in the columns do not differ by Tukey's test ($P<0.05$). *Value significant at 1%. **Value significant at 5%.

Source: Elaboration of the authors.

Table 3. Soil chemical properties as a function of residues from micronutrient doses applied to soil for the corn crop and analysis of variance during the 2008/2009 crop season, in Goiânia, Goiás, Brazil.

Fertilizer dose (kg ha^{-1})	P	K	Ca	Mg	H + Al	Al	CTC
	----(mg dm^{-3})----			------------------------(cmol$_c$ dm^{-3})---------------------			
0.0	1.45	58.81	1.84	0.54	3.99	0.00	6.52
33.33	1.25	58.31	1.05	0.41	4.38	0.07	6.00
66.66	1.64	57.81	1.04	0.45	4.39	0.01	5.99
133.32	1.31	64.00	0.92	0.48	3.99	0.01	5.54
66.66 + CaO$^{(1)}$	1.59	57.00	1.17	0.46	4.18	0.00	5.88
Depth							
0-20 cm	2.10	62.27	1.29	0.49	4.38	0.03	6.30
	a	a	a	a	a	a	a
20-40 cm	0.79	56.10	1.12	0.44	3.96	0.00	5.67
	b	b	a	a	b	a	b
F Test							
Treatment	0.40	1.50	4.3**	2.50*	1.56	1.17	1.63
Depth	29.2**	9.27**	1.17	3.35	8.72	2.12	6.60
Treatment x Depth	1.21	0.18	0.26	0.86	0.29	1.17	0.29
CV (%)	52.85	10.83	41.19	18.37	10.77	434.2	12.97

[1]CaO (Calcium oxide). Means followed by the same lowercase letter in columns do not differ by Tukey's test ($P<0.05$).*Value significant at 1 %. **Value significant at 5%.

Source: Elaboration of the authors.

The highest Mn, Zn, OM, P, and K values were found in the 0-20 cm soil layer when fertilizer was applied as a micronutrient source during the 2007/2008 crop season (Table 3). Thus, this fertilizer had the greatest effect at the depth at which it was applied, showing low mobility, which also interferes with other chemical elements, such as P and K. Accordingly, applying this fertilizer decreased the pH, Ca, Mg, P, K, CTC, V, and Mn values and increased the H+Al, Al, Cu, Fe, and Zn values during the 2008/2009 crop season (Table 3) compared to the values prior to the beginning of the experiment (Table 1).

According to Alleoni et al. (2009), low cation retention is the main chemical characteristic of highly weathered soils (Latosols). The ability of soils to retain ions by electrostatic attraction depends on the charges on the surface of clays and OM. This complex carries positive and negative charges on its surface, which can be permanent or transient, as evidenced by its ability to retain cations and anions. Many soil properties are influenced by the type and amount of cations, including Ca^{2+}, Mg^{2+}, K^{+}, and Na^{2+}, offsetting the negative charges available on the surface of soil colloids. CO_2 dissolution in solution, nitrification, mineralization of organic compounds, and ionic release by plant roots leave enough H^{+} in the soil solution to acidify it. Given these claims, using fertilizer as a micronutrient source stimulated the development of crops and plants located at the site, providing higher nutrient absorption and placing more negative charges in the soil. Thus, the soil became more acidic, increasing the availability of Al^{+}, H^{+}, Cu^{+}, Fe^{+}, and Zn^{+} and decreasing the pH, Ca, Mg, P, K, CTC, V, and Mn values.

Al and H increased due to soil acidification. Cu, Fe, and Zn exhibited higher values when fertilizer was applied as a micronutrient source. The lower the pH value, the higher the amount of H^{+} ions in the soil solution. However, Ca and Mg are chemical elements that are absorbed by plants in addition to correcting soil acidity. Because there was no supply of these elements through liming, they were exported by plants, reducing their levels in the soil. Furthermore, P and K are connected to the pH of the solution; the lower the pH, the lower the K and P availability is in the soil solution. These elements are also absorbed by plants. With decreasing levels of the soil bases Ca, Mg, and K, the CTC and V values, which are calculated from these chemical elements, also decreased.

The fertilizer applied to the soil supplied Mn, meaning that there was less of a decrease in this value. The decrease was due to Mn leaching into acidic and well-drained soils (Latosols) because oxidation and acidity increase its solubility (TROEH; THOMPSON, 2007). Thus, Mn added through fertilization was leached, and colloids did not remain in the soil.

The fertilizer had a residual effect for the micronutrients B, Cu, Fe, and Zn. However, soil acidification occurred, even when the fertilizer was applied with CaO. Soil acidification is due to several factors, including the removal of basic soil cations and replacement with acidification sand the chemical reaction of fertilizers applied to the soil that alter the pH (FURTINI NETO et al., 2001).

The Zn content in the soil increased as increasing fertilizer doses were applied. The fertilizer doses that produced the highest Zn content in the soil were133.32 kg ha^{-1} followed by 66.66 kg ha^{-1} and 66.66 kg ha^{-1} plus 1.4 t ha^{-1}CaO (Table 2), which was also observed by Galrão and Mesquita Filho (1981).

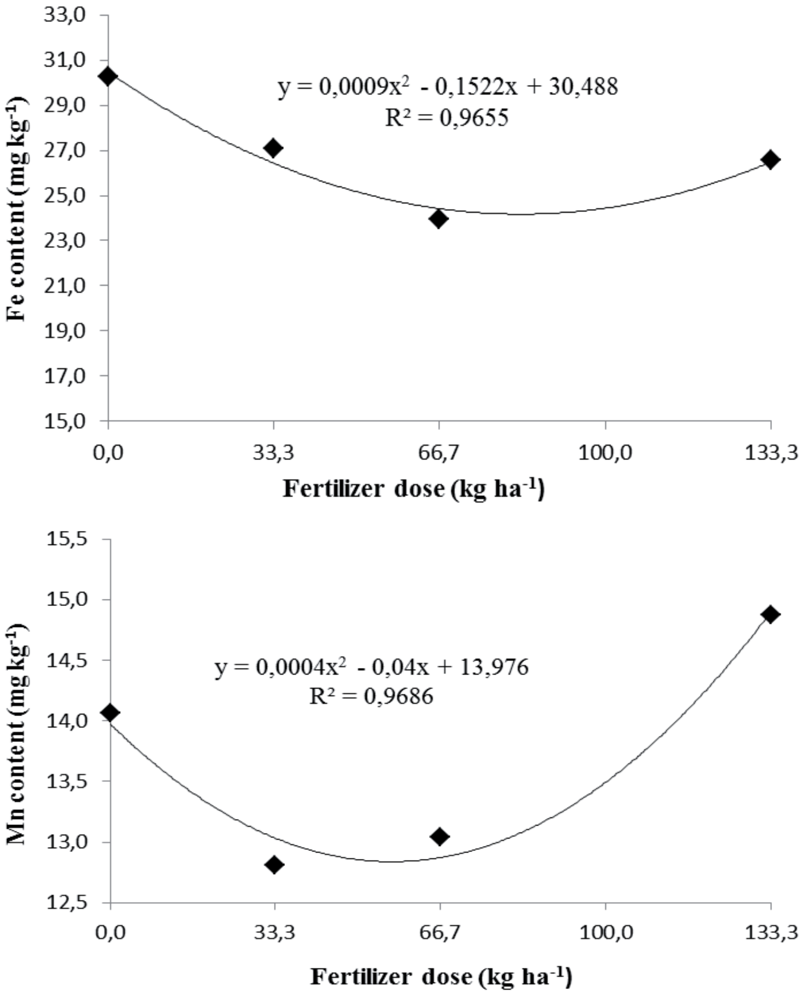
Table 2 shows the mean micronutrients at the 0-20 cm and 20-40 cm soil depths. There were significant differences in the Cu, Mn, and Zn contents; the latter two had the highest mean levels in the most superficial layers. These results contradict those of Furtini Neto et al. (2001), who indicated that these micronutrients had high mobility in soils with high pH and/or low OM content.

Soil Fe levels were high but did not vary significantly with depth. These results may be related to the soil origin, but no significant difference was observed for the same dose of micronutrient-containing fertilizer with and without CaO, perhaps because the CaO reacted during the first planting year, as suggested by the similar pattern of the pH results (Tables 2 and 3).

In analyzing the soil Mn content, the average was lower during the second year after planting (13.80 mg dm^{-3}) than the first year (24.5 mg dm^{-3}). It can be inferred that there was high micronutrient availability and consequently high absorption by plants. Leite et al. (2003) observed in corn that increased available soil Mn resulted in higher absorption by the roots and higher leaf nutrient concentration, corroborating the results obtained here.

The trend curve for mean Mn and Fe levels as a function of fertilizer doses applied to the soil (Figure 1) suggests that fertilizer doses of 50.00 kg ha^{-1} of Mn and 84.55 kg ha^{-1} of Fe have low residual increases in the soil, to which 3.40 kg ha^{-1} of Mn and 1.77 kg ha^{-1} of Fe were supplied during the previous year. These levels are consistent with the recommendation by Galrão (2004).

Figure 1. Levels (mg dm^{-3}) of manganese (Mn) and iron (Fe) in the soil according to doses of micronutrient- containing fertilizer during the 2008/2009 crop season in Goiânia, Goiás, Brazil. (The mean levels in the 66.66 kg ha^{-1} dose plus 1.4 t ha^{-1} CaO → 14.17 mg dm^{-3} Mn and 23.41 mg dm^{-3} Fe.)



Source: Elaboration of the authors.

In general, the mean soil Ca and Mg contents (Table 3) exhibited no significant differences between the 0-20 cm and20-40 cm depths. The mean levels of Ca (1.20 $cmol_c$ dm^{-3}) and Mg (0.47 $cmol_c$ dm^{-3}) were low according to classification proposed by Sousa and Lobato (2004).

There was a wide variation in the soil P levels (52.85%); this effect was due to the amounts of these nutrients throughout the sampled site, which may be due to the application mode and low mobility in the soil. High variability and low mobility in the soil were also observed by Machado et al. (2007). However, the average P content is below adequate (Table 3) according to the classification of Sousa and Lobato (2004). Importantly, applying high phosphate fertilizer doses may exhibit antagonistic effects on Zn and P contents. According to Olsen (1972), increased P availability can induce Zn deficiencies, which can be corrected by providing micronutrients.

The K levels were within the range considered adequate by Sousa and Lobato (2004) for Cerrado soils (51 mg $dm^{-3}$to 80 mg dm^{-3} and CTC > 4 $cmol_c$$dm^{-3}$ at pH 7.0), although there were significant differences in the mean amounts of K at different soil depths (Table 3). Among the K dynamics in the soil, it is notably important to highlight the possibility of its movement to the layer away from the roots because K leaching can cause nutrient losses (FURTINI NETO et al., 2001).

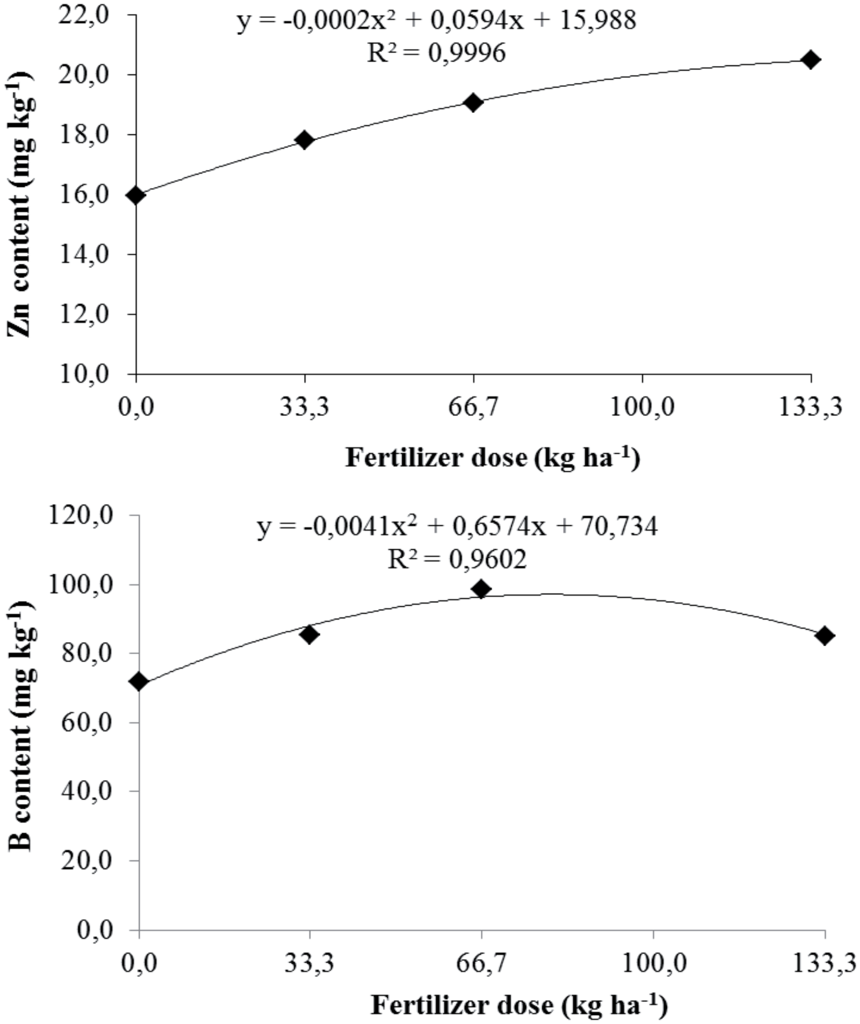
Based on the leaf analysis results, the micronutrient levels were not affected by the treatments, except for Zn, which is absorbed by plants with increasing doses provided (Figure 2), with a greater tendency to increase leaf content at a 133.32 kg ha^{-1} dose, which provided 5.20 kg ha^{-1} of Zn to the soil. According to the reference values for interpretation of the leaf variables proposed by Malavolta (2006), the average Zn value (18.3 mg kg^{-1}) falls within the below-adequate class; Cu (8.1 mg kg^{-1}), Fe (166.0 mg kg^{-1}), and Mn (53.3 mg kg^{-1}) fall within the adequate class; and B (85.1 mg kg^{-1}) falls within the above-adequate class. The 133.32 kg ha^{-1} Zn dose fell within the adequate class, reinforcing micronutrient accumulation in the soil and consequent absorption by plants.

Among the micronutrients, corn exhibits high sensitivity to Zn deficiency, average sensitivity to Cu, Fe, and Mn deficiencies, and low sensitivity to B deficiency. Zn is also the most limiting micronutrient in Brazilian agricultural production (CANTARELLA; DUARTE, 2004). Leaf Zn concentrations in corn increased when applying fertilizer as a micronutrient source. The highest fertilizer doses yielded higher Zn concentrations, demonstrating the residual effect of the element applied to the soil. This increase may be related to the availability of Zn in the soil, which is promoted by higher OM mineralization (GALRÃO, 1996). In relation to B, Cu, Fe, and Mn, the treatments did not significantly differ.

The average leaf B content (85.16 mg kg^{-1}) was much higher than the range accepted as sufficient, which is 15 mg $kg^{-1}$to 20 mg kg^{-1} (MALAVOLTA, 2006). The leaf B content increased in response to increasing doses applied, fitting polynomial functions (Figure 2). The dose that represented the peak absorption was 80.17 kg ha^{-1} of fertilizer with the supply of 0.88 kg ha^{-1} of B to soil during the 2007/2008 crop season. The B content varied from52.01 mg kg^{-1}to132.05 mg kg^{-1}. The plants that received no treatment exhibited increased B values, demonstrating the presence of B in the soil solution.

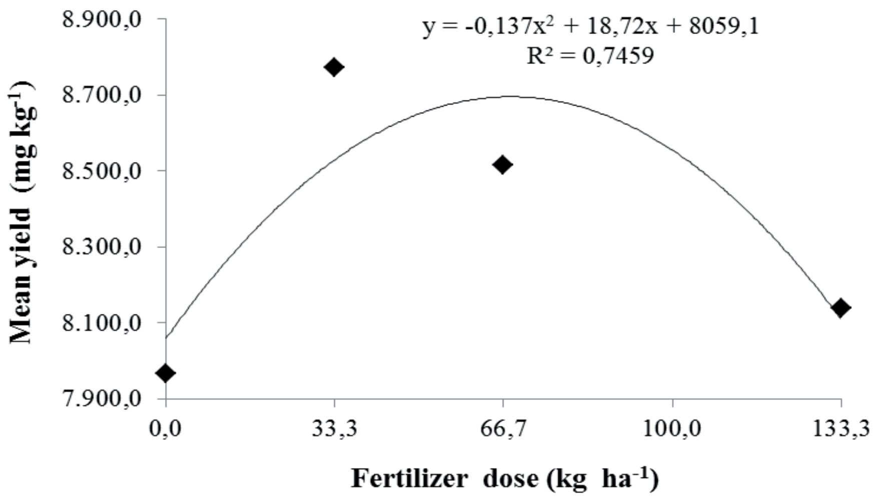
There was no significant difference in yield among the treatments that received or did not receive fertilizer (Figure 3). The 33.33 kg ha^{-1} dose provided an increase of 10.08% in corn yield compared to the treatment without micronutrient application. The yields in the experiment were high compared to the mean yield for Goiás State, Brazil (5.733 kg ha^{-1}) during the 2010/2011 crop season (CONAB, 2011), indicating the great response potential of the Pioneer 30A04 Y simple hybrid. Accordingly, Troeh and Thompson (2007) describe that higher yields require more nutrients for the plants, which can deplete the supply of nutrients available in the soil, and as a result, the subsequent crops can suffer from micronutrient deficiency. Thus, in the present study, this deficiency does not occur, due to the residual effect of the fertilizer applied as a micronutrient source.

Figure 2. Levels (mg dm^{-3}) of zinc (Zn) and boron (B) in corn leaves that received doses of micronutrient- containing fertilizer during the 2008/2009 crop season in Goiânia, Goiás, Brazil. (The mean levels in the 66.66 kg ha^{-1} dose plus 1.4 t ha^{-1} CaO → 18.45 mg kg^{-1} Zn and 85.15 mg kg^{-1} B.).



Source: Elaboration of the authors.

Figure 3. Relative yield (kg ha^{-1}) of corn that received residual doses of micronutrients during the 2008/2009 crop season in Goiânia, Goiás, Brazil. (The relative yield of the 66.66 kg ha^{-1} dose plus 1.4 t ha^{-1} CaO→ 8,176.30 kg ha^{-1}.)



Source: Elaboration of the authors.

The second-degree polynomial fit between the average yield for corn production as a function of the doses used indicated that the dose producing the maximum yield was 69.08 kg $ha^{-1}$of applied micronutrients, which provided 4.7 kg ha^{-1}Mn, 2.69 kg ha^{-1} Zn, 1.45 kg ha^{-1} Fe, 0.8 kg ha^{-1} Cu, and 0.76 kg ha^{-1} B (Figure 3).

Galrão (2004) recommends that 1/4 of the total dose recommended be applied each year for four consecutive years in the planting furrow. The amount applied at the beginning of the experiment during the 2007/2008 crop season was consistent with that recommended for corn because the dose referring to two years of planting was applied.

Conclusions

The dose of micronutrient-containing fertilizer with best residual effect on corn yield was 69.08 kg ha^{-1}. Zn showed a residual effect; the maximum yield was obtained when applying 2.69 kg ha^{-1} Zn. Furthermore, better Zn absorption by plants occurred with a 148.5 kg ha^{-1} fertilizer dose, and there was no significant response for the micronutrients B, Cu, Fe, and Mn.

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