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# Use of boron sources and doses in the industrial tomato under irrigation

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Boron sources and doses can positively increase fruit quality and tomato yield. This study aimed to evaluate the influence of boron doses and sources on the development and yield of industrial tomatoes under irrigation. A randomized block design with four replications in a 3x4x2 factorial scheme was used. Three boron sources, boric acid, borax, and ulexite; four boron doses (0, 1, 2, and 3 kg/ha); and two locations, Goianésia, GO (AE I) and Vila Propício, GO (AE II) were evaluated. Stem diameter (SD), plant height (PH), the total number of fruits (TNF), the number of ripe fruits (NRF), the number of green fruits per plant (NGF), the number of lateral branches per plant (NLB), longitudinal fruit diameter (LFD), transversal fruit diameter (TFD), yield (YLD), total soluble solids content (°BRIX), pH, and titratable acidity (TA) were evaluated. There was no significant difference for the evaluated boron sources, while boron doses statistically influenced the increase in the TNF, NRF, °BRIX, and YLD. The dose of 1.23 kg $ha^{-1}$ provided the highest values of ºBRIX (4.75%). The dose of 1.89 kg/ha provided the highest yield (119001.5 kg/ha), regardless of sources and locations. Boron sources did not significantly affect tomato crops, so both can be used for the study conditions.
**Keywords:** Boric acid, borax, yield, *Solanum lycopersicum*, ulexite.

## INTRODUCTION

The tomato (*Solanum lycopersicum* L.) is a plant of the dicotyledon class, belonging to the Solanaceae family, genus *Solanum*, section *Lycopersicon*, order Tubiflorae, classified botanically as *Solanum lycopersicum* L. (Becker *et al*., 2016). The expansion of tomato cultivation in the country has increased yearly because the crop has a relatively short cycle, good economic prospects, and high yields in a short period, making it a vegetable of great economic importance in the world (Sousa *et al*., 2011). The availability of nutrients and water is directly linked to crop yield, directly affecting the commercial quality of the product, thus requiring more effective management of mineral nutrition and soil moisture (Smith and Hui, 2004; Macêdo and Alvarenga, 2005).
Although toxic in excess, boron (B) is essential in higher plants (Kot, 2009). It is an essential micronutrient for the growth and development of the tomato crop. It acts directly on the activity of cell membranes, the development of the pollen tube, protein and phenolic metabolism, and, mainly, the germination of pollen grains (Malavolta *et al*., 1997). Most sources of boron are quite soluble, showing greater mobility and leaching in the soil, thus increasing the demand for more controlled sources of solubility to reduce leaching (Mortvedt, 1994).
Boron deficiency is related to the reduction of pollen grain twinning, decreased fruits and internodes, smaller leaves, impediment of apical growth, fruit fall, and abortion of flower buds (Goldbach, 1997). According to Princi *et al*. (2016), the concentration range between boron deficiency and toxicity is narrow and depends on plant species. However, these extreme conditions severely reduce the yield and quality of crops worldwide (Tanaka *et al*., 2008).
Understanding the ideal dosage of boron to be applied to meet the needs of plants is essential for achieving good nutritional effectiveness and correcting micronutrient deficiency without promoting toxicity to plants (Gondim *et al*., 2014).
According to Marouelli *et al*. (2012), excess irrigation can contribute to the increase of crop diseases, thus requiring strategies that aim to supply water adequately for the crop, reducing problems related to environmental impacts and reducing energy expenses. Therefore, this study aimed to evaluate the influence of different sources and doses of boron in cultivating industrial tomatoes under irrigation by center pivot sprinkler.

## MATERIALS AND METHODS

The first experimental area was at the Jair Laje Farm, in Goianésia, GO, called Experimental Area I (AE I), with geographical coordinates 15°20'24.3" S, 49°08'37.9" W, and an altitude of 659 meters. The second experimental area,

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called Experimental Area II (AE II), was at Pivô da Vila Propício Farm, in Vila Propício, GO, with geographical coordinates 15°24'08.9 "S, 48°53'54.0" W, and altitude of 684 meters. The climate in both areas is classified as tropical savannah, hot and humid, with dry winter and rainy summer (Aw) according to Köppen-Geiger Climate Classification, and the annual rainfall average is 1500 mm. The soils are characterized as Latossolo Vermelho (Santos *et al*., 2018) or Oxisol (Soil Survey Staff, 2014) for both areas.

Chemical and physical analyses of soil samples from the experimental areas were conducted before the implementation of the experiments in the 0-20 cm layers, and the results are shown in Table 1.

Before transplanting the tomato seedlings, weed control was conducted in both experimental areas. Subsequently, the planting rows were opened and fertilized according to the soil analysis results. As fertilization, 1400 kg/ha of the NPK formulation 04:30:06 were applied in the planting rows, which resulted in 56 kg/ha of N, 420 kg/ha of $P_2O_5$, and 84 kg/ha of $K_2O$. The NPK formulation also had 7.6% Ca + 8.5% S + 5.4 $SO_4^{-2}$. Fertilization was done on the planting rows one week before transplanting the tomato seedlings. Crop management followed recommendations for tomato culture for industrial processing (Naika, 2006).

A randomized block design with four replications in a 3×4×2 factorial scheme was used. Three boron sources, boric acid ($H_3BO_3$) (17.48%B), borax ($Na_2B_4O_7.4H_2O$) (11.3%B), and ulexite ($CaNaB_5O_9.8H_2O$) (10%B); four boron doses (0, 1, 2 and 3 kg/ha); and two locations, Goianésia, GO (AE I) and Vila Propício, GO (AE II) were evaluated.

The tomato hybrid used was Heinz 9553, with concentrated maturation and determined growth, with full maturation from 110 to 120 days, according to Soares and Rangel (2012), one of the hybrids most used actually for industrial processing. Irrigation was performed by sprinkling using a center pivot sprinkler system.

The experimental plots comprised four tomato planting rows spaced 1.10 m between rows and 0.35 m between plants. Boron sources and doses were distributed in the four rows of each plot before transplanting the tomato seedlings into the field.

***Experimental area I (AE I)*:** The tomato seedlings were transplanted on April 16, 2018, when they had four fully expanded leaves. The transplant was done using tomato transplanter equipment with four transplant units. The spacing used was 1.10 m between rows and 0.35 m between plants. The harvest took place on August 5, 2018, and, in total, 433 mm of water was applied during the crop cycle. The final plant population was 24543 $ha^{-1}$.

***Experimental area II (AE II)*:** The tomato seedlings were transplanted on April 29, 2018, when they had four fully expanded leaves, using tomato transplanter equipment with four transplanting units. The spacing used was 1.10 m between rows and 0.35 m between plants. The harvest took place on August 18, 2018, and, in total, 441 mm of water were applied during the crop cycle. The final plant population was 26588 $ha^{-1}$.

For both areas, the center pivot sprinkler system was used. Irrigation was managed by tensiometers installed at 0 - 20 and 20 - 40 cm soil depths in the areas.

The evaluations of the matrix potential of the tensiometers were made daily, and the soil tension to determine the irrigation time was defined according to the stages of the tomato crop. Irrigation occurred whenever the average matrix potential of the soil was in the ranges of 70 kPa in the initial and vegetative stage (from1 to 32 days after planting (DAT), 30 kPa in the fruiting (from 33 to 87 DAT) and 70 kPa in the maturation stage (from 88 to 110 DAT), following recommendations by Marouelli *et al.* (1991). The irrigation depths were estimated based on the soil water retention curve and were calculated to raise the soil water content to the field capacity (tension of 10 kPa).

**Table 1. Chemical and physical characteristics of 0-20 cm soil layer from Experimental Area I (AE I) and Experimental Area II (AE II).**

| Areas | mmol$_c$ dm$^{-3}$ | | | | | mg dm$^{-3}$ | | |
|---|---|---|---|---|---|---|---|---|
| | **Ca** | **Mg** | **K** | **Al** | **H+Al** | **K** | **P(Mellich)** | **S** |
| AE I | 28.1 | 11.9 | - | 0.0 | 24.7 | 205 | 21.0 | 9.0 |
| AE II | 24.3 | 9.5 | - | 0.0 | 33.5 | 169 | 37.6 | 15.2 |
| | Micronutrients - mg dm$^{-3}$ | | | | | | | |
| | **Na** | **Co** | **Zn** | **B** | **Cu** | **Fe** | **Mn** | **Mo** |
| AE I | - | - | 1.6 | 0.25 | 4.8 | 27.5 | 4.78 | - |
| AE II | - | - | 4.58 | 0.47 | 8.16 | 48.2 | 4.10 | - |
| | **Particle size (g kg-1)** | | | **Complementary data** | | | | |
| | Clay | Silt | Sand | pH | S. Bases | CEC | O.M. (g kg-1) | |
| AE I | 406.0 | 66.0 | 528.0 | 5.5 | 65% | 6.73 | 23.0 | |
| AE II | 457.0 | 100.0 | 443.0 | 5.1 | 53% | 5.72 | 23.0 | |

$Ca^{2+}$ and $Mg^{2+}$ extracted with KCl 1 mol $L^{-1}$ pH 7.0; $Na^+$ and $K^+$ extracted using $NH_4OAc$ 1 mol $L^{-1}$ pH 7.0. Soil analysis conducted by the Unisolo laboratory – Goianésia – GO, 2018

The evaluations of the experiments were conducted in the two central rows of the plot, neglecting 0.5 m at the ends, and three plants were collected per plot. Stem diameter (SD) (mm), plant height (PH), the total number of fruits (TNF), the number of ripe fruits (NRF), the number of green fruits per plant (NGF), the number of lateral branches per plant (NLB), longitudinal fruit diameter (LFD), transversal fruit diameter (TFD), yield (YLD), total soluble solids content (°BRIX), pH, and titratable acidity (TA) were evaluated.

The data were subjected to analysis of variance, and the means were compared by the Tukey test at 5% probability. Regression equations for variables were adjusted according to boron doses. The analyses were performed with the R software, using the easyanova package (ARNHOLD, 2014).

## RESULTS

The summary of the analysis of variance is shown in Table 2, with values and significance of the mean square for the variables studied. There was a statistical difference between the locals ($p < 0.01$) for the variables PH, SD, and NLB. There was also a significant effect at 5% and 1% probability for TNF and NRF, respectively, for interactions involving doses. The local x source interaction influenced only the NGF, while the interaction between source x doses influenced the NRF.

For locations, there was a statistical difference in plant height (PH), and AE I had taller plants, higher 12.03% than AE II. PH was not statistically influenced by the application of boron sources and doses (Table 3).

For stem diameter (SD), a statistical difference was observed between locations, and AE I had plants with stem diameters 16.6% higher than AE II. Boron sources and doses did not influence stem diameter (SD) (Table 3).

Regarding the number of lateral branches per plant (NLB), there was a statistical difference between locations, and NLB in AE I was 13.9% higher than in AE II. The NLB was not statistically influenced by the application of boron sources and doses (Table 3).

**Table 3. Plant height (PH), stem diameter (SD), number of lateral branches per plant (NLB), number of total fruits per plant (TNF), number of ripe fruits per plant (NRF), and number of green fruits per plant (NGF) of the industrial tomato under irrigation in different locations, with boron sources and doses, from April to August 2018.**

| Boron sources | PH (m) | SD (mm) | NLB | TNF |
|---|---|---|---|---|
| Boric acid | 1.41a | 12.83a | 6.00a | 91.66a |
| Borax | 1.42a | 13.06a | 5.53a | 82.66a |
| Ulexite | 1.41a | 12.67a | 5.78a | 88.34a |
| Boron doses | | | | |
| 0.0 kg/ha | 1.38 | 12.85 | 5.54 | 81.29 |
| 1.0 kg/ha | 1.43 | 13.16 | 5.83 | 86.75 |
| 2.0 kg/ha | 1.42 | 12.74 | 5.79 | 84.42 |
| 3.0 kg/ha | 1.42 | 12.67 | 5.92 | 97.75 |
| Location | | | | |
| AE I | 1.49a | 13.84a | 6.15a | 88.96a |
| AE II | 1.33b | 11.87b | 5.40b | 86.15a |

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

The averages from the interaction between locations x boron sources for the number of green fruits per plant (NGF) are shown in Table 4. There was a statistical difference for boron sources in AE I, and the lowest NGF (14.43) was observed when ulexite was used as a boron source. In AE II, no statistical difference existed among the boron sources for NGF. About the sources within each location, a significant difference was found only for the boric acid source in AE II, which had the lowest NGF (17.87). There was no difference

**Table 2. Summary of analysis of variance with the values and significance of mean squares for the effects of locations, boron sources, and doses for plant height (PH), stem diameter (SD), number of lateral branches per plant (NLB), number of ripe fruits per plant (NRF), and number of green fruit per plant (NGF) of industrial tomato under irrigation, from April to August 2018.**

| Source of variation | Mean square | | | | | | |
|---|---|---|---|---|---|---|---|
| | DF | PH | SD | NLB | TNF | NRF | NGF |
| Location | 1 | 0.547‡ | 91.635‡ | 13.500‡ | 189.843$^{ns}$ | 20.166$^{ns}$ | 30.375$^{ns}$ |
| Boron sources (BS) | 2 | 0.001$^{ns}$ | 1.256$^{ns}$ | 1.760$^{ns}$ | 663.041$^{ns}$ | 129.781$^{ns}$ | 136.572$^{ns}$ |
| Boron doses | 3 | 0.010$^{ns}$ | 1.130$^{ns}$ | 0.625$^{ns}$ | 1229.316† | 559.388‡ | 43.902$^{ns}$ |
| Location×BS | 2 | 0.017$^{ns}$ | 1.977$^{ns}$ | 0.031$^{ns}$ | 703.625$^{ns}$ | 262.197$^{ns}$ | 88.156† |
| Location×Doses | 3 | 0.004$^{ns}$ | 4.232$^{ns}$ | 0.194$^{ns}$ | 626.899$^{ns}$ | 230.500$^{ns}$ | 6.791$^{ns}$ |
| Sources×Doses | 6 | 0.006$^{ns}$ | 0.831$^{ns}$ | 0.552$^{ns}$ | 283.097$^{ns}$ | 248.753‡ | 33.225$^{ns}$ |
| Location×BS×Doses | 6 | 0.013$^{ns}$ | 0.853$^{ns}$ | 1.184$^{ns}$ | 129.680$^{ns}$ | 147.531$^{ns}$ | 24.364$^{ns}$ |
| Block | 3 | 0.020$^{ns}$ | 1.429$^{ns}$ | 1.069$^{ns}$ | 95.093$^{ns}$ | 129.083$^{ns}$ | 4.513$^{ns}$ |
| Error | 69 | 0.012 | 1.485 | 0.721 | 401.767 | 102.344 | 20.492 |
| CV (%) | | 8.03 | 9.47 | 14.72 | 22.89 | 15.30 | 25.71 |

$^{ns}$ Not significant, † Significant at 5% probability by the F test. ‡ Significant at 1% probability by the F test.

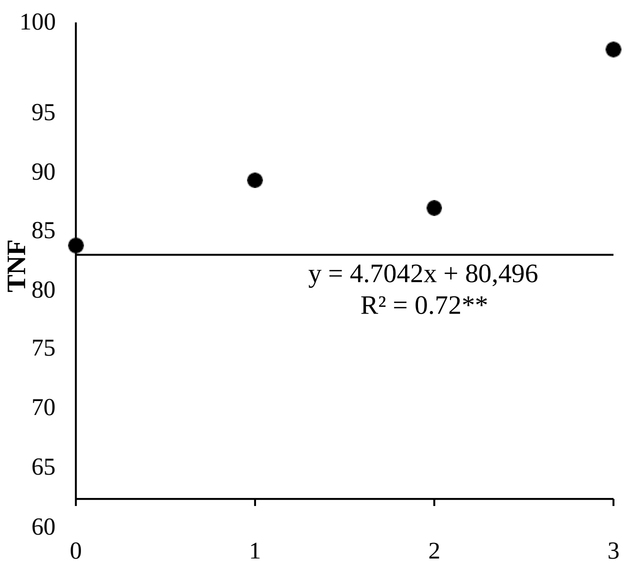
between locations for the total number of fruits (TNF). Also, the influence of boron sources on the total number of fruits was not observed (Table 3).

**Table 4. Number of green fruits per plant (NGF) of industrial tomato under irrigation processing according to different locations and boron sources, regardless of doses, from April to August 2018.**

| Boron sources | Location | |
|---|---|---|
| | **AE I** | **AE II** |
| Boric acid | 21.75 aA | 17.87 aB |
| Borax | 18.31 aA | 16.25 aA |
| Ulexite | 14.43 bA | 17.00 aA |

Means followed by the same uppercase letter in the line and lowercase letters in the column do not differ by the Tukey test at 5% probability.

There was a statistical difference for boron doses, and the dose of 0 kg/ha had the lowest TNF (81.29) compared to the other doses (1, 2, and 3 kg/ha), which had averages of 86.75, 84.42, and 97.75, respectively. The increase in boron doses applied to the plants had significant effects ($p < 0.05$) on the total number of fruits of the industrial tomato, adjusting to the increasing linear model according to the regression equation (Figure 1).




**Boron (kg/ha)**

**Figure 1. Total number of fruits per plant (TNF) of industrial tomato under irrigation according to the application of boron doses, regardless of location and sources, from April to August 2018.**

For the variable number of ripe fruits per plant (NRF), there was a statistical difference for locations, and it was found AE

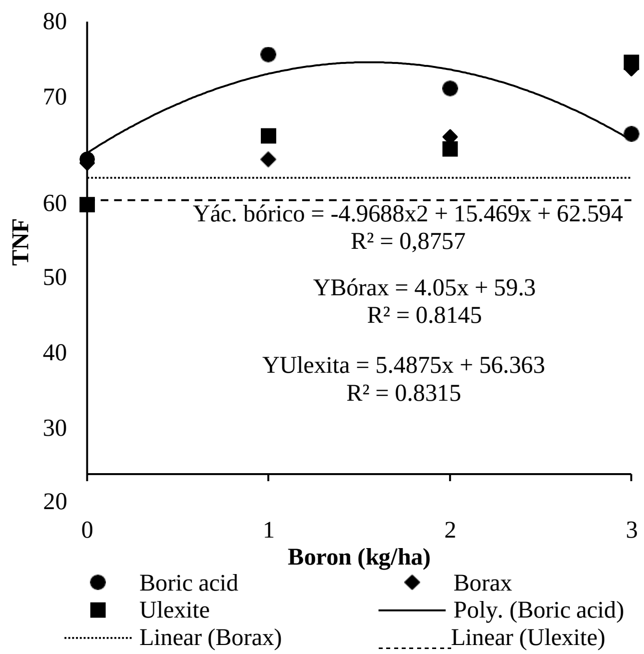
Regarding the effect of the sources with the application of each boron dose, there was a statistical difference only in the dose of 1 kg/ha (Table 5).

**Table 5. Number of ripe fruits per plant (NRF) of industrial tomato under irrigation according to different boron sources and doses, regardless of locations, from April to August 2018.**

| Doses (kg/ha) | Sources | | |
|---|---|---|---|
| | **Boric acid** | **Borax** | **Ulexite** |
| 0 | 61.75 bA | 61.25 aA | 55.75 bA |
| 1 | 75.63 aA | 61.75 aB | 64.88 abAB |
| 2 | 71.12 abA | 64.75 aA | 63.13 abA |
| 3 | 65.13 abA | 73.75 aA | 76.63 aA |

Means followed by the same uppercase letter in the line and lowercase letters in the column do not differ by the Tukey test at 5% probability.

The number of ripe fruits of the industrial tomato showed an increasing linear response for borax and ulexite sources, increasing the number of ripe fruits per plant as the boron dose increased, thus presenting maximum responses of 73.75 and 74.63, respectively (Figure 2).




I had NRF 1.4% higher than AE II. The source x dose interaction had a significant effect ($p < 0.05$) on the NRF.

**Figure 2. Number of ripe tomato fruits per plant (NRF) according to the doses of three boron sources, regardless of location, from April to August 2018.**

The summary of the analysis of variance with values and significance of mean squares for the end-of-cycle variables, longitudinal fruit diameter (LFD), transversal fruit diameter (TFD), total soluble solids content (°BRIX), hydrogenionic

**Table 6. Summary of analysis of variance with the values and significance of mean squares for the effects of locations, boron sources, and doses for longitudinal fruit diameter (LFD), transversal fruit diameter (TFD), total soluble solids (°BRIX), hydrogenionic potential (pH), titratable acidity (TA), and yield (YLD) of industrial tomato under irrigation, from April to August 2018.**

| Source of variation | Mean square | | | | | | |
|---|---|---|---|---|---|---|---|
| | DF | LFD | TFD | °BRIX | pH | TA | YLD |
| Location | 1 | 628.838‡ | 94.962† | 1.815† | 0.198‡ | 0.001803‡ | 9100592.61† |
| Boron sources (BS) | 2 | 5.753$^{ns}$ | 5.539$^{ns}$ | 0.568$^{ns}$ | 0.010$^{ns}$ | 0.000073$^{ns}$ | 2602477.40$^{ns}$ |
| Boron doses | 3 | 3.461$^{ns}$ | 6.822$^{ns}$ | 0.980† | 0.011$^{ns}$ | 0.000163$^{ns}$ | 1550295.79‡ |
| Location×BS | 2 | 2.447$^{ns}$ | 1.189$^{ns}$ | 0.290$^{ns}$ | 0.043† | 0.000021$^{ns}$ | 1983371.96$^{ns}$ |
| Location×Doses | 3 | 9.354$^{ns}$ | 6.197$^{ns}$ | 0.233$^{ns}$ | 0.006$^{ns}$ | 0.000028$^{ns}$ | 8509700.00$^{ns}$ |
| BS×Doses | 6 | 10.826$^{ns}$ | 9.024$^{ns}$ | 0.089$^{ns}$ | 0.010$^{ns}$ | 0.000070$^{ns}$ | 6368510.80$^{ns}$ |
| Location×BS×Doses | 6 | 9.683$^{ns}$ | 5.473$^{ns}$ | 0.196$^{ns}$ | 0.024$^{ns}$ | 0.000070$^{ns}$ | 2644392.28$^{ns}$ |
| Block | 3 | 9.744$^{ns}$ | 6.488$^{ns}$ | 0.133$^{ns}$ | 0.007$^{ns}$ | 0.000022$^{ns}$ | 1325752.78$^{ns}$ |
| Error | 69 | 8.032 | 9.992 | 0.26 | 0.010 | 0.000061 | 1604119.78 |
| CV (%) | | 4.690 | 6.790 | 11.27 | 2.100 | 19.42 | 11.37 |

$^{ns}$ Not significant, † Significant at 5% probability by the F test. ‡ Significant at 1% probability by the F test.

**Table 7. Longitudinal fruit diameter (LFD), transversal fruit diameter (TFD), total soluble solids content (°BRIX), hydrogenionic potential (pH), titratable acidity (TA), and yield (YLD) of the industrial tomato under irrigation, in different locations, with boron sources and doses, from April to August 2018.**

| Boron source | LFD (mm) | TFD (mm) | pH | TA (%) | °BRIX (%) | YLD (kg/ha) |
|---|---|---|---|---|---|---|
| Boric acid | 60.95a | 46.79a | 4.82a | 0.039a | 4.50a | 111834.6a |
| Borax | 60.42a | 46.07a | 4.67a | 0.040a | 4.67a | 110323.2a |
| Ulexite | 60.11a | 46.79a | 4.79a | 0.042a | 4.41a | 111931.3a |
| Boron dose | | | | | | |
| 0.0 kg/ha | 60.65 | 46.85 | 4.81 | 0.042 | 4.53 | 100047.1 |
| 1.0 kg/ha | 60.37 | 46.36 | 4.80 | 0.037 | 4.56 | 119001.5 |
| 2.0 kg/ha | 60.92 | 47.09 | 4.80 | 0.041 | 4.75 | 112641.2 |
| 3.0 kg/ha | 60.03 | 45.89 | 4.84 | 0.041 | 4.26 | 113762.3 |
| Locations | | | | | | |
| AE I | 63.05a | 47.54a | 4.89a | 0.044a | 4.66a | 114442.0a |
| AE II | 57.93b | 45.55b | 4.76b | 0.036b | 4.39b | 108284.1b |

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

potential (pH), titratable acidity (TA), and yield (YLD) are shown in Table 6. It was observed that the locations influenced all variables, at 1% probability for LFD, pH, and TA; and at 5% probability for TFD, °BRIX, and YLD. There was also a statistical effect for regressions according to the boron doses for the °BRIX. The local x source interaction was significant for the pH variable. In other interactions, no significant effects were observed.

A statistical difference was observed between locations about the longitudinal diameter of fruits (LDF). AE I had fruits with LFD 8.8% higher than AE II. The applications of boron sources and doses did not influence LDF (Table 7).

Statistical difference was observed between the locations for the transversal diameter of fruits (TFD), and AE I had TFD 4.4% higher than AE II. The boron sources and doses did not influence the transversal fruit diameter (TFD), with no statistical difference for this variable (Table 7). There was a statistical difference between locations for the soluble solids content (°BRIX).

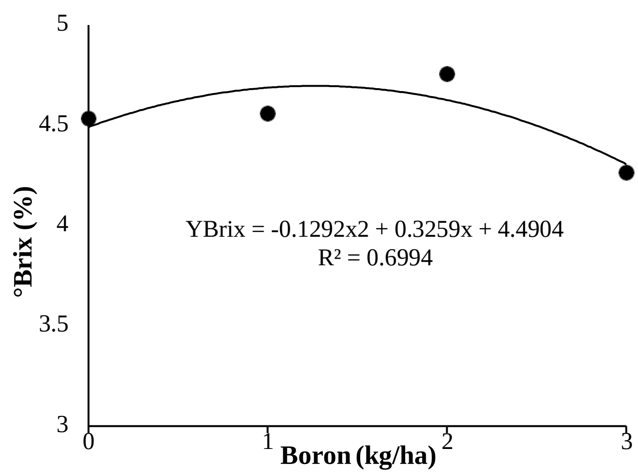



**Figure 3. Total soluble solids content (°BRIX) of industrial tomato under irrigation according to the application of boron doses, regardless of location and sources, from April to August 2018.**

The ºBRIX in AE I was 6.2% higher than AE II. The boron sources did not influence the °BRIX (Table 7). The boron doses influenced the soluble solids content ($p<0.05$).
The maximum percentage of °BRIX of the fruits (4.69%) was estimated at a dose of 1.26 kg $ha^{-1}$. The model that best represented the results was the quadratic model (Figure 3).
The evaluation of the interaction between location x source on the hydrogenionic potential (pH) variable of tomato fruits is presented in Table 8.

**Table 8. Hydrogenionic potential (pH) of industrial tomato under irrigation according to different locations and boron sources, regardless of doses, from April to August 2018.**

| Boron source | Location | |
|---|---|---|
| | AE I | AE II |
| Boric acid | 4.89 aA | 4.76 abB |
| Borax | 4.82 aA | 4.82 aA |
| Ulexite | 4.86 aA | 4.73 bB |

Means followed by the same uppercase letter in the column and lowercase letters in the line do not differ by the Tukey test, at 5% probability.

About yield (YLD), there was a statistical difference between locations, and the tomato yield of AE I (114442.0 kg/ha) was 5.7% higher than AE II (108284.1 kg/ha). The fruit yield was not statistically influenced by applying different sources of boron (Table 7). Boron doses significantly influenced ($p<0.05$) the tomato yield. The model that best fitted for yield was the quadratic model (Figure 4).

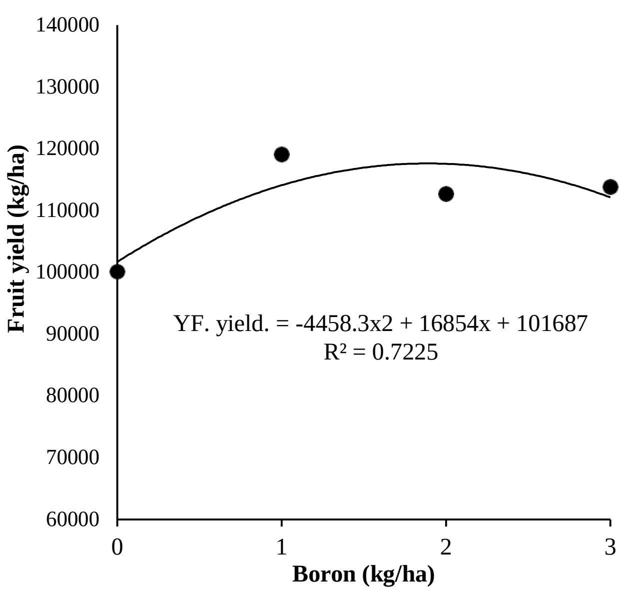



**Figure 4. Fruit yield (kg/ha) of industrial tomato under irrigation according to the application of boron doses, regardless of location and sources, from April to August 2018.**

**DISCUSSION**

According to Porto *et al*. (2014), evaluating the PH attribute is important to verify the responses of plants to the crop management used and, consequently, their yield potential (Table 3).
In an experiment under field conditions, Rashid *et al*. (2017) evaluated the influence of five doses of boron (0, 0.5, 1.0, 1.5, and 2.0 kg/ha) with boric acid as the source. The applications were made at the flowering stage of the crop. The authors observed a significant difference in plant height. The application of 1.5 kg/ha resulted in the highest mean for plant height (63.87 cm). Osman *et al*. (2019) evaluated the effect of boron on tomato growth and yield, and in this study, the authors applied three boron doses (0, 1, and 2 kg/ha) on the crop. Plant height was significantly different, ranging from 82.40 to 100.98 cm, from the lowest to the highest dose applied. Mallick *et al*. (2020), evaluating the application of boron doses (2.0 and 3.0 kg/ha) using boric acid as a source, observed a significant increase in plant height. The authors found that the application of 3.0 kg/ha resulted in the tallest plants (94.83 cm).
According to Mazzoni-Viveiros and Trufem (2004), a larger stem diameter (Table 3) can allow plants to translocate more water and nutrients to the shoot, which will be used in photosynthesis, vegetative growth, metabolic processes, and biomass accumulation of plants.
Osman *et al*. (2019) studied the effect of boron on tomato crops. Three doses of boron (0, 1, and 2 kg/ha) were applied using boric acid as a source. The authors found a significant increase in NLB (17.14) with 2 kg/ha of boron application. Rab and Haq (2012), studying boron doses of 0, 0.2, and 0.4 kg/ha, also reported an increase in NLB (6.41) with the application of boron at a dose of 0.2 kg/ha on tomato plants. Mallick *et al*. (2020), studying the application of boron doses (2.0 and 3.0 kg/ha), did not find a significant increase in NLB in tomato plants (Table 3).
It is observed that, as the boron dose was increased, the number of total fruits per plant increased up to 3 kg/ha of boron, with an increase of 17.52% concerning the dose of 0 kg/ha (Figure 1). Rab and Haq (2012) found a significant increase in TNF with a dose of 4.0 kg/ha of boron, with 82.84 fruits per plant. Ejaz *et al*. (2011) also found results that showed boron efficiency in increasing TNF. Haleema *et al*. (2018) found that the application of boron resulted in a higher number of fruits per plant. The authors evaluated three doses of boron (0, 2.5, and 5.0 kg/ha) and reported that the highest TNF occurred when the dose of 2.5 kg/ha was used, with an average of 88.14 fruits per plant. Davis *et al*. (2003) observed an increase in TNF with the increase in the application of boron doses. This was explained by the fact that the boron participates in active photosynthesis, contributing to the increase in weight and the number of fruits per plant (Kumar and Sen, 2005). Boron may be able to provide a higher

number of branches, and this, according to Portes (1996), may contribute to the increase of the number of reproductive structures capable of increasing TNF.

The increments from the control to the maximum dose were 20.5 and 29.2% for borax and ulexite sources, respectively. For the boric acid source, the data were adjusted to the quadratic model. The maximum response (75.63 ripe fruits) was obtained when the dose of 1.56 kg/ha of boron was applied, corresponding to an increase of 22.47% concerning the control. The higher than 1.56 kg/ha of boric acid caused a reduction in NRF (Table 5 and Figure 2). Zamban *et al*. (2018), evaluating the effects of boron doses (0, 2, and 4 $g^{-1}$) applied via soil in cultivars of Italian tomato, also reported that boron doses increased NRF. According to Desouky *et al*. (2009), boron actively improves fruit quality because it is associated with fruit ripening and genetic activity, showing importance in the physiological role and the mechanisms of nutrition in fruit development. It also benefits the production and retention of flowers and, consequently, greater development of seeds and fruits (Hanson, 1991; Xu *et al*., 2001).

According to Penteado (2004), the diameter of the fruits (Table 7) is a genetic characteristic of the plant. It can be influenced mainly by the spacing, the number of floral clusters on the plant, and fruit pruning. The availability of water is also a factor that can promote changes in the transverse and longitudinal diameter of the fruits, especially under conditions of water deficiency, when there may be a reduction in the rate of cell division and elongation, resulting in less expansion of the cell wall (Silva *et al*., 2013; Taiz and Zeiger, 2013). Rashid *et al*. (2017), evaluating the influence of boron, using five doses (0, 0.5, 1.0, 1.5, and 2.0 kg/ha), observed a significant difference for longitudinal fruit diameter (LFD). The best results were observed in the dose of 1.0 kg/ha, with an LFD of 50.7 mm. As for the transversal fruit diameter (TFD), the same authors found no statistical difference, with the averages ranging from 40.87 to 40.98 mm. Osman *et al*. (2019) found a difference in these variables. The authors used three boron doses (0, 1, and 2 kg/ha) using boric acid as a source. For LFD, the highest result was 90.53 mm at a dose of 2 kg/ha, while for TFD, 60.97 mm was observed at 2 kg/ha. Mallick *et al*. (2020), studying boron doses (2.0 and 3.0 kg/ha) in the tomato crop, verified an increase in the attributes TFD and LFD. In the study, the authors observed that using 2.0 kg/ha of boron resulted in the highest TFD (4.2 cm) and LFD (5.29 cm) in tomato fruits.

There was a significant difference between locations for the hydrogenionic potential (pH); the averages were 4.87 and 4.77 from AE I to AE II, respectively. Regarding titratable acidity (TA), a significant difference was also observed between the studied locations, and means of 0.044% and 0.036% in AE I and AE II were observed, respectively. There was no statistical difference for the pH and TA attributes with the application of boron sources and doses (Table 7). It is noted that the boron sources evaluated did not influence these characteristics of tomato fruits. Ramos *et al*. (2013) point out that TA can be influenced by agronomic practices, such as irrigation and fertilization, besides the climatic conditions and maturation stage.

Harris and Lavanya (2016), evaluating the efficiency of boron concentrations in the tomato crop (150, 250, and 350 mg $dm^{-3}$), found significant effects on the pH of the fruits, which varied from 4.18 to 4.63, with the highest values found in the highest doses. The same authors also found a significant difference in the TA (Table 7) variable, ranging from 0.43 to 0.73ºBrix. According to Coimbra (2014), TA measures the quantities of organic acids in the fruit, indicating its astringency, which directly influences its flavor and energy expenditure during processing operations, such as pulp concentration and sterilization. Fruits with a TA higher than 0.032% are considered good quality (Kader *et al*., 2002). Thus, the results of TA found in the present study are within the standards of adequate quality of the fruits.

The quadratic model (Figure 3) estimed boron dose de 1,23 kg/ha promotec highest °BRIX. Harris and Lavanya (2016) evaluated the efficiency of different boron concentrations in the tomato crop (150, 250, and 350 mg $dm^{-3}$), and they found that the applications significantly influenced the °BRIX of the tomato. The best result was 6.0%, found at a dose of 150 mg $dm^{-3}$. According to Ali *et al*. (2004), the total soluble solids content is considered one of the main fruit quality variables. The ideal is for °BRIX values to be higher than 5.0%, ensuring a greater yield in fruit industrialization (Cemeroglu *et al*., 2003; Melo and Vilela, 2005). According to Silva and Giordano (2000), for each °BRIX degree of increase in the raw material, there is an increase of 20% in the industrial yield. According to Reid (2014), boron is an essential element in plants having several functions such as the formation of cell walls, sugar transport, and plasma membrane stability, among others not yet known. According to Jyolsna *et al*. (2008), this micronutrient has an important role in increasing the °BRIX quality of tomato fruits. Ullah *et al*. (2015), evaluating the yield and growth of tomato submitted to four doses of boron (0, 0.5, 1.0, and 1.5 kg/ha), also found similar results, with °BRIX of 5.47%, at a dose of 0.05 kg/ha.

Marschner (1995) reports that boron helps in the vascular movement of the carbohydrate, contributing to the increase in the °BRIX of the fruits. The main cultivars of tomatoes used for processing have a high content of soluble solids, which improves the characteristics of the final products (Moelants *et al*., 2013).

In AE I, the results were similar, with no statistical difference between the sources used. There was a statistical difference for AE II, and the highest pH (4.82) value was found with the borax source. About the sources between locations, there was a statistical difference only for the ulexite source, which had a higher pH in AE I (4.73) than AE II (Table 8). When ulexite was used, the pH was closer to that recommended by the literature. According to Monteiro *et al*. (2008), pH is an intrinsic factor of food, capable of affecting the ability of microorganisms to survive or grow. It should be between 4.0 and 4.5, as in these conditions, there is an impediment to the proliferation of microorganisms in the concentrated tomato pulp during storage (Azeredo, 2012)

The maximum yield (119001.5 kg/ha) was estimated at the dose of 1.89 kg/ha, evidencing that fruit yield is also associated with fertilization with boron in the tomato crop (Figure 4). The increase in yield at the optimal dose was 15.66% concerning the control. Note that yield decreased in doses higher than optimal as boron doses increased. Rashid *et al*. (2017) evaluated the influence of five boron doses (0, 0.5, 1.0, 1.5, and 2.0 kg/ha) on tomato, and they observed a significant difference in tomato yield, which reached 101.4 t $ha^{-1}$ at a dose of 1.5 kg/ha. Osman *et al*. (2019) developed a study to evaluate the influence of boric acid doses (0, 1, and 2 kg/ha) on tomato plants. They observed that applying 2 kg/ha boron resulted in the highest yield, reaching 79.2 t $ha^{-1}$. Chand and Prasad *et al*. (2017) evaluated the yield and quality of tomato fruits grown with different doses of boron and zinc. The authors observed that the yield had a significant difference with boron (0, 100, and 150 mg $dm^{-3}$), the Gurmani *et al*. (2012) and Ullah *et al*. (2015) also observed a positive influence of boron doses on tomato yield. According to Sakamoto (2012), the deficiency or excess of boron levels can significantly compromise the development of plants, leading to a reduction in the quality and yield of crops. Boron is of great importance in the development and yield of plants, influencing the absorption rate and use of other essential elements (Mello *et al*., 2002).

***Conclusions*:** The boron dose of 1.23 kg/ha results in higher values (4.75%) of ° brix under the study conditions. The boron dose of 1.89 kg/ha promoted the highest fruit yield (119001.5 kg/ha) under the study conditions, regardless of sources and location. Boron sources do not have significant effects on tomato crops; therefore, for the conditions of the study, both can be used.

***conflict of interest*:** No conflicts of interest

***Author's contribution*:** Rafael Matias da Silva contributed to the installation of the experiment, data collection and tabulation, and manuscript writing. Roriz Luciano Machado performed the corrections of data and manuscript writing and checked the manuscript guidelines. Wilian Henrique Diniz Buso assisted in the installation of the experiment, carried out the data analysis and graph preparation, and guided the first author of the manuscript.

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