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Agronomic performance of corn grown with sources and doses of boron

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ABSTRACT

Corn is a crop of great socio-economic importance due to its high energy value and use in human and animal food. This study aimed to evaluate the agronomic characteristics of corn grown with boron (B) sources and doses. The experimental design was a randomized block arranged in a 3x4 factorial scheme with four replications. Three B sources (boric acid, borax, and ulexite) and four doses (0; 1.5; 3.0, and 4.5 kg ha^{-1}) were evaluated. The experiment was carried out over two consecutive crop seasons. The variables analyzed were plant height, first ear insertion height, ear length, number of grain rows per ear, number of grains per row, 1000-grain weight, and grain yield. The data was submitted for analysis of variance, and the means were compared using the Tukey test at 5% significance. For ear length, there was an interaction between the factors in the first year, and at a dose of 1.5 kg ha^{-1}, Boric Acid was superior to Borax and Ulexite. Regarding grain yield, there was a difference between the sources and doses in the two crop seasons, and Ulexite was superior to the other sources. The regression analysis estimated the highest grain yield with doses of 1.6 kg ha^{-1} and 2.03 kg ha^{-1} in the first and second crop seasons, respectively. There was no difference between the sources and doses of B for plant height, first ear insertion height, number of grain rows per ear, number of grains per row, and 1000-grain weight.

Keywords: *Zea mays*, Micronutrient, Yield.

Desempenho agronômico de milho cultivado com fontes e doses de boro

RESUMO

O milho é uma cultura de grande importância socioeconômica, devido seu alto valor energético e utilização na alimentação humana e animal. Objetivou-se neste trabalho avaliar as características agronômicas da cultura do milho cultivada com fontes e doses de B. O delineamento experimental foi em blocos ao acaso, esquema fatorial 3x4 com três fontes de B (ácido bórico, bórax e ulexita) e quatro doses (0; 1,5; 3,0 e 4,5 kg ha^{-1}), com quatro repetições por tratamento. O experimento foi realizado em 2 safras consecutivas. As variáveis analisadas foram: altura de planta, altura de inserção da primeira espiga, comprimento da espiga, número de fileiras de grãos por espiga, número de grãos por fileira, massa de mil grãos e produtividade. Os dados foram submetidos à análise de variância e as médias comparadas pelo Teste de Tukey a 5% de significância. Para comprimento da espiga houve interação entre os fatores no primeiro ano, na dose de 1,5 kg ha^{-1} o Ácido Bórico foi superior ao Boráx e Ulexita. Para produtividade houve diferença entre as fontes e doses nas duas safras e a Ulexita foi superior às demais fontes, pela análise de regressão a dose de 1,6 kg ha^{-1} apresentou maior produtividade na primeira safra, e a dose de 2,03 kg ha^{-1} na segunda safra. Para altura de planta, altura de inserção da primeira espiga, número de fileiras de grãos, número de grãos por fileira e massa de 1000 grãos não houve diferença entre as fontes e doses de B.

Palavras-chave: *Zea mays*, Micronutriente, Produtividade.

1. Introduction

Corn (*Zea mays* L.) is a crop of great socio-economic importance in world agriculture due to its high energy value and use in human and animal food (Tavares et al., 2015). Corn cultivation in Brazil has grown yearly and has become an important crop for the agricultural sector, being the second most exported grain in the country (Souza et al., 2018). According to CONAB (2022), the total area for corn cultivation in Brazil in the 2021/2022 crop season grew to 21.58 million hectares, an increase of approximately 8.2% from the previous 2020/2021 crop season, presenting a total production, considering the three times of cultivation, of around 113.27 million tons of the grain (30.1% higher than the previous crop season).

The crop in Brazil has shown yield increases every year, mainly due to the technologies implemented in the cultivation system, such as crop rotation, no-tillage system, soil fertility management, and adequate fertilization with macro and micronutrients (Teixeira et al., 2015). According to Souza et al. (2011), tropical soils usually have a low pH, and boron (B) deficiency is common in these soils due to the high acidity. B is an important nutrient for plants, as it is related to meristematic growth, root formation, cell wall synthesis, membrane function, hormonal responses, and cell cycle regulation (Araújo and Silva, 2012).

It is also essential for pollen germination and pollen tube development (Javorski et al., 2014). B deficiency in the plant impairs its development and reduces its yield potential (Silva et al., 2014), as well as generating disturbances in the physiological processes dependent on the presence of B in the plant tissues (Brunes et al., 2015). Kumar et al. (2019), evaluating different application ways of B in corn (foliar and soil), observed in their studies gains in grain yield with the application of 0.5 kg ha^{-1} of B in the sowing furrow, totaling a 25% increase over the control. Given the above, this study aimed to evaluate the agronomic characteristics of corn grown with sources and doses of boron.

2. Material and Methods

The experiment was carried out in the experimental sector of annual crops at the Federal Institute Goiano - Campus Ceres - GO (15°21'00" S; 49°35'57" W) at an altitude of 564 meters. The study occurred over two consecutive crop seasons in the same area, the first in the 2019/2020 crop season and then reproduced in the 2020/2021 crop season. The climate in the region is Aw-type according to the Koppen classification, characterized as tropical humid with a rainy season in summer and a dry season in winter. The results of the soil analysis are shown in Table 1.

The area was desiccated using a boom sprayer and Glyphosate at a dose of 3.0 L ha^{-1}. Weeds were controlled during the growing season by applying the pre-emergent herbicide Dual Gold at a dose of 1.2 L ha^{-1}. Sowing was carried out on 12/10/2019 and 12/04/2020 for the first and second crop seasons, respectively, during the period that presented ideal conditions for crop germination.

A corn planter machine was used (direct sowing), with row spacing of 0.85 m, aiming to obtain a population of 61,000 plants ha^{-1}. In the first crop season, the area had been left fallow before being sown, while in the second crop season, the crop was grown on the straw from the first year of study, and there was no off-season cultivation in the area. The hybrid was Feroz VIP 3, a double-cross hybrid with RR and Viptera technology.

The fertilization in the sowing furrow was 38 kg ha^{-1} of N, 144 kg ha^{-1} of P_2O_5, and 48 kg ha^{-1} of K_2O in both crop seasons. The topdressing fertilization was carried out by applying 100 kg ha^{-1} of N (urea) when the plants had fully opened leaves (V4). The seeds were treated with the systemic insecticide Imidacloprid + Thiodicarb and the fungicide Thiram at 500 mL and 200 mL per 100 kg of seeds, respectively. The other crop treatments to control insects and invasive plants during the experiment followed the technical recommendations for the crop.

The experimental design used was randomized blocks arranged in a 3x4 factorial scheme, with three sources of B (boric acid (17.48%); borax (11.3%), and ulexite (10%) and four doses (0; 1.5; 3.0, and 4.5 kg ha^{-1}). Each plot consisted of four 5 meter rows, spaced 0.85 m apart. The two central rows were considered useful, with 0.85 m at the ends being disregarded as a border. The treatments were applied manually in the row immediately after sowing.

Table 1. Results of the chemical and particle-size analysis of the soil at 0-20 cm depth before the experiment was set up.

Sand	Silt	Clay	pH in H_2O	O.M.	Ca	Mg	Al
	g kg^{-1}			g dm^{-3}		cmol$_c$ dm^{-3}	
482	60	458	5.92	18	3.05	1.24	0.00
	H+Al	K	CEC	B	P	BS	
		cmol$_c$ dm^{-3}		mg dm^{-3}			
	3.00	0.50	9.34	0.25	20.00	60.50%	

O.M. – organic matter; CEC – Cation exchange capacity; BS – Base saturation

The following variables were assessed: plant height (m), first ear insertion height (m), ear length (mm), number of grain rows per ear, number of grains per row, 1000-grain weight (g), and grain yield (kg ha^{-1}). The experiment was harvested manually by removing all the ears from each plot and identifying them; then, they were threshed and weighed to estimate the grain yield corrected to 13% moisture content. The harvesting occurred on 12/05/2020 and 06/05/2021 in the first and second crop seasons of the experiment, respectively.

The data was subjected to analysis of variance, and the means were compared using the Tukey test at 5% probability. Regression analysis was carried out on the variables analyzed according to the doses of B applied. The analyses were carried out using the R statistical software.

3. Results and Discussion

The results of the analysis of variance are shown in Table 2 for the two years of the experiment. Boron sources influenced the grain yield in both crop seasons. Similarly, the boron dose effect was also observed for grain yield in both crop seasons. Regarding the interactions between the Sources and Doses (Table 2), there was a significant interaction between the factors for the ear length in the first crop season. In the second crop season, there was no interaction between the factors in any of the variables studied.

The regression analysis according to the B doses proved significant for the ear length variable in the first harvest, fitting the linear model when Borax was used as the B source. Due to the interaction observed between the sources and doses studied, when Boric Acid was used as the B source, the regression results showed that it fitted the quadratic model, altering the behavior of the data according to the source used. Regression analysis also proved significant for the grain yield in the two crop seasons, fitting the quadratic model on both occasions.

The comparative averages of the variables are shown in Tables 2 and 3 for the two crop seasons. B sources and doses did not influence plant height in the two crop seasons. Similarly, the first ear insertion height (FEH) (Table 3) was not influenced by the sources and doses in the two crop seasons. Jamami et al. (2006), evaluating different doses of boron in corn fertilization, reported that increasing the doses of B (0, 1, and 2 kg ha^{-1}) did not lead to an increase in the plant height, a result similar to that observed in this study.

Table 2. Mean squares of the variables analyzed in the 2019/2020 and 2020/2021 crop seasons.

2019/2020 crop season					
Variables	Mean square¹			Regression	
	Source	Dose	F x D	Linear	Quadratic
PH	0.0206 ns	0.0038 ns	0.0170 ns	0.007348 ns	0.00009 ns
FEH	0.0105 ns	0.0079 ns	0.0038 ns	0.02208 ns	0.00090 ns
EL	1.6204 ns	102.0568 ns	119.3645 *	165.315 *	212.664 *
NRG	1.7510 ns	1.0467 ns	0.5650 ns	2.81840 ns	0.23102 ns
NGR	7.9220 ns	2.2495 ns	6.2384 ns	0.3629 ns	5.7852 ns
1000W	2788.201 ns	1600.266 ns	1762.481 ns	2584.2 ns	2088.6 ns
YIELD	516980.3 *	174905.7 *	1154054.3 ns	2407205 ns	2826581 *
DF	2	3	6	-	-

2020/2021 crop season					
Variables	Mean square¹			Regression	
	Source	Dosage	F x D	Linear	Quadratic
PH	0.0113 ns	0.0222 ns	0.0094 ns	0.026062 ns	0.0172 ns
FEH	0.0029 ns	0.0025 ns	0.0023 ns	0.001037 ns	0.00312 ns
EL	22.7981 ns	79.6426 ns	81.7369 ns	198.024 ns	34,456 ns
NRG	2.0347 ns	0.9257 ns	0.1015 ns	0.90418 ns	1.80692 ns
NGR	4.1526 ns	3.4578 ns	4.8470 ns	3.6423 ns	0.8274 ns
1000W	2288.459 ns	3213.332 ns	2179.297 ns	8830.502 ns	2088.6 ns
YIELD	2314800.0 *	1234341.7 *	993800.0 ns	357282 ns	3297008 *
DF	2	3	6	-	-

ns = not significant, * significant at 5% by Tukey test. DF= degrees of freedom; PH= Plant height (m); FEH = First ear insertion height (m); EL = Ear length (mm); NRG = Number of grain rows per ear; NGR= Number of grains per row; 1000M= 1000-grain weight (g); YIELD= Grain yield (kg ha^{-1}).

Silva and Buso (2022) worked with 11 corn hybrids and observed that the plant height was 2.30 to 2.43 m, corroborating this research. The B levels in the soil (Table 1) met the crop needs during vegetative growth. For the number of grain rows per ear (Table 3), there was no influence of B sources and doses in both crop seasons. The number of grains per row (Table 3) was also not influenced by sources and doses in the two crop seasons. Dourado Neto et al. (2004), evaluating the B application in corn, also found no differences in the number of grain rows per ear. These authors also report that the application of B only increased the number of grains per row when 8.0 kg ha^{-1} of B was applied, reflecting the result found in this work since the doses studied here were lower than 8.0 kg ha^{-1} of B.

According to Table 3, the 1000-grain weight was not influenced by B sources and doses in both crop seasons. Contrary to these results, Anjum et al. (2017), studying to the application of B via soil and foliar application, observed an increase in the 1000-grain weight compared to the control with the application of 3.0 kg ha^{-1} of B in the soil. Silva and Buso (2020), who worked with B sources (boric acid, borax, and ulexite), found values ranging from 365.16 to 389.16 g for the sources used, and the regression analysis for the doses resulted in the highest 1000-grain weight with a dose of 1.74 kg ha^{-1} of B.

The boron sources influenced the grain yield in both crop seasons as we can observe in Table 3. In the first crop season, Ulexite stood out compared to the others, guaranteeing a 10.2% and 12.1% increase in grain yield compared to Borax and Boric Acid, respectively. In the second harvest, Ulexite was again superior to the other sources, increasing 11.08% and 9.27% compared to Borax and Boric Acid, respectively. Concerning the doses on grain yield, there was a difference between the doses in the first crop seasons, where the application of 1.5 kg ha^{-1} of B was superior, showing a 2.8% increase in grain yield compared to the control.

Similar results were found by Cruz et al. (2022), who, studying B doses via soil in the corn, reported a difference among the B doses in their studies, with the application of 3.0 kg ha^{-1} showing the highest grain yield (19.29% more than the control). In the second crop year, the doses of 0, 1.5, and 3.0 kg ha^{-1} did not differ for the grain yield, while the dose of 4.5 kg ha^{-1} provided the lowest grain yield, 4.00% lower than the control.

Table 3. Mean values for the variables analyzed in the 2019/2020 and 2020/2021 crop seasons.

2019/2020 crop season						
B source	PH	FEH	NRG	NGR	1000W	YIELD
Borax	2.31 a	1.31 a	15.33 a	34.62 a	288.00 a	8830.50 b
Boric Ac.	2.35 a	1.30 a	15.83 a	35.48 a	299.86 a	8681.00 b
Ulexite	2.38 a	1.35 a	15.21 a	36.02 a	314.36 a	9731.75 a
Dose (kg ha^{-1})						
0	2.33	1.28	15.22	34.86	303.26	9146.33
1.5	2.33	1.32	15.22	35.83	312.81	9401.50
3.0	2.36	1.33	15.56	35.61	301.86	9246.00
4.5	2.35	1.35	15.83	35.19	285.03	8530.50
CV (%)	3.68	7.10	7.27	6.64	10.71	9.84
2020/2021 crop season						
B source	PH	FEH	NRG	NGR	1000W	YIELD
Borax	1.87 a	1.02 a	14.79 a	33.21a	290.13 a	6363.75 b
Boric Ac.	1.91 a	1.02 a	14.08 a	32.71a	297.62 a	6468.75 ab
Ulexite	1.85 a	1.04 a	14.37 a	33.73a	313.55 a	7068.75 a
Dose (kg ha^{-1})						
0	1.94	1.03	14.44	32.56	308.78	6501.67
1.5	1.84	1.03	14.11	33.69	314.35	6891.67
3.0	1.88	1.05	14.33	33.00	301.38	6900.00
4.5	1.86	1.01	14.78	33.61	277.22	6241.67
CV (%)	6.08	8.32	7.43	12.58	16.58	11.0

Means followed by the same letter in the column do not differ at 5% probability by the Tukey test. PH = Plant height; FEH = First ear insertion height; NRG = Number of grain rows per ear; NGR = Number of grains per row; 1000W = 1000-grain weight; YIELD = Grain yield (kg ha^{-1}).

In the second crop year, the doses of 0, 1.5, and 3.0 kg ha^{-1} did not differ for the grain yield, while the dose of 4.5 kg ha^{-1} provided the lowest grain yield, 4.00% lower than the control. On the other hand, Nogueira et al. (2019) evaluated B doses (0, 1, 2, 3, and 4 kg ha^{-1}) applied to corn in the soil and found no effect of B doses on grain yield. During reproductive development, the B content in the soil was insufficient to meet the plant demand, so the doses of B promoted increased grain yield in the first crop season in the present study.

The negative effect observed in this study for doses above 3.0 kg ha^{-1} can be explained by the fact that corn is a crop that is sensitive to excess boron, with a narrow limit between requirement and toxicity of the nutrient, and it is possible to observe negative effects of phytotoxicity when the amount in the soil is above that required by the crop (Javorski et al., 2014). In the regression analysis of grain yield in the first crop season, a quadratic equation was fitted, where the dose of 1.6 kg ha^{-1} of B showed the highest grain yield, as shown in Figure 1. For the second year of the experiment, similarly, the regression analysis fitted the quadratic model for grain yield, where the application of 2.03 kg ha^{-1} resulted in the highest grain yield (Figure 2).

Based on the regression analysis results for grain yield, it was observed that in the first crop season, there was an increase in grain yield up to the dose of 1.6 kg ha^{-1}, with a subsequent decrease in the variable as the dose increased (Figure 1). In the second crop season, there was an increase up to the dose of 2.03 kg ha^{-1}, subsequently decreasing as the B dose increased (Figure 2). The corn crop need for B varies according to environmental conditions, but it is known that for every ton of grain produced, corn exports around 13 grams of B, and normally, the recommended doses of B for the crop are around 0.5 to 1.0 kg ha^{-1} (Javorski et al., 2015), values close to those found in this study.

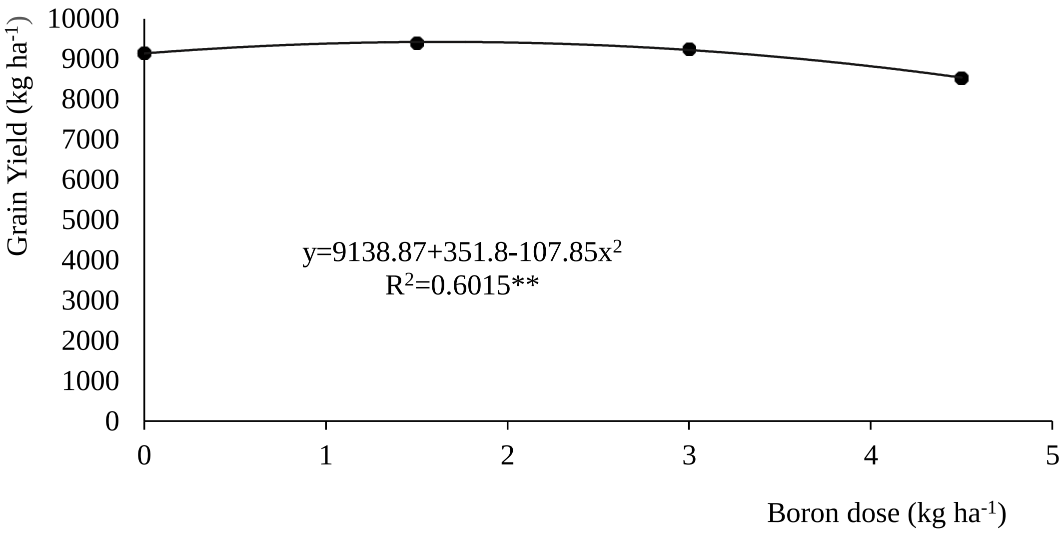

Figure 1. Grain yield (kg ha^{-1}) according to the B doses applied (kg ha^{-1}) in the 2019/2020 handcrop season.

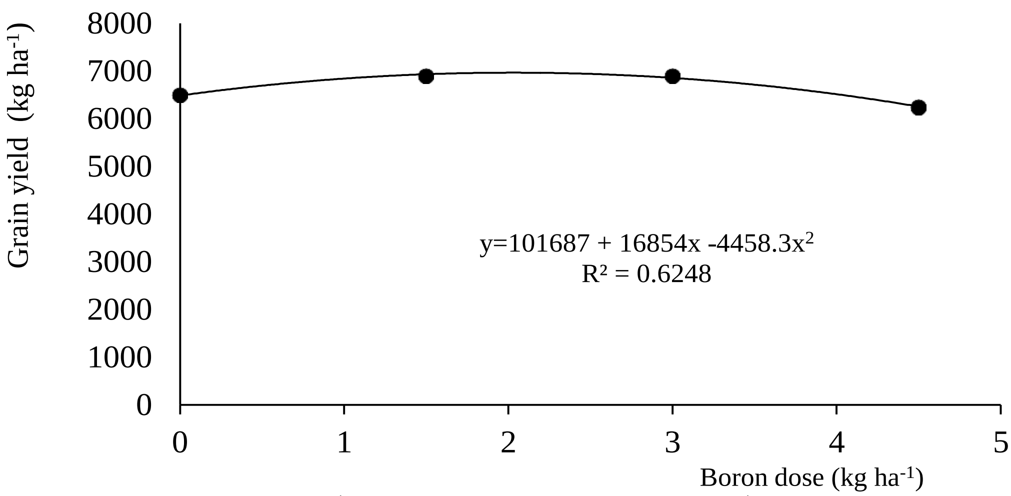

Figure 2. Grain yield (kg ha^{-1}) according to the B doses applied (kg ha^{-1}) in the 2020/2021 crop season.

There was a significant interaction between the source and dose factors for ear length (EL) in the first crop season (Table 4). Regarding the sources within each dose (Table 4), it was possible to see that the sources were similar, except when applying 1.5 kg ha^{-1} of B. In this dose, there was a difference among sources; Boric Acid showed superior results to the other sources when applying this dose.

The speed at which B is released differs between the sources analyzed. Boric acid is the source that releases the nutrient most quickly into the soil, followed by borax and ulexite, as it makes B available in the same form as it is absorbed by the plant (H_3BO_3) (Moura et al., 2021). According to Tomicioli et al. (2021), it is likely that boric acid made B available more quickly after sowing, before the plant defined the ear length, improving the nutritional status of the seedlings and consequently the formation and growth of the ears, since B plays a key role in the plant cell division.

Regarding the doses within each source (Table 4), it can be seen that there was no influence on the ear length when Borax was used as the B source. When boric acid was used, there was a difference between the doses, with an increase in ear length up to the dose of 1.5 kg ha^{-1}, which was 9.67% higher than the control. This may indicate that Boric acid is more efficient at supplying small doses of B, up to around 1.5 kg ha^{-1}, and that other sources of B should be sought when working with higher doses, as shown in Figure 3.

Figure 3 shows a difference in the behavior of the variable according to the B source. When Borax was used, the ear length increased in the same proportion as the dose of B was applied, however, when Boric acid was used to supply the nutrient, there was an increase in ear length up to a dose of 2.4 kg ha^{-1}, with a subsequent decrease as the B dose increased.

There was a difference between the doses of Ulexite. However, a more inconstant result can be seen in this case, where the value for ear length fluctuated as the Dose increased (Table 4). Jamami et al. (2006), studying the application of Boron doses to corn, also observed an influence on ear length, and the application of up to 2.0 kg ha^{-1} of the nutrient showed larger ears (151.0 mm). Cruz et al. (2022), studying B doses via soil (0, 1.0, 2.0, 3.0, 4.0, and 5.0 kg ha^{-1} of B) in corn, reported no effect of B doses on ear length.

Table 4. Interaction between the B source and dose mean values for ear length (mm) in the 2019/2020 crop season.

Dose (kg ha^{-1})	Source		
	Borax	Boric acid	Ulexite
0	153.75 a*	150.83 a	156.25 a
1.5	154.58 ab	165.42 a	152.92 b
3.0	159.58 a	156.25 a	166.25 a
4.5	161.67 a	156.25 a	155.83 ab
CV (%)		4.36%	

*Means followed by the same lowercase letter in the line do not differ at 5% probability by the Tukey test.

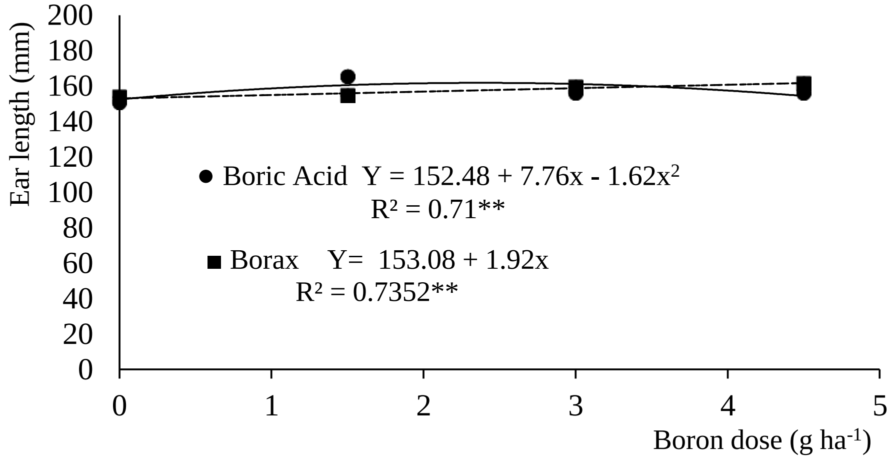

Figure 3. Ear length (mm) according to the B doses applied (kg ha^{-1}) in the 2019/2020 crop season.

4. Conclusions

Applying 2.4 kg ha^{-1} of B using boric acid as the source led to the greatest ear length in the first year. Ulexite as a B source in both crop seasons ensured higher grain yields. The application of 1.6 and 2.03 kg ha^{-1} of B provided the highest grain yield in the first and second crop seasons, respectively.

Authors' Contribution

Wytalo Oliveira Lopes contributed to implementing the experiment, collecting and tabulating the data, and writing the manuscript. Wilian Henrique Diniz Buso helped set up and conduct the experiment, reviewed the data and manuscript writing, analyzed the data, built the graphs, and advised the first author.

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