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Productivity of maize by leaf application of zinc (Zn) and copper (Cu)

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Abstract

The frequent use of the similar formulated fertilizers has reduced the supply of micronutrients to the crops. The application of micronutrients through leaf has increased the crops productivity. In this context, this study aimed to assess the effects of copper and zinc micronutrient applications in biometric variables and grain yield of maize crop. The experiment was conducted at the Agricultural Research Center of Copacol, using copper phosphite and zinc phosphite, using treatment (1) 100 g.ha^{-1} of copper, treatment (2) 500 g.ha^{-1} of zinc, treatment (3) 100 g.ha^{-1} of copper + 500 g.ha^{-1} of zinc and the treatment (4) witness (control). The treatments were applied at V6 phenological stage of maize with costal pump. The experimental design was randomized blocks with six repetitions. The variables measured were: number of plants per plot, number of spikes per plot, number of rows per spikes, number of grains per row and number of grains per spike, thousand grains weight and productivity of grains. For thousand-grain weight, there was higher effect of micronutrient treatments, compared to the control. For number of grains per row, there was no significant effect. However, application of single Zn showed better effects than Zn+Cu. In conclusion, application of Zn via leaf increased productivity. The Zn increased productivity of maize even when used in the soil with high Zn content.

Keywords: Agronomic performance; competitive inhibition; leaf fertilization; micronutrients; *Zea mays* L.

Introduction

The average of maize productivity has increased due to the advances in agronomic knowledge, plant physiology and plant nutrition. The knowledge has led to grow the cultivation area by 7 % in summer as second crop. The production has increased by 35% in 2014, reaching 80 million tons in Brazil (CONAB, 2015). Fancelli (2014) pointed out that fertilization planning, based on the plants nutritional needs is extremely important, taking in account mineral absorption of nutrients, soil analysis and expected productivity. In this context, this management becomes essential in Brazilian soils, which have low organic matter content and increasingly compacted soils without crop rotation farming system (Araujo et al., 2007; Alves Neto et al., 2016). According to EMBRAPA (2011), for the production of 9 t ha^{-1} of maize grains the following nutrients are extracted: 2.1 g of iron, 340 g of manganese, 400 g of zinc, 170 g of boron, 110 g of copper and 9 g of molybdenum. However, deficiency of one of them may cause disorganization in the metabolic processes or reduction in productivity (Kparmwang et al., 2000). Zinc is the most required micronutrient for maize crop, with demand from 2 to 6 kg ha^{-1}, especially in Brazilian cerrado soils that is sandy and poor in organic matters (Eteng et al., 2014). Zinc is part of dehydrogenases, proteinases, peptidases and fosfohidrogenases enzymes components. The basic functions of zinc in plants are related to carbohydrate metabolism, besides being a component in the formation of auxin structures, RNA and ribosomes and fertility of pollen grain (Prado et al., 2008). For copper (Cu), the lack of this micronutrient contributes to the predisposition of corn to cercospora leaf spot and complex white spot (Fancelli, 2014). Copper is an enzymatic activator, especially in photosynthesis and severe deficiency of this micronutrient inhibits reproduction (Favarin et al., 2008). Several methods can be used to apply copper and zinc for corn production. They can be applied in the soil or through leaf or seeds. Leite et al. (2003) studied increasing doses of Cu (0 to 16 mg kg^{-1}) and Zn (0 to 32 mg kg^{-1}) through leaf in Dystrophic Quartzeneic Neosol. They showed an increase of dry matter in maize, and also increase in leaf content. With leaf applications of Cu Barbosa et al. (2013) showed an increase in chlorophyll index, leaf area, thousand grain weight and productivity when they used Cu doses up to 100 g ha^{-1} in Oxisoil with clayey texture, because the higher doses had toxic effect on maize, with losses to growth and productivity of grains. Prado et al. (2008) studied application of Zn on nutrition and production of corn BRS 1001 dry matter via soil, seeds and leaf, and observed that the leaf application promoted absorption of the nutrient by the plant. Rastija et al. (2002), studied leaf Zn application of corn in a form of sulphate. Coelho-Filho (2006), confirmed that due to the use of high concentration fertilizer in Brazil, there was a reduction in the supply of micronutrients, which has raised leaf micronutrient applications in recent years. The determination of sources, doses and micronutrient application times and check for possible toxic effects to plants should be evaluated in different cropping systems with maize.

Although some studies indicate positive response of maize to zinc application in Brazil, many doubts still arise regarding the most appropriate way of nutrient delivery and that promotes better plant nutrition. Moreover, it is known that Zn is a nutrient with little mobility in the phloem. It is necessary to study the efficiency of the foliar application of this nutrient in the maize plant. The objective of this work was to evaluate the biometric variables and grain yield, as a function of foliar application of copper and zinc in maize.

Results and discussion

The basic assumptions of normality (Shapiro-Wilk) and homogeneity of variance (Levene) were not significant at 1% error probability, validating the analysis (Table 1). According to Orioli et al. (2008), the micronutrient deficiency is common in Brazilian soils, because most of zinc and copper available in Brazil's soils are insufficient to meet the need of crops, or there is increase in pH by the application of relatively high amounts of lime, reducing the availability of these elements for the plants.

In contrast, in the present experiment, the contents of Cu and Zn in the area where the study was conducted were considered high (Table 2). Ferreira et al. (2001) reported that responses to micronutrients application can occur even in soils with high contents of Cu and Zn, and in soil with adequate organic matter content and high availability of nitrogen by mineral fertilizer. Corn plants have higher growth, which results in dilution of micronutrients such as zinc and copper in the plant, causing disability and necessity of its use in fertilizing.

The increase in absorption of micronutrients such as Cu and Zn by maize plants can be influenced by other factors such as low soil P levels, due to further development and colonization of the roots by mycorrhizal fungi, which linearly increases the absorption of Cu (Liu et al., 2000).

No differences were found for the variables plants per plot-stand (PP) and number of spikes per plot (SP) (Fig 1A and 1B). The results of the analysis revealed differences only for thousand grain weight (TGW) compared to witness and all other treatments (Fig 1C). There was greater effect on average, in the application of isolated micronutrients and together compared to the control, checking that the treatment with Zn was superior than control by the applied t test. Studying the effect of doses of 0.5 and 10 mg dm^{-3} in maize yield components in two soil types, with Zn contents of 2.8 and 2.7 mg dm^{-3}, Gonçalves Junior et al. (2007) found no differences in mean weight of cobs, straw average weight, number of grains per ear and thousand grain weights. In this work, the authors attributed this behavior to the soil Zn levels that were adequate and the parameters that indicate the quality of soil as adequate organic matter and absence of compression.

Furlani et al. (2005) evaluated 24 commercial maize hybrids for the efficiency in absorbing Zn doses ranging from 0.0 to 0.8 mg L^{-1} of nutrient solution in a greenhouse of young plants, evidenced by the increase in the Zn concentration in the air part of the maize plant, biometric variables, height of dry plants and dry mass of the aerial part, increased linearly with the doses.

For the characteristic such as number of grains per ear (GE), there was effect of contrast Cu, Zn versus Cu + Zn, the isolated effects from the products versus two concurrently, with the superiority of the individual effects (Table 1). In the average test, Zn treatment was superior to both micronutrients together and for the variables (Fig 2). According to Gianello et al. (1995), the behavior of plants for micronutrients must be studied on a regional basis, taking into account the particularities of each soil, due to plant uptake and availability of Zn and Cu in soils, depends on the microbial activity in the soil and about 98 to 99% of Zn occurs in the form of organic complexes.

For the grain yield, it was found that isolated effects of Cu and Zn exceeded the treatment with both products applied together (Table 1). For this characteristic in the average test, Zn treatment is better than both together and the control (Fig 3). There is the same behavior for the features weight per parcel (P). This reduction trend on grain yield may be due to the imbalance in the absorption or in the metabolism of other nutrients.

Productivity

According to Malavolta et al. (1997), copper has an antagonistic effect on calcium, the same way that zinc has competitive inhibition with calcium. It is extremely important to invest on maize crop researches to evaluate the implications of the applications of these two nutrients together to assess the effects on productivity. The author also points out that zinc has inhibition on assimilation of Mg^{2+} and on H_2BO^{3-}, which would mean deficiency of these nutrients in high doses of zinc.

Barbosa et al. (2013) studied the influence of Cu in maize crop with doses of 0, 100, 200, 300, 400, 500 and 600 g ha^{-1} of Cu in Distroferric Red Latosol, with an average content of 2.1 mg dm^{-3} of Cu, alert to the phytotoxic effects of this micronutrient in environments with high availability of this element by giving a dose of 100 g ha^{-1}, which was the highest productivity of the crop.

Jamami et al. (2006) studied the addition of doses of 2 kg ha^{-1} of boron and 4 kg ha^{-1} of zinc in the maize crop, in Yellow Oxiso with sandy texture and observed less weight of total dry matter of the plant 90 days after emergence. According to the authors, these two nutrients should not be applied together at higher doses due to the fact that they can reduce the production of carbohydrates by photosynthesis, which is the main component of the total plant dry weight, providing less physiological development, leading to slower growth of hybrids. Experiments conducted in the maize crop by Souza et al. (1998) and Gonçalves Junior et al. (2007), showed that, there were no advantages in applying doses higher than 2.5 mg dm^{-3} of Zn, and the productivity of certain hybrids cannot respond to the application of this nutrient in soils with appropriate Zn concentrations. Fancelli (2014) emphasized that the supply of Cu and Zn may have an effect on maize yield, even in soils with adequate levels of these micronutrients. Zinc is the micronutrient required in greater amount, where the effects are observed in the quality of the

Table 1. Analysis of variance summary for the number of plants per plot-stand (PP), number of spikes per plot (SP), thousand grain weight (TGW), number of rows per spike (RS), number of grains per row (GR), number of grains per spike (GS), weight per portion (P) and productivity (PROD).

Variation sources	PP (-)	SP (-)	TGW (g)	RS (-)
Control vs others	2.000^{ns}	1.125^{ns}	329.817*	0.009^{ns}
Cu, Zn vs Cu+Zn	2.250^{ns}	0.250^{ns}	1.778^{ns}	0.538^{ns}
Cu vs Zn	4.083^{ns}	10.083^{ns}	87.480^{ns}	0.013^{ns}
Basic assumptions [2]				
Shapiro-Wilk – W	0.9669^{ns}	0.9819^{ns}	0.9745^{ns}	0.9585^{ns}
Levene – QM	0.7150^{ns}	0.3619^{ns}	11.5720^{ns}	0.0889^{ns}
Variation sources	GF (-)	GS (-)	P (g)	PROD (kg.ha^{-1})
Control vs others	1.051^{ns}	71.601^{ns}	544968.000^{ns}	1513797.100^{ns}
Cu, Zn vs Cu+Zn	3.240^{ns}	2939.086*	779689.000*	2165792.967*
Cu vs Zn	2.613^{ns}	286.554^{ns}	30200.333^{ns}	8388.585^{ns}
Basic assumptions [2]				
Shapiro-Wilk – W	0.9788^{ns}	0.9533^{ns}	0.9886^{ns}	0.9886^{ns}
Levene – QM	0.5124^{ns}	38.2090^{ns}	45336.9837^{ns}	125935.5140^{ns}

[1] *: significant effect at 5% by F test; ns: non-significant effect at 5% by F test. [1]
[2] Basic Assumptions: normality of the residues by Shapiro-Wilk – calculated W value; homogeneity of variances by Levene – QM: average square. [2].

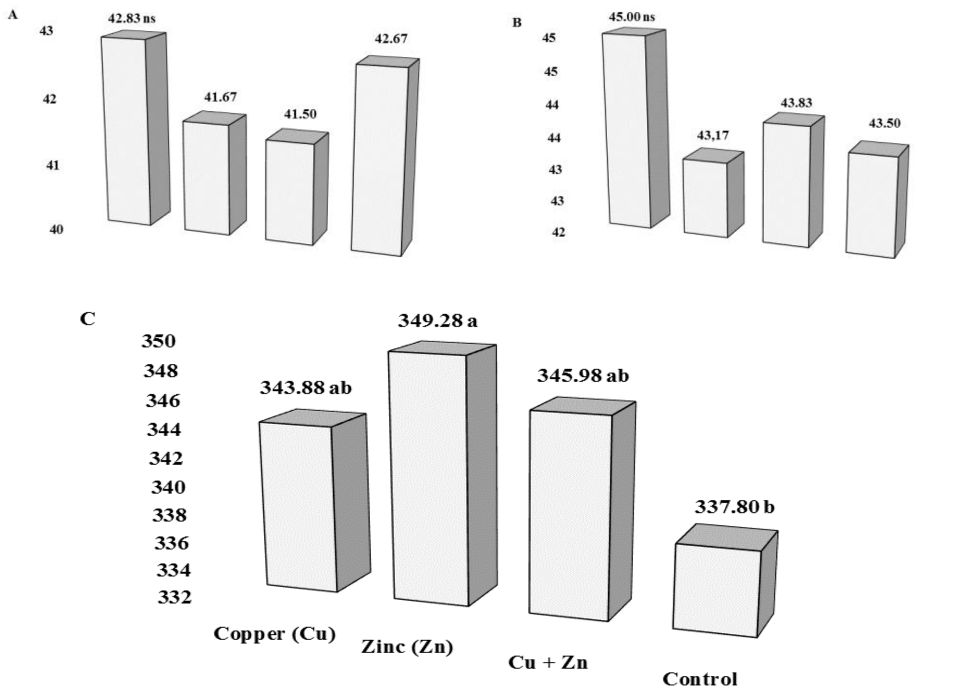

Fig 1. Averages resulting from t-test (LSD) of the characteristics in maize, (A) number of plants per plot-stand (PP), (B) number of spike per plot (SP) and (C) thousand grain weight (TGW), in experiment conducted in Cafelândia 2015.

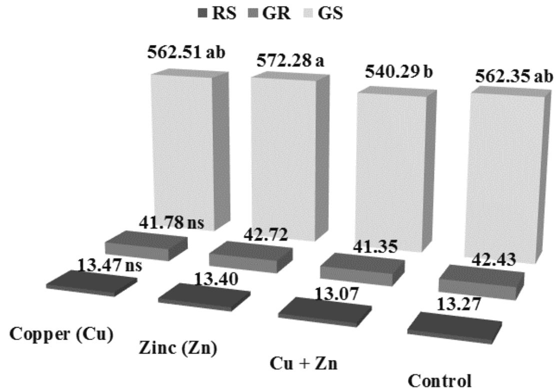

Fig 2. Averages resulting from t test (LSD) of the characteristics in maize: eight characteristics in corn number of rows per spike (RS), number of grains per row (GR), number of grains per spike (GS), in experiment conducted in Cafelândia 2015.

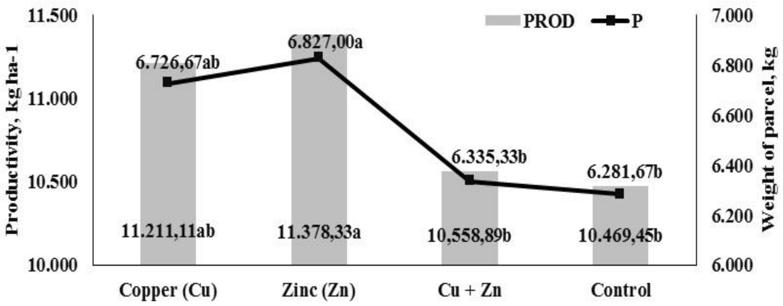

Fig 3. Maize productivity through the application of zinc and copper, Cafelândia-PR, Brazil.

Table 2. Chemical properties of the samples before the experiment, Cafelândia, PR, Brazil.

Layer	P	M.O	pH $CaCl_2$	Ca^{+2}	Mg^{+2}	K^{+}	H + Al	Al^{+3}	CTC	SB	Ca/Mg
m	mg dm^{-3}	g dm^{-3}		----------------------------cmol$_c$ dm^{-3}----------------------							
0 – 0.10	21.10	23.77	4.60	5.15	1.44	0.50	7.20	0.08	14.29	7.09	3.58
0.10 – 0.20	13.00	17.14	4.50	4.48	1.21	0.34	7.20	0.19	13.23	6.03	3.70
0 – 0.20	17.05	20.46	4.55	4.82	1.33	0.42	7.20	0.14	13.76	6.56	3.64

Layer	V%	Al	Ca	Mg	K	S-SO_4^{-2}	B	Mn	Zn	Cu	Fe
m	-----------% de saturation in CTC-------						----------------mg dm^{-3}-------------------				
0 – 0.10	49.62	1.12	36.04	10.08	3.50	3.75	0.60	101.00	13.34	13.47	15.00
0.10 – 0.20	45.58	3.05	33.86	9.15	2.57	5.15	0.55	93.00	8.64	15.58	22.00
0 – 0.20	47.60	2.08	34.95	9.61	3.03	4.45	0.57	97.00	10.99	14.52	18.50

V%: Sum of bases; P, K^+, Cu, Zn, Fe e Mn – Mehlich-1; Ca^{2+}, Mg^{2+} e Al^{3+} – KCl; M.O – Walkey Black; pH – Calcium chloride; H + Al – Buffer SMP; $S(SO_4)^{-2}$ – Monocalcium phosphate; B – Barium chloride (EMBRAPA, 1997).

harvested product, plant vigor and tolerance to diseases and pests. The recommended application of these micronutrients should be made based on soil analysis and also based on the peculiarities of farming systems and regionalized research work.

Materials and Methods

The experiment was conducted in the Agricultural Research Center of the Agroindustrial Cooperative Consolota in the city of Cafelândia, west of Paraná, Brazil. The experiment was conducted in the area of maize cultivation with ten years of tillage system, in which the succession system of soybean in summer and wheat, oats and maize in the winter crop have been fertilized with mineral fertilizers, as the usual crop requirements. The nitrogen fertilization in maize coverage was performed manually in the V4 stage, with 30 kg ha-¹ of N as urea in all plots.

Soil characterization

The soil was classified as Distroferric Red Latosol (EMBRAPA, 2013), with clay, silt and sand contents of 720, 130 and 150 g kg^{-1}, respectively. The soil samples were collected at the depths of 0-0, 10 and 0.10-0.20 m. The data of chemical analysis are shown in Table 2. Dolomitic lime was applied according to the necessity to raise base saturation (V%) to 70%. The system used for cultivation was tillage system. The contents of Cu and Zn in the area considered as high (EMBRAPA, 2011).

Climate characterization

The climate, according to Koppen, is Cfa, with hot summer with concentration of rainfall, winter with infrequent frosts without defined station. The average annual rainfall is around 1,500 mm, with average summer temperatures exceeding 20°C and winter average temperatures below 18ºC (IAPAR, 2014).

Experimental design

Treatments were applied at V6 stage of maize, being the treatment (1) 100 g of copper ha^{-1}, treatment (2) 500 g of zinc ha^{-1}, treatment (3) 100 g of copper ha^{-1} + 500 g ha $^{-1}$ zinc and treatment (4) witness/control. Liquid products used did not have other micronutrients in their composition, being applied to the crop with costal pump with capacity for 20 liters, PJB model - 20c - Jacto®, 1.5 meters long bar fitted with 3 nozzles (distance 0.5 m between nozzles) with pressure in bar set to 350 kPa and volume regulated tank to apply a flow of 150 L ha^{-1}, with nozzle plant jet (range) 110 02.

In this study, we used the hybrid Dekalb 240 PRO, seeded on September 12, 2014, with spacing of 0.5 m. The main plots were allocated as 10 m long × 2.50 m wide (25 m²), but the harvest was held on a 3-line spacing 0.5 m, 4 m long, totaling 6 m^2 of area.

Characteristics assessed

The number of plants per plot (PP-stand), number of spikes per plot (SP) and weight of a thousand grains (WTG) were determined according to the methodology described in the RAS (Brazil 1992), and the number of rows per spike (RS), number of grains per row (GR) were determined with the count of ten ears per plot and number of grains per spike (GS) from the determination of the number of rows multiplied by the number of grains per row. The weight per portion (P) and grain productivity (PROD) were made from the harvest of maize and threshed in batter plots and weighed on a precision scale, standardized to 13% moisture.

Data analysis

The results were submitted to variance analysis, while the comparisons between the means by F-test, with 5% error probability and the breakdown of the sum of squares for treatments in orthogonal contrasts. Statistical analysis was performed using the statistical program SISVAR 5.1 (Ferreira, 2011).

Conclusion

The application of copper on leaf with high levels of this nutrient in the soil did not increase the grain productivity. The application of zinc provided increment in grain yield due to the higher weight of thousand grains and grains per spike. The Zn leaf fertilizing should be recommended in a typical dystroferric red soil. The application of Cu and Zn together did not reflect as higher productivity, weight per plot and number of grains per ear.

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