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Residual Effect of Zinc Application Doses and Methods on Nutrition and Productivity of Corn

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Abstract

Zinc is the micronutrient that presents the greatest response in corn grain production. However, the mode of application and the dose used are decisive factors with respect to fertilizer efficiency in the crop. Thus, the objective of the present study was to evaluate the residual effect of zinc application methods and rates on corn nutrition and productivity. The experiment was conducted in the experimental area of the Teaching, Research and Production Farm of the FCAV/UNESP. Soil in the area is classified as dystrophic Dark-Red Latosol (dRL). The experimental setup consisted of a randomized complete block design with four replications. Treatments included three localized Zn doses applied to the soil (planting row); three Zn doses incorporated into the soil at depth of 0 - 20 cm; foliar application, seed application and treatment without addition of Zn. Two evaluations of growth during cultivation were performed. Grain productivity of the crop and the zinc content in soil, leaves and seeds were evaluated. Foliar spraying with Zn simultaneously promoted increased leaf Zn content and basal diameter of the plant. The Zn contents in grains and in the soil, as well as grain yield, were not affected by the Zn application methods or the applied doses. The residual effect of incorporated Zn doses was observed only in the basal diameter and number of leaves at 60 days after emergence.

Keywords

***Zea mays* L., Fertilization, Fertilizer Management, Micronutrient**

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1. Introduction

Corn is the third most cultivated cereal in the world, whose production is currently only behind wheat and rice. The United States is responsible for producing 36%, followed by China with 21% and Brazil, which accounts for 7% of world production [1]. However, several factors contribute to low productivity of the corn crop, among which are aspects related to mineral nutrition, which involves the fertilization with micronutrients, such as boron and zinc, whose deficiencies can limit productivity [2].

The most common nutrient deficiencies in corn are related to the micronutrients boron (B) and zinc (Zn). The low fertility of some soils, the exportation of crops, and the increasing use of lime and phosphate fertilizers are factors that contribute to the greater insolubility of zinc [3]. However, requirements of the plants are relatively low and the presence of small concentrations in soil potentially provided by plant residues can meet the plant nutrition, therefore there is a need for further studies to verify the effects of these residues on crop yields and the best method of application.

Of all the micronutrients, zinc is that which presents the best productivity responses in the corn crop in Brazilian soils, due to widespread deficiency that occurs, mainly in soils of the Cerrado [4]. Zinc is essential for different enzyme systems of the plant, controlling the production of important growth regulators. Its basic function is related to the metabolism of carbohydrates, proteins, phosphates, and also the formation of auxins, RNA (deoxyribonucleic acid) and ribosomes [5] [6]. Despite the benefits described in literature with the application of zinc to corn, [2] [7] did not encounter increased productivity after applying doses of this nutrient.

There are currently three known methods of zinc application to corn production systems, including application on: the ground (located or incorporated), leaves or seeds. It should be highlighted that incorporated zinc application to the soil may result in important residual effects in corn production [8]. Meanwhile, Galrão (1994) [9] noted that the mode of incorporated Zn application to the soil (broadcasting) had a superior effect on the first crop, where the second crop applications to the soil and also the leaves or seeds resulted in the same effects on crop production. Sakal *et al.* (1983) [10] found that foliar applications of zinc were similar to soil applications, either by broadcasting or application in the row at planting.

Given that the zinc doses required by crops are small [11], there are difficulties in even distribution of fertilizer when applied to the soil [12] [13], and therefore leaf application is an alternative. However, foliar applications have the disadvantage of low zinc mobility in the phloem [14] [15]. On the other hand, studies have indicated another method of Zn application, via the seed, considered viable for providing this micronutrient to the corn crop, especially to meet the initial phase of plant growth [16].

Thus, the objective of the present study was to evaluate the residual effect of zinc application methods and rates on nutrition and productivity of corn.

2. Material and Methods

The experiment was conducted in the experimental area of the Teaching, Research and Production Farm of the FCAV/UNESP (21˚15'22"S, longitude 48˚18'58"W, altitude of 575 m) in a dystrophic Dark-Red Latosol (dRL) [17], with very clayey texture and gently undulating relief. Chemical analysis of soil (0 - 20 cm) was performed according to the methods described by Raij [18] and presented the following properties: pH $CaCl_2$ = 5.5, (O.M.) = 1.6 $g \cdot dm^{-3}$, P (resin) = 31 $mg \cdot kg^{-1}$, K = 0.11 $cmol_c \cdot kg^{-1}$, Ca = 2.5 $cmol_c \cdot kg^{-1}$, Mg = 1.2 $cmol_c \cdot kg^{-1}$, H + Al = 2.2 $cmol_c \cdot kg$1, sum of bases (SB) = 3.8 $cmol_c \cdot kg^{-1}$, V% = 63, S = 1.0 $mg \cdot kg^{-1}$, B = 0.30 $mg \cdot kg^{-1}$, Cu = 1.0 $mg \cdot kg^{-1}$, Fe = 13.0 $mg \cdot kg^{-1}$, Mn = 16.1 $mg \cdot kg^{-1}$ and Zn = 0.5 $mg \cdot kg^{-1}$. Each experimental unit consisted of four planted rows measuring 5.0 m long, spaced at 0.90 m, totaling 18 m^2. For assessment of the treatments the two central lines were considered, discarding the 1.0 m from the ends and the other remaining lines which were considered the borders. A simple corn hybrid was used (Dow AgroSciences® 2B710). Planting was performed in December 2010. The average rainfall during the experimental period from planting to harvest was 1425 mm, and the average temperature for the period was 22˚C.

At the time of planting, basic fertilizer was applied uniformly to all treatments with the following composition: 30 $kg \cdot ha^{-1}$ of N, 50 $kg \cdot ha^{-1}$ of P_2O_5 and 50 $kg \cdot ha^{-1}$ of K_2O, in the form of urea and NPK fertilizer (02-20-20), according to the recommendations of Raij and Cantarella [19].

Nine treatments were distributed as follows: three Zn doses (2, 4 and 8 kg of Zn ha^{-1}) for application in the rows at planting, three Zn doses (6, 12 and 24 kg of Zn ha^{-1}) incorporated with the soil at 0 - 20 cm depth, foliar application (0.4 kg of Zn ha^{-1}), application to the seeds (40 g of Zn kg^{-1} of seeds) [20] and the control (no Zn application). The treatments applied to the soil and leaf received Zn in the form of zinc sulfate (22.7% Zn and 11% S). In the treatment applied to the seeds Zn oxide was used (79% Zn). Leaf applications of Zn were performed at 15 and 30 days after crop emergence [21]. For zinc applied via the seeds, a sugar solution was prepared and mixed with the seed to ensure better adhesion of the fertilizer. The experimental design consisted of randomized blocks with four replicates.

To establish the doses of Zn located, was adopted as the reference indication Raij and Cantarella (1997), as 4 $kg \cdot ha^{-1}$ Zn, and D1: half standard dose; D2: standard dose and the D3: twice the standard dose, then corresponding to 2, 4 and 8 $kg \cdot ha^{-1}$, respectively. For doses of Zn incorporated settled triple the dose for localized application, with the default amount of 12 $kg \cdot ha^{-1}$ Zn. Thus, treatments were incorporated into zinc consisting of: D1: half standard dose; D2: standard dose and the D3: twice the standard dose then corresponds to 6, 12 and 24 $kg \cdot ha^{-1}$, respectively.

The amounts of Zn incorporated in the soil were applied earlier, in December 2009, by means of the assay developed by Puga [22]. In the present study the residual affect was evaluated. Thus, the results of the Zn analysis in soil at the depth of 0 - 20 cm in the localized treatment with 2 $kg \cdot ha^{-1}$ of Zn was 0.88 $mg \cdot dm^{-3}$; in the localized treatment with 4 $kg \cdot ha^{-1}$ of Zn was 1.70 $mg \cdot dm^{-3}$; in the localized treatment with 8 $kg \cdot ha^{-1}$ of Zn was 1.88 $mg \cdot dm^{-3}$; in the incorporated treatment with 6 $kg \cdot ha^{-1}$ of Zn was 1.0 $mg \cdot dm^{-3}$; for the incorporated treatment with 12 $kg \cdot ha^{-1}$ of Zn was 2.01 $mg \cdot dm^{-3}$; in the incorporated treatment with 24 $kg \cdot ha^{-1}$ of Zn was 1.68 $mg \cdot dm^{-3}$; in the leaf treatment with 0.4 $kg \cdot ha^{-1}$ Zn the result was 0.55 $mg \cdot dm^{-3}$; in the seed treatment with 40 $g \cdot kg^{-1}$ of Zn the result was 0.78 $mg \cdot dm^{-3}$; and in the control treatment was 0.47 $mg \cdot dm^{-3}$.

Weed management was performed by mechanized spraying of the post-emergence herbicides Atrazine (4 $L \cdot ha^{-1}$) and Glyphosate (3 $L \cdot ha^{-1}$). Broadcast fertilizing was performed by applying 90 $kg \cdot ha^{-1}$ of N and 60 $kg \cdot ha^{-1}$ of K_2O in the forms of ammonium sulfate and potassium chloride, respectively, uniformly in all treatments.

Two evaluations of growth were conducted, the first at 30 days after crop emergence and the second during the flowering period of the plants, considering that the crop cycle is about 120 days. Factors analyzed were the number of fully expanded leaves, plant height by measuring from the soil surface to the last fully expanded leaf and basal diameter (at the first internode).

To evaluate the nutritional status, leaf sampling was performed according to the indications of Cantarella [23], in which the central third of the leaf at the base of the corn cob was collected. Determinations of Zn in the leaf were performed according to the methodology proposed by Battaglia [24].

Corn harvest was performed from plants of the useful area of each plot. The corn ears were separated mechanically into cob and grains. Grains were stored in paper bags identified and weighed to calculate productivity, with moisture adjusted to 130 $g \cdot kg^{-1}$. The Zn content in grains was then determined according to the methodology of Bataglia [24].

Soil sampling was performed in each experimental plot at the depth of 0 - 20 cm, by collecting ten points in the row (fertilization area) of the useful area of the corn crop. In treatments where Zn was applied in a localized form, points near the plant rows were sampled. In the other treatments sampling was done conventionally, in the area of fertilization.

Data was submitted to analysis of variance (ANOVA) according to the experimental design described. Means were compared by the Tukey test ($P < 0.05$), and for the doses a polynomial regression analysis was also applied, using the statistical program Sisvar [25].

3. Results and Discussion

3.1. Effect of the Treatments on Growth of the Corn Crop

The residual effect of doses and methods of Zn application did not cause significant effects on the growth variables of plant height and basal diameter at 30 days after corn emergence (**Table 1**). Orioli Júnior *et al.* [26], when studying wheat, also found no influence of Zn applied in different ways on plant height at 42 and 52 days after emergence. However, Romualdo [27] found taller heights of corn plants in treatments which received foliar Zn compared to soil fertilizations.

A lower number of leaves were observed in the foliar Zn treatment in the first assessment, 30 days after corn emergence, justified by the short period for the plants to absorb the nutrient and use it in their metabolic activities (**Table 1**). Similar behavior was observed in the other treatments.

The localized zinc applications quadratically affected the number of leaves per plant (**Figure 1**), with in-

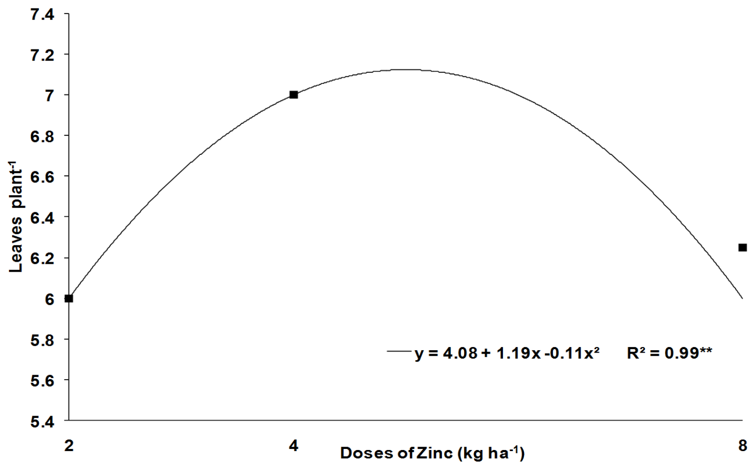


Figure 1. Number of leaves of the corn crop at 30 days after emergence, in function of localized zinc sulfate application to the soil. **Significant at 1% probability, by the F-test.

Table 1. Plant height (PH), basal diameter (BD) and number of leaves (NL) of the corn crop in function of zinc fertilization (Jaboticabal—SP, 2011).

Treatments	PH	BD	NL	PH	BD	NL
	cm	mm	Units	cm	mm	Units
		30 days			60 days	
Localized, 2 kg·ha^{-1}	75.75	22.90	6.00 ab	189.25	20.41 bc	13.50 ab
Localized, 4 kg·ha^{-1}	74.50	23.23	7.00 a	179.75	20.60 bc	13.00 ab
Localized, 8 kg·ha^{-1}	72.25	23.03	6.25 ab	180.00	21.38 abc	13.00 ab
Incorporated, 6 kg·ha^{-1}	73.75	22.92	6.00 ab	185.50	20.37 bc	13.00 ab
Incorporated, 12 kg·ha^{-1}	75.75	22.33	6.25 ab	176.25	19.89 c	13.00 ab
Incorporated, 24 kg·ha^{-1}	77.50	22.84	6.50 ab	179.00	21.52 abc	13.75 a
Leaf, 0.4 kg·ha^{-1}	74.50	22.38	5.75 b	171.25	22.53 a	13.25 ab
Seed, 40 g·kg^{-1}	72.50	23.04	6.75 ab	189.25	21.87 ab	13.75 a
Control	71.00	22.66	6.00 ab	186.75	21.80 ab	12.50 b
			F value			
Treatments	1.10^{NS}	1.81^{NS}	2.56*	1.06^{NS}	6.16**	2.62*
LR (Incorporated)	2.51^{NS}	0.01^{NS}	1.02^{NS}	1.46^{NS}	16.15**	16.07**
QR (Incorporated)	0.14^{NS}	2.01^{NS}	0.04^{NS}	3.66^{NS}	8.29*	1.93^{NS}
LR (Localized)	2.09^{NS}	0.05^{NS}	0.01^{NS}	1.04^{NS}	3.24^{NS}	0.86^{NS}
QR (Localized)	0.01^{NS}	1.12^{NS}	25.93**	0.85^{NS}	0.07^{NS}	0.64^{NS}
CV (%)	5.23	1.98	8.04	6.61	3.32	3.84

Results: Means followed by the same letter in the column do not differ by the Tukey test (P < 0.05). F value: *, ** and NS—significant at 5% and 1% probability, and non-significant, by the F-test. LR = Linear Regression; QR = Quadratic Regression.

creases in the dose of up to 5.4 kg·ha^{-1} of Zn. However, when evaluating the influence of nitrogen, zinc and boron and their interactions on the development of corn, Soares [7] did not observe effects of zinc doses applied to the row on the number of leaves in the corn plants at 20 days after crop emergence.

At 60 days after corn emergence, the R1 stage, the treatments had no effect on plant height, but influenced the basal diameter and number of leaves (**Table 1**). A greater basal diameter was observed in the treatment with foliar application and the lowest result was found for zinc applied to the soil, incorporated with the soil and at the dose of 12 kg·ha^{-1}. According to Fancelli & Dourado Neto [28], growth of the corn plant stalk occurs primarily from the emission of the eighth leaf and extends to flowering, where the stems not only act as a support for leaves and inflorescences, but mainly as a structure for the storage of soluble solids to be used in grain formation. Thus, the stem diameter of corn plants is very important for obtaining a high grain yield, since the larger the stem diameter, the greater the ability of the plant to store photo assimilates that contribute to grain filling. In this case the treatment that best influences this variable may contribute to increases in productivity.

For the number of leaves at 60 days, it was observed that application of Zn incorporated into the soil at a dose of 24 kg·ha^{-1} and application via the seed provided greater number, different from the control treatment. Studies developed in a greenhouse with corn showed similarity for the number of leaves between the control treatment and the methods of Zn application for the corn cultivar BRS 1001 [29] and for cv. P30K75 [27]. This difference is probably due to cultivation conditions.

It was observed that, for the basal diameter (**Figure 2(a)**) and the number of leaves (**Figure 2(b)**) in function of the incorporated application of zinc sulfate, there was a linear increase in the doses applied. Jamami [2], in a study with Zn doses in corn under field conditions, observed no response in stalk height and diameter of the plants for the evaluations performed.

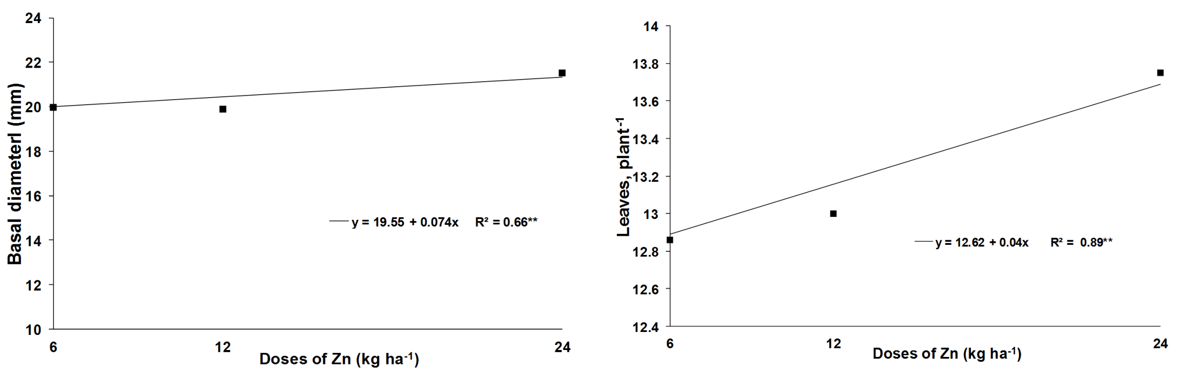
3.2. Concentration of Available Zn in the Soil, Leaf and Grains, as Well as the Corn Grain Yield

The Zn content in the soil was not influenced by the treatments when compared with the control (**Table 2**). According to Raij [30], the concentrations of this nutrient found in the experiment are classified as average (0.6 - 1.2 mg·dm^{-3}).

The treatments with incorporated Zn did not differ from those with localized application, seed application and the control; however, they were lower than foliar application which presented higher zinc content in the shoots (**Table 2**). Coutinho Neto [31] also found that foliar application and associated application via the seed increased concentrations of the micronutrient in corn leaves for silage. Malavolta [32] attributed the higher Zn concentration in the plant tissues after foliar application to the predominant negative charges of the cell walls and cuticles of the leaves, where the CEC is greater than the AEC, favoring the adsorption of cations such as Zn, the same phenomena that occurs in the soil.

Correia [33], in an experiment conducted in pots cultivated with rice and evaluating methods of Zn application, found that the largest content of this element in the shoots was promoted by foliar application of Zn, corroborating with the present work.

The highest leaf Zn content observed in the treatment with foliar application may also be explained by the addition of surfactant to the spray mixture, which may have contributed to greater adherence of the element on the



(a) (b)

Figure 2. Basal diameter of the corn plants (a) and number of leaves of the corn crop (b) at 60 days after emergence, in function of incorporated zinc sulfate application to the soil. **Significant at 1% by the F-test.

Table 2. Available zinc content in the soil, in the leaf, in the grain and corn grain yield, in function of fertilization with zinc (Jaboticabal—SP, 2011).

Treatments	Zn (Soil)	Zn (Leaf)	Zn (Grain)	Yield
	$mg \cdot dm^{-3}$	$mg \cdot kg^{-1}$		$kg \cdot ha^{-1}$
Soil, localized, 2 $kg \cdot ha^{-1}$	0.80	14.3 b	18.50	9195.0
Soil, localized, 4 $kg \cdot ha^{-1}$	0.78	19.0 b	22.25	9348.0
Soil, localized, 8 $kg \cdot ha^{-1}$	1.00	20.7 b	18.25	9840.3
Soil, incorporated, 6 $kg \cdot ha^{-1}$	0.78	16.0 b	24.25	9507.0
Soil, incorporated, 12 $kg \cdot ha^{-1}$	1.10	16.0 b	15.25	9044.5
Soil, incorporated, 24 $kg \cdot ha^{-1}$	0.98	17.0 b	21.00	9958.0
Leaf, 0.4 $kg \cdot ha^{-1}$	0.80	30.0 a	21.50	10054.3
Seed, 40 $g \cdot kg^{-1}$	0.95	13.7 b	19.00	9209.0
Control	0.73	13.7 b	17.25	10170.8
		F value		
Treatments	0.83^{NS}	8.14^{**}	1.97^{NS}	0.47^{NS}
LR (Incorporated)	0.24^{NS}	4.64^{NS}	0.16^{NS}	0.33^{NS}
QR (Incorporated)	1.81^{NS}	1.01^{NS}	5.28^{NS}	0.45^{NS}
LR (Localized)	0.29^{NS}	0.17^{NS}	0.29^{NS}	1.37^{NS}
QR (Localized)	0.25^{NS}	0.02^{NS}	4.68^{NS}	0.03^{NS}
CV (%)	29.0	20.2	20.1	12.7

Results: Means followed by the same letter in the column do not differ by the Tukey test ($P < 0.05$). F value: *, ** and NS—significant at 5% and 1% probability, and non-significant, by the F-test. LR = Linear Regression, QR = Quadratic Regression.

leaf, making it difficult to remove by washing. Faifer [34], studying methods for washing of corn leaves submitted to spraying with Zn in the presence and absence of surfactant, noted that in the presence of surfactant the nutrient content was higher. Based on this result it is important to highlight that the washing methods of leaf tissues were not effective for complete removal of this nutrient from the leaf surface.

Leaf concentrations were within the range of 15 - 100 $mg \cdot kg^{-1}$, considered appropriate by Cantarella [23]. Korndörfer [35] observed that the levels of Zn in the corn leaf increased with increasing doses of Zn applied to the soil and the average levels in the leaf ranged from 13 $mg \cdot kg^{-1}$ in the control treatment to 23 $mg \cdot kg^{-1}$ in the treatment with 4 $kg \cdot ha^{-1}$ of Zn.

Zinc content in the corn grains and the productivity obtained were not affected by the treatments (**Table 2**). In contrast, Ferreira [36] reported a 6.6% increase in Zn content of corn grains (significant difference by the F-test at 1%) resulting from application of the nutrients to the planting row, at a dose of 3 $kg \cdot ha^{-1}$. Kanwal [37], who analyzed doses of Zn applied to the soil in the planting row, also found increases from 21.8 to 30.7 $mg \cdot kg^{-1}$ of the micronutrient in the same culture.

The accumulation of Zn in grains or seeds is a complex process that includes a series of steps ranging from its translocation from roots to shoots, and finally phloem unloading in grain development [38]. For the productivity levels obtained, it may be that the initial Zn concentrations in the soil were sufficient, noting that leaf zinc concentrations are within the proper range for the crop and that the soil application did not increase its levels in the plant or promote an increase in productivity.

Igue [39] studied the effect of Zn application on corn productivity under field conditions, but showed no differences in productivity when assessing application of Zn to the soil and leaf. Was also observed by Jamami [2] in a study of Zn in corn, the application of this micronutrient to the soil did not increase production. However, Decaro [40] in an experiment with doses from 5 to 15 kg·ha^{-1} of Zn in corn, observed significant increases in grain yield.

4. Conclusions

Foliar spraying with Zn simultaneously promoted increased leaf Zn content and basal diameter of the corn plant.

The Zn content in grains and soil and the grain yield were not affected by Zn application methods or by the applied doses.

The residual effect of the incorporated Zn doses applied was observed only in the basal diameter and the number of leaves at 60 days after emergence.

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