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BORON AND ZINC FERTILIZER APPLICATION TO MAIZE CROPS IN A LITHIC QUARTZIPSAMMENT[1]

SIHÉLIO JÚLIO SILVA CRUZ[2]*, JOSÉ ROBERTO DA COSTA JÚNIOR[3],
SILVIA SANIELLE COSTA DE OLIVEIRA[2], VANESSA DE FÁTIMA GRAH PONCIANO[2],
ROMANO ROBERTO VALICHESKI[2]

ABSTRACT - The objective of this work was to evaluate the effect of soil application of different boron (B) rates to the soil, with and without application of zinc (Zn), on growth, production components, and grain yield of maize crops grown in a Lithic Quartzipsamment with low B and Zn contents. A randomized block experimental design was used, in a 6×2 factorial arrangement corresponding to six B rates (0, 1, 2, 3, 4, and 5 kg ha^{-1}), with and without application of Zn (2.0 kg ha^{-1}), applied to the soil at sowing, with four replications. Growth variables (stem diameter and plant height), and chlorophyll SPAD index were evaluated at the R1 phenological stage. Maize ear length, one-thousand grain weight, and grain yield, and the B maximum efficiency rate were evaluated at the R6 phenological stage. Application of B and Zn to the soil increases maize grain yield in soils with sandy clay loam texture and low B and Zn contents; the plant absorption and metabolism indicated synergism between these elements when using soil applications of 1.0 kg ha^{-1} of B combined with 2.0 kg ha^{-1} of Zn to the planting furrows. The rates with maximum technical efficiency for grain yield were 3.29 and 4.31 kg of B ha^{-1} in treatments without and with application of Zn, respectively.

Keywords: *Zea Mays* L. Mineral nutrition. Micronutrient.

ADUBAÇÃO COM BORO E ZINCO NO CULTIVO DE MILHO EM NEOSSOLO LITÓLICO DISTRÓFICO

RESUMO - O objetivo desse trabalho foi avaliar o efeito da aplicação via solo de doses de boro (B), com ou sem adubação com zinco (Zn), sobre o crescimento, componentes de produção e produtividade do Milho em Neossolo Litólico distrófico, com baixos teores de B e Zn. O delineamento experimental utilizado foi blocos casualizados, em esquema fatorial 6 x 2, correspondente a seis doses de (B) aplicadas no solo (0, 1, 2, 3, 4 e 5 kg ha^{-1}) e, sem e com adubação de Zn (2,0 kg ha^{-1} de Zn), ambas realizadas na semeadura, com quatro repetições. No estádio fenológico R1, foram avaliadas as variáveis de crescimento: diâmetro de colmo e altura de plantas, juntamente com o índice SPAD de clorofila. No estádio fenológico R6 foram analisados comprimento da espiga; massa de mil grãos, produtividade e dose de máxima eficiência (DME). A adubação com boro e zinco aumenta a produtividade do milho em solo com textura franco-argilo arenosa e baixos teores desses elementos, existindo sinergismo na absorção e metabolismo da planta quando se aplica 1,0 kg ha^{-1} de B juntamente com 2,0 kg de Zn ha^{-1} via solo no sulco de plantio. Neste estudo, as doses de máxima eficiência técnica para produtividade de grãos foi de 3,29 e 4,31 kg de B ha^{-1} para os tratamentos sem e com adubação com Zn.

Palavras-chave: *Zea Mays* L. Nutrição mineral. Micronutriente.

*Corresponding author
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[2]Department of Agronomy, Instituto Federal de Educação, Ciência e Tecnologia Goiano, Iporá, GO, Brazil; sihélio.cruz@ifgoiano.edu.br – ORCID: 0000-0002-1602-5312, silvia.oliveira@ifgoiano.edu.br – ORCID: 0000-0002-3476-1807, vanessa.grah@ifgoiano.edu.br – ORCID: 0000-0001-7177-8942, romano.roberto@ifgoiano.edu.br – ORCID: 0000-0002-9623-1385.
[3]Department of Agronomy, Instituto Federal de Educação, Ciência e Tecnologia Goiano, Rio Verde, GO, Brazil; dacostajuniorjoseroberto@gmail.com – ORCID: 0000-0001-9064-7040.

INTRODUCTION

Agricultural systems in Brazil are under a period of high efficiency, profitability, and yield; thus, the sustainability of production processes is very important. Approximately 102 million Mg of maize grains are produced in Brazil every year, with yields that reach 14 Mg per hectare. In this context, adequate nutritional management is essential to maintain the current stability and further increases in grain yield (CRUZ, 2013; CONAB, 2020).

One of the important variables to reach high grain yields is the supplying of nutrients, including boron (B) and zinc (Zn) (ABREU et al., 2016; SONGKHUM et al., 2018). Unfortunately, most soils in tropical regions are characterized as low-fertility soils (SANTOS et al., 2018).

The main factors and causes of this low soil fertility, which affects B and Zn availability, are: soil pH (the higher the soil acidity, the lower the B availability to plants); soil texture (low availability of nutrients in sandy soils); low soil moisture maintenance capacity; low soil organic matter contents (mainly sandy soils); leaching (low soil water retention capacity); high phosphorus (P) rates (high P concentrations may result in Zn deficiency); application of products to correct soil acidity; and exports of nutrients through harvests (NOGUEIRA, 2016; OLIVEIRA et al., 2017).

B absorption occurs by the combination of two types of passive transport through the plasma membrane, by simple diffusion of the nutrient through the lipid double layer, whose coefficient of permeability varies according to the species (TOMBULOGLU et al., 2016). Zn is absorbed by roots and transported as a divalent cation by symplastic and apoplastic pathways (GUPTA; RAM; KUMAR, 2016). The lack of B and Zn indirectly affects the plant water absorption and root growth and, consequently, the absorption of these nutrients is also hindered (WIMMER; EICHERT, 2013).

However, the research results are still inconsistent regarding the responses of crops to application of boron fertilizers, mainly due to the small difference between deficiency and toxicity levels and the boron absorption by organic matter and iron and aluminum oxides in the soil. (WIMMER; EICHERT, 2013). It often discourages B application, even to soils with deficiency of this nutrient. However, the interaction between B and Zn is confirmed by several studies on biochemical and physiological processes of plants, such as synthesis of dehydrogenases, proteinases, peptidases, and phosphohydrolases, which are essential enzymes for the photosynthesis (ARAÚJO; SILVA, 2012; MOUSAVI; GALAVI; RAZAEI, 2013). Both micronutrients are indispensable for the growth and reproduction of plants, participating in the metabolism and translocation of carbohydrates, cell growth, integrity of plasma membrane, and production of flowers, fruits, and seeds (SOOMRO; BALOCH; GANDHAIL, 2015).

New maize hybrids usually present higher productivity and nutrient demand. Therefore, considering that B and Zn deficiencies are common in soils in the Brazilian Cerrado biome, where the application of high phosphorus rates induces Zn deficiency, and that the existence of synergistic or antagonistic effect in B and Zn interactions for absorption of these soil micronutrients is debatable, the development of researches for this region is needed.

In this context, the objective of this work was to evaluate the effect of soil application of different B rates, with and without application of Zn, on growth, production components, and grain yield of maize crops grown in a Lithic Quartzipsamment with low B and Zn contents.

MATERIAL AND METHODS

The experiment was conducted at the School Farm of the Federal Institute Goiano, Iporá campus, Goiás, Brazil (16°15'S, 51°12'W, and 611 m of altitude). The soil used was classified as Lithic Quartzipsamment (Neossolo Litolico distrofico; SANTOS et al., 2018), with predominance of quartzose gravel (2.0 the 20.0 mm); the chemical attributes and granulometric composition are presented in Table 1 (TEIXEIRA et al., 2017).

Table 1. Chemical attributes and granulometric composition of a Lithic Quartzipsamment.

Layer	pH	OM	$P_{mehlich-1}$	Al^{3+}	H+Al	K	Ca	Mg	S	B	Zn	CEC	BS	AS
cm	$CaCl_2$	g dm^3	mg dm^3	----------$cmol_c$ dm^3---------					-----mg dm^3-----					
0-20	5.6	16	1.5	0	2.4	0.4	3.5	1.7	2	0.05	0.7	8	70	0
20-40	4.7	10	0.7	0.1	2.4	0.2	1.8	0.9	1	0.03	0.1	6.3	46	3.5

CEC = cation exchange capacity at pH 7.0; BS = base saturation; AS = aluminum saturation; OM = organic matter.

The climate of the region is Aw, tropical with two well-defined seasons (dry and rainy seasons), according to classification of Köppen (1900) adapted by Cardoso, Marcuzzo, and Barros (2015). The dry season encompasses five months; the mean annual temperature is 24 ºC and the mean annual rainfall depth is 1,613 mm. Climate data were recorded during the experiment by a meteorological station of the Federal Institute Goiano at 300 meters from the experimental area (Figure 1).

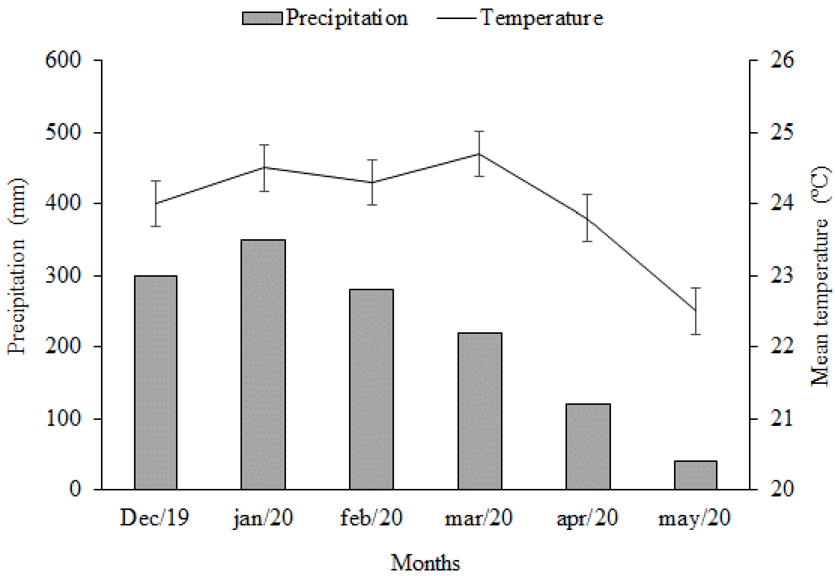

Figure 1. Mean temperatures (ºC) and rainfall depths (mm) during the experiment at the School Farm of the Federal Institute Goiano, Iporá, GO, Brazil.

A randomized block experimental design was used, in a 6×2 factorial arrangement consisting of six B rates (0, 1, 2, 3, 4, and 5 kg ha^{-1}), with and without application of Zn (2.0 kg ha^{-1}), applied to the soil at sowing, with four replications. The Zn rate was calculated as recommended by Sousa and Lobato (2004). The B and Zn sources used were: boric acid and zinc sulfate, respectively.

The experimental plot consisted of five 4-meter rows, spaced 0.5 m apart. The evaluation area of the plot consisted of the three central rows, excluding 0.5 m from each end. The maize hybrid used was the MG711 PW.

The sowing was carried out manually; the seeds were placed at 0.05 m depth in the sowing furrows for a stand of 80,000 plants ha^{-1}. Soil fertilizer application at sowing consisted of 30, 150, and 75 kg ha^{-1} of N, P_2O_5, and K_2O, respectively, and topdressing was carried out when the plants reached the V4 vegetative stage, with application of 145 kg of N ha^{-1}. These two fertilizer applications were carried out as recommended by Sousa and Lobato (2004).

Weed control was carried out by applying the herbicides nicosulfuron and atrazine at the rates of 20 g and 1000 g a.i. ha^{-1}, respectively. The application was carried out using a CO_2-pressurized backpack sprayer equipped with a 2-meter spray boom with 4 nozzles with DG11002 tips, maintained at constant pressure (210 kPa) and an application rate of 200 L ha^{-1}. Application of insecticides was also needed; lufenuron and chlorpyrifos were used at rates of 0.2 and 0.5 L ha^{-1} respectively, to control *Spodoptera frugiperda* caterpillars.

When 50% + 1 maize plants reached the R1 phenological stage (silk stage and pollination) (MAGALHÃES et al., 2006), the growth variables were evaluated, namely, stem diameter; plant height; and chlorophyll SPAD index, determined in the leaf +1. When the plants reached the R6 phenological stage (physiological maturation) (MAGALHÃES et al., 2006), 20 ears per plot were collected to determine ear length, one-thousand grain weight, and grain yield, considering a grain water content of 13%, according to the method recommended by the Rules for Seed Analysis (BRASIL, 2009). The B maximum efficiency rate (MER) was determined through the fit of the data to two-degree equation ($RG = b_0 \pm b_1 \times \pm b_2 x^2$) to estimate the maximum efficiency ($MER = -[(b_1)/(2b_2)]$).

The obtained data were subjected to analysis of variance; the means were compared by the Tukey's test at 5% probability level, for comparison of mean results of B application, with and without application of Zn, and subjected to regression analysis for studying the effect of B rates.

RESULTS AND DISCUSSION

The increase of B rates, with and without Zn application, did not result in increases in plant height; the overall mean for plant height was 2.2 m (Table 2). This is consistent with other studies that also showed no changes due to application of B rates varying from 0 to 4 kg ha^{-1} (JAMAMI, 2006). However, the stem diameter increased significantly due to B application (F = 0.00), but the interaction between B and Zn applications was not significant for this variable (Figure 2).

Table 2. Height and stem diameter of maize plants as a function of application of six B rates at sowing, with or without application of 2.0 ha^{-1} of Zn.

Fertilization	Culm diameter (mm)					
2.0 kg ha^{-1}	Rates of B (kg ha^{-1})					
of Zn	0	1	2	3	4	5
With	17 b	19 ab	19 a	20 a	19 ab	19 a
Without	17 b	19 ab	18 ab	20 a	20 a	19 a
"F" (rates of B)						0.00
"F" (Zn Fertilization)						0.81
"F" (B x Zn interaction)						0.28
CV%						4.27

Means followed by the same lowercase letter in the rows, or uppercase in the columns, are not different from each other by the Tukey's test at 5% probability level; CV% = coefficient of variation.

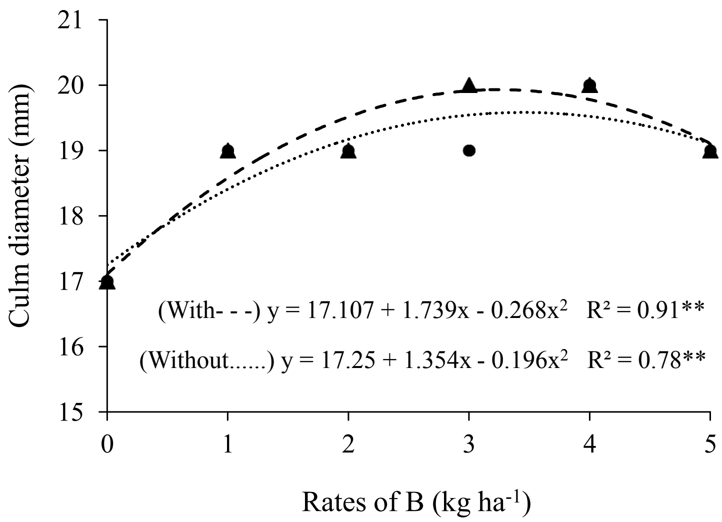

Figure 2. Stem diameter of maize plants as a function of application of six B rates at sowing, with or without application of 2.0 ha^{-1} of Zn.

Soares (2003) found no increases in stem diameter when applying B rates to the bottom of sowing furrows, which was probably because the soil presented enough boron contents (0.35 mg dm^{-3}). According to Fancelli and Dourado Neto (2000), adequate soil boron contents for maize crops are between 0.1 and 0.3 mg dm^{-3}. Therefore, the response of maize to B rates in the present study was due to the initial B content in the soil (control), which was 0.05 mg dm^{-3}, below that recommended for maize crops.

The increases in stem diameter found in the present study, as a function of increase in B rate, also denote that B is essential not only at the crop reproduction stages (POSSAN, 2010), but also at the vegetative growth stages, because it has several vital functions, including sugar transport, cell wall synthesis and lignification, cell wall structuring, and metabolism of carbohydrates and RNA (TOMBULOGLU et al., 2016). Plants with larger stem diameters also present higher growth of ears, with positive effect on grain yield (FANCELLI, 2013).

The interaction between Zn and B was significant for chlorophyll SPAD index; however, the means were higher when applying Zn only for the rate of 1.0 kg of B ha^{-1} (Table 3). This increase can be connected to the fact that Zn is a component of dehydrogenases, proteinases, peptidases, and phosphohydrolases, which are essential enzymes for the photosynthesis process; in addition, Zn deficiency reduces the concentration of chlorophylls *a* and *b* (MOUSAVI; GALAVI; REZAEI, 2013), which are also essential for the photosynthetic process. Araújo and Silva (2012) evaluated the interaction between B and Zn on growth of cotton plants and found that B contents in plant shoots increased as a function of increases in Zn concentrations in the soil solution.

Table 3. Chlorophyll SPAD index of the leaf +3 of maize plants as a function of application of six B rates at sowing, with or without application of 2.0 ha^{-1} of Zn.

Fertilization	Chlorophyll SPAD index					
2.0 kg ha^{-1}	---------- Rates of B (kg ha^{-1}) ----------					
of Zn	0	1	2	3	4	5
With	39 bA	49 aA	48 aA	48 aA	47 aA	40 bA
Without	42 aA	44 aB	47 aA	45 aA	46 aA	42 aA
"F" (rates of B)						0.00
"F" (Zn Fertilization)						0.16
"F" (B x Zn interaction)						0.03
CV%						6.47

Means followed by the same lowercase letter in the rows, or uppercase in the columns, are not different from each other by the Tukey's test at 5% probability level; CV% = coefficient of variation.

The absence of increases in chlorophyll SPDA index indicates that the B levels required for the maximum expression of chlorophyll in leaves of maize plants can be achieved in soils with low B contents by applying a B rate of 1.0 kg ha^{-1}. Souza et al. (2015) applied B rates of up to 8.0 kg ha^{-1} for wheat crops and found no significant differences in chlorophyll SPAD indexes.

The analysis of production components showed no difference between the means of ear lengths due to the treatments; the overall mean for ear length was 12.9 cm. It is consistent with the results found by Jamami et al. (2006), who also found no significant changes in plants with and without application of B. Similarly, Dourado Neto et al. (2004) found no significant effect of application of increasing B rates (up to 8 kg ha^{-1}) on ear length. The highest B rate applied to sowing furrows in the present study (5 kg ha^{-1}) and by Dourado Neto et al. (2004) did not affect negatively the maize ear lengths.

The one-thousand grain weight and grain yield increased due to the application of B (Table 3). The one-thousand grain weight means ranged from 293 g (control) to 330 g (application of 4.0 kg of B) in treatments with application of B and Zn. The treatments with application of only B presented no changes in one-thousand grain weight. Contrastingly, the interaction between application of B and Zn was significant for grain yield, with an increase of 793 kg in grain yield when applying the rate of 1.0 kg of B ha^{-1}.

According to Taiz et al. (2017), the quantity of chlorophyll is one of the factors that most affect the plant growth and development, as this molecule is essential for photosynthesis, i.e., transformation of atmospheric CO_2 into metabolic energy. Therefore, a high chlorophyll index in leaves is connected to increases in grain weight and, consequently, with the grain yield (Tables 4 and 5), because this molecule is responsible for capturing solar energy and converting it into photoassimilates, directly affecting the crop yield.

Table 4. One-thousand grain weight and grain yield of maize plants as a function of application of six B rates at sowing, with or without application of 2.0 ha^{-1} of Zn.

Fertilization	Weight of 1000 grains (g)					
2.0 kg ha^{-1}	Rates of B (kg ha^{-1})					
of Zn	0	1	2	3	4	5
With	293 a	306 ab	330 b	329 b	330 b	305 ab
Without	303 a	308 a	312 a	318 a	315 a	305 a
"F" (rates of B)						0.00
"F" (Zn Fertilization)						0.21
"F" (B x Zn interaction)						0.39
CV%						4.81

Means followed by the same lowercase letter in the rows, or uppercase in the columns, are not different from each other by the Tukey's test at 5% probability level; CV% = coefficient of variation.

Table 5. Grain yield of maize plants as a function of application of six B rates at sowing, with or without application of 2.0 ha^{-1} of Zn.

Fertilization	Grain yield with 13% grain water content (kg ha^{-1})					
2.0 kg ha^{-1}	Rates of B (kg ha^{-1})					
of Zn	0	1	2	3	4	5
With	9569 aA	10305 abB	11380 bcA	11308 bcA	11586 cA	10883 bcA
Without	9085 aA	9512 aA	10766 bA	10838 bA	11448 bA	11021 bA
"F" (rates of B)						0.00
"F" (Zn Fertilization)						0.01
"F" (B x Zn interaction)						0.52
CV%						4.84

Means followed by the same lowercase letter in the rows, or uppercase in the columns, are not different from each other by the Tukey's test at 5% probability level; CV% = coefficient of variation.

In addition, the means of production components as a function of application of B rates fitted to quadratic models. The maximum efficiency rate for one-thousand grain weight was 2.87 kg of B ha-1 with Zn application (Figure 3). The maximum efficiency rate for grain yield was 3.29 and 4.31 kg of B ha-1 for the treatments without and with application of Zn, respectively (Figure 4).

Jamami et al. (2006) and Nogueira (2016) evaluated responses of maize hybrids (AG 1043 and BKB 350 PRO) to application of B (0, 1, 2, 3, and 4 kg ha^{-1}) and Zn (0, 2.0, and 4.0 kg ha^{-1}) and found that the applications of B and Zn to the sowing furrows did not increase B and Zn leaf contents, nor gains in grain yield. These results were probably due to the initial contents of B and Zn in the soil of the experimental areas used (0.07 and 0.16 mg of B dm^{-3} and 0.3 and 1.2 mg of Zn dm^{-3}), which were enough to meet the crop demand in those crop conditions.

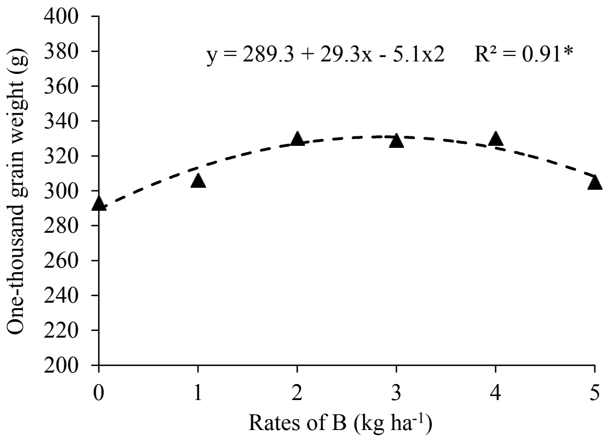

Figure 3. One-thousand grain weight (3A) of maize plants as a function of application of six B rates at sowing, with or without application of 2.0 ha^{-1} of Zn.

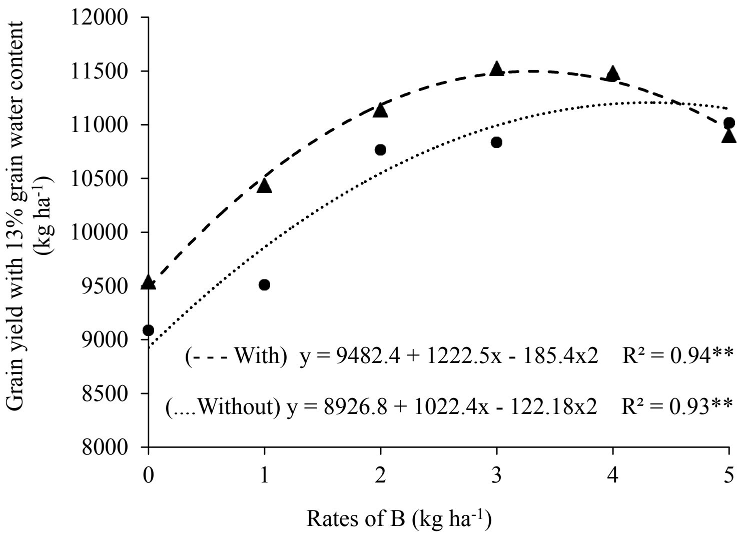

Figure 4. Grain yield of maize plants as a function of application of six B rates at sowing, with or without application of 2.0 ha^{-1} of Zn.

According to Fancelli and Dourado Neto (2000), the adequate B and Zn contents in the soil for maize crops are 0.1 to 0.3 mg dm^{-3} (B) and 0.5 to 1.0 mg dm^{-3} (Zn). The B and Zn contents in the soil used in the present experiment were, according to means of samples of two soil layers (0-20 and 20-40 cm), 0.03 and 0.4 mg of dm^{-3}, respectively (Table 1), i.e., well below the recommended level for the crop.

The type of soil may have also contributed to the increase in grain yield; it was a Lithic Quartzipsamment (Neossolo Litolico distrofico; SANTOS et al., 2018) with predominance of quartzose gravel in its coarse fraction, originally from leucocratic granitic rocks poor in nutrients. According to Castillo (2016) and Hansel and Oliveira (2016), soils from this class of rocks, poor in organic matter, tend to present low B and Zn availability; thus, plants grown in these soils present positive responses when the availability of these micronutrients is increased through soil fertilizer application.

CONCLUSIONS

The soil fertilizer application with boron (B) and zinc (Zn) increases the maize grain yield in soils with sandy clay loam texture and low B and Zn contents; the plant absorption and metabolism indicated synergism between these elements when using soil applications of 1.0 kg ha^{-1} of B combined with 2.0 kg ha^{-1} of Zn to the planting furrows. The rates with maximum technical efficiency for grain yield were 3.29 and 4.31 kg of B ha^{-1} for treatments without and with application of Zn, respectively.

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