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Borate Application at Different Phenological Stages in Sunflower Cultivation

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Abstract

Boron (B) is important for the nutrition and development of sunflower crops because of the damage that its deficiency can cause in plants, compromising the final crop productivity. This work aimed to evaluate the application of B doses at different phenological stages of the sunflower crop. The project was conducted in the experimental area of the Goiás State University, Campus of Ipameri, located in Ipameri-GO, in a randomized block design, arranged in a 2 x 5 x 6 factorial scheme, with four replications. The factors consisted of crop seasons (2017 and 2018), application at different phenological stages (V0, V6, V18, R1, and R3), and B doses (0, 1, 2, 3, 4, and 5 kg ha^{-1}), respectively. In each crop season, leaf boron content, relative chlorophyll index, plant height, stem diameter, capitulum diameter, capitulum mass, number of achenes per capitulum, 1000-achene weight, and achene yield were assessed. The use of doses between 3.38 and 3.74 Kg ha^{-1} of B influenced the characteristics of leaf boron content, plant height, and 1000-achene weight. Most of the parameters assessed, including crop yield, were influenced by crop seasons due to rainfall distribution during the crop cycle. The 2017 off-season had the best results.

Keywords: boron, *helianthus annuus* L., nutrition, productivity

1. Introduction

Sunflower is used for various purposes, such as animal feed and vegetable oil for human consumption, and is also a promising source for biodiesel production. This makes the crop important for the country's economy and, consequently, the one chosen by producers due to its demand. The crop's high yield and genetic improvement are linked to essential factors such as soil fertility and plant nutrition.

According to the 12th CONAB survey (2018), the national area for the 2016/2017 crop season was 62,700 hectares, the average yield was 1,702 kg ha^{-1}, and the national production was 103,700 tons. For the 2017/2018 crop season, there was a 52.3% variation in the area planted compared to the 2016/2017 crop season, with 95,500 hectares being cultivated, the average yield was 1,489 kg ha^{-1}, and national production increased by 37.1%, producing 142,200 tons. The state of Goiás is responsible for 24,000 tons of this national production.

In Brazil, sunflower is grown in different regions with diverse soil and climate conditions. Although the crop stands out for its broad capacity to adapt to different environments and for its hardiness (Poelking et al., 2018), it is necessary to pay attention to the factors that intervene in sunflower production and quality, including mineral nutrition, involving the balanced supply of nutrients, both via soil and foliar fertilization (Martins et al., 2014).

In the sunflower crop, the greatest absorption of nutrients and water occurs in the period from the emission of the flower bud until full bloom, stage R5.5 (Castro & Oliveira, 2005). This period is important for the plants' yield potential (Hocking & Steer, 1983). As for boron, the requirements are greater for the reproductive process than for the vegetative growth of plants (Faquin, 1994).

Sunflower plants are highly demanding of boron (B), and it has been used as an indicator to assess the availability of B in the soil (Oyinlola, 2007). This nutrient is essential for plant development, flowering, and achene formation. Among the functions performed by boron are the translocation of sugar and anion, absorption of cations, nitrogen, phosphorus, and carbohydrates, lipid metabolism, the formation of cell walls, cell division, pollen germination, and fruiting (Fageria et al., 2002; Al-Amery et al., 2011), thus highlighting the importance of studies aimed at the boron requirements of the sunflower crop.

Boron deficiency also causes a reduction in leaf area, with the development of brittle, small, and thick leaves, and in some cases, there may be an accumulation of nitrogen compounds in the older parts, reduced root growth, and flower abortion (Dechen & Nachtigall, 2006). Several factors influence the absorption and availability of boron in the soil, including the plant root system and its ability to exploit it, water availability, and climatic conditions. Thus, proper fertilization ensures that crop needs are met, plants develop, and yield is high.

Micronutrient applications often do not follow the variables determined according to the foliar and soil analysis results and may not maximize the responses to fertilizer application (Kappes et al., 2008). The analyses provide the correct recommendation, implying better absorption of the nutrients in their relationships, thus reducing toxicity risks due to excessive fertilizer use or deficiency due to lack of correct fertilization (Leite, 2018). Thus, applying micronutrients via soil aims to increase their content in the soil solution, allowing them to be absorbed by the plants.

Given the importance of boron for the nutrition and development of the sunflower crop, and considering the damage that boron deficiency can cause to plants, compromising the final yield of the crop and the high capacity for recycling nutrients absorbed in depth by the sunflower crop, it is essential to know the nutritional needs of plants (Santos et al., 2010). This study aimed to evaluate the application of boron doses at different phenological stages of the sunflower crop.

2. Materials and Methods

2.1 Location and Installation of the Experiment

The experiment was conducted during the off-season of 2017 and 2018, under agricultural zoning, in the experimental area of the Goiás State University, Campus of Ipameri, located in Ipameri-GO, whose geographical coordinates for 2017 were 17º42'40" S and 48º 08'13" W, and 2018, 17º43'04" S and 48º 07'55" W, with an average altitude of 759 m. The region climate, according to the Köppen Geiger classification (Cardoso et al., 2014), is defined as a tropical climate (Aw-type) with a dry season in winter.

The soil in the experimental area was described as LATOSSOLO VERMELHO Amarelo distrófico (Santos et al., 2013). The soil chemical and physical characteristics were determined before the experiment was set up and showed the following chemical attribute values in the 0.0-0.20 layer for the experiment in 2017: 9.3 mg dm^{-3} of P (Melich); 17.1g dm^{-3} O.M.; 6.20 pH ($CaCl_2$); 0.26 K; 2.40 Ca; 0.90 Mg, and 1.70 H+Al cmol$_c$ dm^{-3}, respectively, 67.7% base saturation and the B content was 0.20 mg dm^{-3}, which is considered low in the soil. The particle size analysis of the soil had the following results: 475, 75, and 450 g of clay, silt, and sand, respectively. For 2018, the chemical attributes of the area in the 0.0-0.20 layer were: 8.1 mg dm^{-3} of P (Melich); 21.0 g dm^{-3} of O.M.; 6.3 pH ($CaCl_2$); 0.13 K; 3.4 Ca; 0.8 Mg, and 1.4 H+Al cmol$_c$ dm^{-3}, respectively, 75.9% base saturation and the B content was 0.23 mg dm^{-3}, which is considered low in the soil. The results of soil particle size analysis were 320, 80, and 600 g of clay, silt, and sand, respectively.

2.2 Cultivar Used

The cultivar used was Aguará 4, developed by Atlântica Sementes, a simple hybrid with an early cycle and a height between 1.5 and 1.8 meters. The cultivar has good tolerance to the main diseases that attack the sunflower crop. Also, it has high yield potential with high oil content and resistance to lodging.

2.3 Experimental Design

The experimental design used was randomized blocks arranged in a 2 x 5 x 6 factorial scheme with four replications. Two crop seasons (off-seasons of 2017 and 2018), boron application at five different phenological stages (V0, V6, V18, R1, and R3), and six boron doses (0, 1, 2, 3, 4, and 5 kg ha^{-1}) were evaluated. The boron doses were manually applied via soil in the rows using boric acid (17%) as the boron source, distributed evenly over the entire plant row length. The three central rows, discarding 0.5 meters at either end of each row, were used for the evaluations (useful plot).

2.4 Conducting the Experiment

The sunflower was sown on soybean (*Glycine max* L.) straw in a no-tillage system. Before sowing, desiccation was conducted with the 2.4-D and Glyphosate (ZAPP) herbicides at 0.3L ha^{-1} and 2.0L ha^{-1}, respectively. Pre-emergent applications were made with Dual Gold herbicide at 1L ha^{-1} and Trichodermil SC biological fungicide at 0.3L ha^{-1}. Seven-row tractor-driven seed drill was used for sowing. Sowing in the first crop season (2017 off-season) was conducted on 02/25/2017, and in the second (2018 off-season), on 03/14/2018.

The fertilization at sowing furrow and in topdressing were based on soil analyses and recommendations for sunflower crops for both crop seasons. In 2017 (first year), fertilization comprised 200 kg ha^{-1} of 08-20-20 (N-P_2O_5-K_2O) in the sowing furrow and 90 kg ha^{-1} of urea in topdressing. In 2018 (second year), fertilization comprised 200 kg ha^{-1} of 08-20-15 (N-P_2O_5-K_2O) in the sowing furrow and 100 kg ha^{-1} of urea in topdressing.

Boron was applied manually along the entire plant row length according to the phenological stages described by Poelking et al. (2018) for sunflower cultivars. The rest of the management required during the experiment in the two crop seasons was conducted mechanically using a tractor-driven boom sprayer. In 2017, the harvest occurred on June 15, and in 2018, on June 28.

During the two crop seasons (off-season 2017 and 2018), maximum and minimum temperature data in degrees Celsius (°C) and rainfall in millimeters (mm) were collected daily (Figure 1).

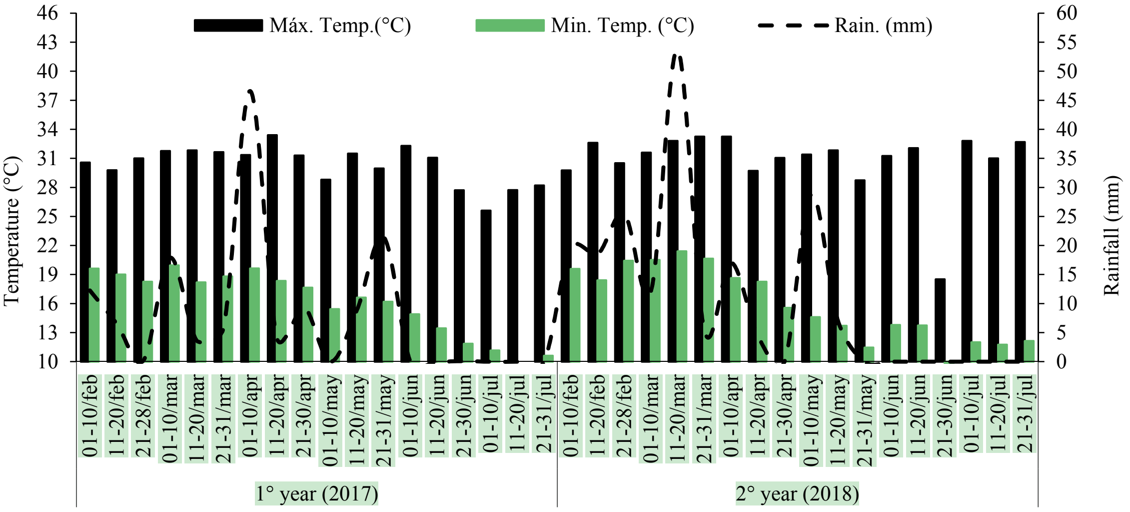

Figure 1. Maximum and minimum temperature and rainfall at the Goiás State University experimental farm in 2017 and 2018 off-seasons. Ipameri-GO, 2018

2.5 Characteristics Evaluated

After the establishment and development of the crop, the following evaluations were conducted: relative chlorophyll index, leaf boron content, yield components, and yield.

Relative Chlorophyll Index (RCI in SPAD): the chlorophyll content of sunflower leaves was read indirectly using the SPAD index, obtained with a portable chlorophyll meter, ChlorofiLOG CFL1030. The leaves analyzed were collected from the middle third of the plant and five plants per plot were randomly sampled, obtaining the average per plot.

Leaf boron content (LBC, in ppm): five leaves were collected from each plot, the fourth leaf from the apex to the base with the petiole of each plant at the start of flowering (R5) (Ribeiro et al., 1999). The leaf boron content was determined following the methods described by Malavolta et al. (1997).

For the yield components, five plants were sampled in each plot at harvest time and taken to the laboratory to determine the following variables:

Plant height (PHT, in m): plants measured in meters from the base to the insertion of the capitulum, individually and randomly, resulting in the average height of plants per plot.

Stem diameter (STD in mm): measured 5 cm from the soil surface using a digital caliper.

Capitulum diameter (CPD, in cm): average of the diameters of the capitula with the achenes from each useful plot, obtained using a measuring tape.

Capitulum mass (CMA, in g): average fresh mass of each capitulum in the useful plot, obtained using a digital scale.

Number of achenes per capitulum (NAC): obtained by counting the achenes in each capitulum of the plants in the useful area.

1000-achene weight (1000W, in g): obtained by directly weighing a thousand achenes using a high precision scale.

Achene yield (YLD, in kg ha^{-1}): determined by harvesting and threshing the plants in the useful plot. To calculate the yield after threshing, the water content of the achenes was adjusted to 11%, and impurities were also deducted, with the result expressed in kg ha^{-1}.

2.6 Statistical Analysis

The leaf boron content and achene yield data were analyzed separately for each year, and the means from the boron application at different phenological stages were compared using the Tukey test at 5% probability; for B doses, regression analysis was applied. For the other variables analyzed, the data was submitted to a joint analysis of variance, according to Banzatto & Kronka (2013). The means from the crop seasons and B application at different phenological stages were compared using the Tukey test at 5% probability; the regression analysis was applied for boron doses. The statistical analyses were processed using R software, 3.1.2 version (R Core Team, 2015).

3. Results and Discussion

Rainfall distribution during the experiment period in the two crop seasons was uneven, with the highest rainfall in April 2017 (46.60 mm). In 2018, the highest rainfall occurred in March with 53.73 mm (Figure 1). The average daily temperature was 23°C during the experiment period in 2017 and 2018 (Figure 1), considered a good temperature for sunflower development, as the crop develops well between 23°C and 28°C (Sunflower Production Guideline, 2010).

The joint analysis of variance for the 2017 and 2018 crop seasons for the variables relative chlorophyll index, plant height, and stem diameter are shown in Table 1. It can be seen that only plant height showed significant results for more than one factor (Table 1). The joint analysis for capitulum diameter, capitulum mass, number of achenes per capitulum, and 1000-achene weight is shown in Table 2. It can be seen that the variables were influenced by the crop seasons, except for the 1000-achene weight, which only showed significant results for boron doses (Table 2). Leaf boron content and achene yield were influenced only by boron doses (Table 3).

Table 1. Relative chlorophyll index (RCI), plant height (PHE), and stem diameter (STD) of sunflower according to the boron application at different phenological stages and doses in the off-season of 2017 and 2018. Ipameri-GO, 2018

Source of variation	RCI	PHE	STD
Crop season (A)	SPAD	m	mm
First year (2017)	37.46a	1,865a	28.56a
Second year (2018)	28.09b	1,545b	23.30b
F-value	2554.03**	665,29**	205.8**
Phenological stages (B)			
V0	32.59a	1,712a	26.33a
V6	32.84a	1,711a	26.04a
V18	32.91a	1,707a	25.96a
R1	32.78a	1,698a	25.83a
R3	32.75a	1,696a	25.50a
F-value	0.34^{ns}	0.26^{ns}	0.53^{ns}
Boron doses (kg ha^{-1}) (C)			
0	32.78	---$^{(1)}$	26.17
1	32.24	---$^{(1)}$	25.53
2	33.14	---$^{(1)}$	25.68
3	32.85	---$^{(1)}$	26.12
4	32.91	---$^{(1)}$	25.99
5	32.74	---$^{(1)}$	26.11
F-value	1.73^{ns}	0.42^{ns}	0.34^{ns}
Interaction A x C	Ns	7.58*	ns
CV (%)	4.37	5.63	10.94

Means followed by the same lowercase letter in the column for each factor studied do not differ by the Tukey test at 5% probability. *= Significant at 5% probability; ns = not significant; $^{(1)}$ = significant regression for the joint analysis of the interaction between the crop season and boron doses. CV (%) = Coefficient of variation.

The results of the joint analysis of variance (Table 1) indicated that the relative chlorophyll index was influenced by the crop seasons; the plants cultivated in 2017 had a higher relative chlorophyll index than plants cultivated in 2018. The relative chlorophyll indexes found were 37.46 and 28.09 SPAD, respectively (Table 1). For the boron application at different phenological stages, the relative chlorophyll index was between 32.59 and 32.91 SPAD, with no statistically significant difference. As for the boron doses, there was no statistical difference, and they did not influence the variable. There was also no significant interaction among crop season, application at different phenological stages, and boron doses (Table 1). Thus, boron fertilization did not influence the relative chlorophyll index with the application at different phenological stages. However, Dechen & Nachtigall (2007) emphasize the importance of boron for the chlorophyll content of leaves since the element participates in nitrogen metabolism and the activity of hormones and is fundamental in translocating sugars and carbohydrate metabolism.

Plant height was significantly influenced by the crop seasons. It can be seen that the plants from the first year (2017) were taller (1.86 m) than the plants grown in the second year (2018) (1.54 m) (Table 1).

The boron application at different stages had no significant influence on plant height. However, the variable was significantly influenced by the interaction between the crop season and boron doses (Table 1). For the interaction, a decreasing linear regression for the first crop season (2017) was fitted, with plant height between 1.82 and 1.94 m (Figure 2). The values found for the first crop season are similar to those found by Feitosa et al. (2013), who observed 1.90 meters for sunflower plants subjected to doses of 6 and 90 kg ha^{-1} of boron and potassium, respectively. For the second crop season (2018), quadratic regression was fitted (Figure 2). From the equation it was estimated that the maximum plant height is obtained with a boron dose of 3.38 kg ha^{-1} (Figure 2).

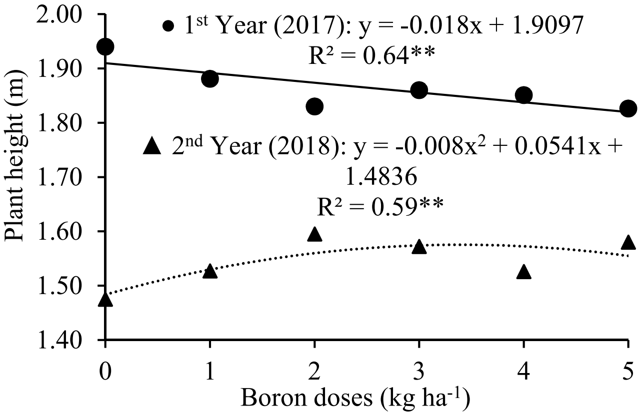

Figure 2. Plant height according to the interaction between crop season and boron doses in the sunflower crop. Ipameri-GO, 2018. **= Significant at 1% probability

These results are close to those found by Capone et al. (2016), who studied three sunflower cultivars and found increasing responses for plant height up to a dose of 3 kg ha^{-1} of boron. The importance of boron for plant height and the significant results found in this study can be explained by its participation in the production and regulation of the auxin in the plant, which is responsible for plant elongation and growth (Taiz &d Zeiger, 1991).

However, plant height can vary depending on the cultivar and weather conditions. These conditions are influenced by the sowing time and low temperatures, which tend to slow down metabolism and, consequently, plant growth rate (Mello et al., 2006). Low temperatures did not negatively influence the results found in this study since the average temperature during the experiment in the two consecutive crop seasons was 23°C (Figure 1).

The stem diameter was only influenced by the crop seasons (Table 1). The sunflower plants grown in the first year (2017) showed better results (28.56 mm) than the plants grown in the second year (2018) (23.30 mm) (Table 1). Silva et al. (2013) emphasized the importance of boron fertilization for the diameter of the sunflower stem, verifying that with the increase in the doses of boron applied, there was an increase in stem diameter. According to Leite et al. (2005), the stem diameter of sunflower plants ranges between 10 and 18 mm, and results within this range were verified in this study despite the absence of significant effects from the applications at different stages and boron doses. The stem diameter in sunflower cultivation is an important characteristic, as it makes the crop less vulnerable to lodging and helps with management practices and cultivation. Because the plant has a capitulum-type inflorescence in its reproductive phase, with a high mass, plants with a reduced stem diameter are subject to lodging (Biscaro et al., 2008).

Capitulum diameter was influenced only by the crop season (Table 2). The first year (2017) showed a smaller capitulum diameter (18.52 cm) than the second year (2018) (23.31 cm) (Table 2). There was no significant influence of other factors and interactions. Despite the absence of the influence of boron doses on capitulum diameter, Bonacin et al. (2009) point out that a lack of boron in sunflower crops causes a reduction in capitulum size, with a reduction in sugar, oil, and starch content.

According to Castro & Oliveira (2005), low boron levels can cause a reduction in the size, deformation, and even the fall of capitula. Capone et al. (2016), when studying three sunflower cultivars, found that the Aguará 4 cultivar showed satisfactory results with the application of boron in the soil and that the cultivars showed an increase in capitulum diameter up to a dose of approximately 3 kg ha^{-1} of boron. These results differ from those found in this study. It should be emphasized that the capitulum diameter in sunflower cultivation is important because it provides the possibility of a higher number of achenes and larger achene size (Souza et al., 2015).

Capitulum mass was not influenced by the boron doses, the application at different phenological stages, and the interaction between the factors evaluated (Table 2). Only the crop seasons have influenced the capitulum mass. In the second year (2018), the capitulum mass (531.73g) was 57,8% higher than in the first year (2017) (336.79g) (Table 2). Zobiole et al. (2011) point out that boron is the most limiting element for sunflower crops since its deficiency can cause symptoms that result in production loss due to leaf fall. Combined with water deficit and high temperatures, especially during the flowering phase, this affects the accumulation of dry matter by the plants and the crop yield (Braz & Rosseto, 2010). The lower capitulum mass of the plants grown in the first year (2017) may be due to the lower volume of rainfall during the experiment period 2017(Table 2). The temperature during the experiment in 2017 and 2018 remained within the standards considered adequate for the development of the sunflower crop (Figure 1).

Table 2. Capitulum diameter (CPD), capitulum mass (CMA), number of achenes per capitulum (NGC), and 1000-achene weight (1000W) of sunflower according to the boron application at different phenological stages and doses in the off-season of 2017 and 2018. Ipameri-GO, 2018

Source of variation	CPD	CMA	NAC	1000W
Crop season	cm	G	un.	G
First year (2017)	18.52b	336.79b	1133.31a	125.75a
Second year (2018)	23.31a	531.73a	746.61b	126.44a
F-value	337.38**	179.96**	189.29**	0.17ns
Phenological stages				
V0	21.29a	457.63a	944.77a	127.67a
V6	21.09a	446.09a	975.56a	125.06a
V18	21.03a	438.47a	942.81a	125.70a
R1	20.63a	424.59a	914.97a	124.87a
R3	20.53a	404.53a	921.70a	127.16a
F-value	1.22ns	1.59ns	0.57ns	0.46ns
Boron doses (kg ha^{-1})				
0	20.66	394.18	965.75	---$^{(1)}$
1	21.03	435.09	912.32	---$^{(1)}$
2	20.11	417.24	953.82	---$^{(1)}$
3	21.35	448.47	948.82	---$^{(1)}$
4	21.05	451.96	914.89	---$^{(1)}$
5	21.28	458.64	944.17	---$^{(1)}$
F-value	2.09ns	1.89ns	0.39ns	5.05*
CV (%)	9.66	25.92	23.16	10.13

Means followed by the same lowercase letter in the column for each factor studied do not differ by the Tukey test at 5% probability. * = Significant at 5% probability; ns = not significant; $^{(1)}$ = significant regression for the effect of boron doses, CV (%) = Coefficient of variation.

The number of achenes per capitulum was significantly influenced only by the crop seasons; the plants grown in the first year (2017) had better results, with 51.7% more achenes (1133,31 achenes) than plants in the second year (2018) (746.61 achenes) (Table 2). These results differ from those found by Lima et al. (2013), who found beneficial effects of boron doses on increasing achene yield. Foloni et al. (2010) observed an increase in the total number of achenes up to a dose of 1 kg ha^{-1} of boron applied via foliar. Castro et al. (2006) analyzed achene yield according to the boron doses and observed that the 0.27 mg dm^{-3} of B in the soil was insufficient to meet the plants nutritional requirements. For the same cultivar in this study, Capone et al. (2016) observed that with a dose of 3 kg ha^{-1} of boron, the cultivar showed better use for achene production.

According to Aguirrezábal et al. (2001), achene yield depends on air temperature, rainfall, and incident solar radiation during the crop cycle. Moriondo et al. (2011) point out that growing a plant at temperatures above or below those considered ideal for its development can harm the final yield. This is closely linked to the number of achenes produced per capitulum, which determines crop yield. In this study, the variation in the number of achenes per capitulum is associated with the rainfall during the crop cycle, which was 271.8 and 310.4 mm for the 2017 and 2018 crop seasons, respectively (Figure 1), which is considered to be outside the ideal range for sunflower cultivation according to Castro et al. (1996), the crop requires 400 to 700 mm of well-distributed rainfall during the cycle for yields close to the cultivar yield potential.

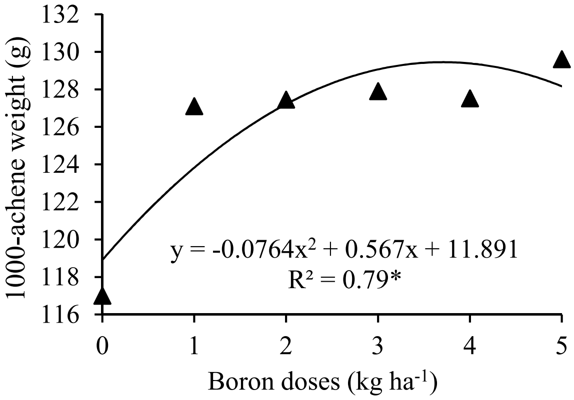

Figure 3. 1000-achene weight of sunflower according to the boron doses. Ipameri-GO, 2018. *= Significant at 5% probability

The crop season and phenological stage of boron application did not influence the 1000-achene weight (Table 2). However, the boron doses affected this variable, in which a quadratic regression was fitted, with a maximum point at 3.71 kg ha^{-1} of boron (Figure 3). These results differ from those of Lima et al. (2013), who found no influence of boron doses on the 1000-achene weight.

The positive results found in this study for the influence of the application of different boron doses on the 1000-achene weight are associated with boron role in cell wall stability in the growth of apical meristems, and membrane permeability, characteristics that influence photosynthetic performance and consequently reflect positively on pollen grain viability and formation and filling of sunflower achenes (Ferreira et al., 2012; Krudnak et al., 2013), thus contributing to greater flower setting.

High temperatures, accompanied by water stress, during the flower bud formation until the end of flowering compromise pollination and fertilization, resulting in poorly formed achenes. During the development stages of the sunflower crop, the greatest assimilation of nutrients and accumulation of dry matter occurs at the beginning of flowering and extends until the physiological maturity of the achenes (Zobiole et al., 2010). These are factors that compromise the 1000-achene weight. However, in this study, the occurrence of both factors was not verified. The temperature remained within the range considered suitable for the crop, and the rainfall for both crop seasons, although below the recommended for sunflower crops, did not characterize a water deficit (Figure 1).

The leaf boron content in the plants grown in the first (2017) and second (2018) crop seasons did not show significant results for the applications at different phenological stages (Table 3). The boron doses applied influenced the leaf boron content in both crop seasons. The data was adjusted to a quadratic regression for the first (2017) and second (2018) crop seasons, with a maximum point at 3.55 kg ha^{-1} (Figure 4A) and 3.74 kg ha^{-1} (Figure 4B) of boron, respectively.

These results differ from those of Euba Neto et al. (2014), who found that boron fertilization did not influence boron levels in the different parts of the sunflower plant, cultivar Hélio 863. Marchetti et al. (2001) observed that increasing the boron doses led to increased levels of this nutrient in both the leaves and the shoot. Alves et al. (2017) found maximum boron contents of 151.38 and 126.14 mg kg^{-1} when they applied 2.49 kg ha^{-1} of B associated with 50 kg ha^{-1} of N to the sunflower cultivars BRS 321 and Neon.

The leaf boron content in this study is above the range considered critical for sunflower crops. According to Asad et al. (2002), the critical content of B for sunflower is 25 mg kg^{-1} of dry matter in new leaves. The pH of the soil in 2017 and 2018, 6.20 and 6.30, respectively, may also be associated with the absorption of the boron applied and the low boron levels in the soil before the experiment was set up.

The sunflower crop yield did not show significant results for any of the factors evaluated in both crop seasons (Table 3). Although there was no statistically significant difference, it can be seen that in the first crop season (2017), for the application at different phenological stages, the maximum yield was 3175 kg ha^{-1}, and for boron doses, the maximum yield was 3153 kg ha^{-1}; for the second year (2018), the maximum yields found for the application at different phenological and boron doses were 2138 and 2125 kg ha^{-1}, respectively (Table 3).

Table 3. Foliar boron content (LBC) and achene yield (YLD) of sunflower according to the boron application at different phenological stages and doses in the off-season of 2017 and 2018. Ipameri-GO, 2018

Source of variation	First Year (2017)		Second Year (2018)	
	LBC	YLD	LBC	YLD
	mg kg^{-1}	kg ha^{-1}	mg kg^{-1}	kg ha^{-1}
Phenological stages				
V0	95.05a	3149a	33.89a	2126a
V6	92.10a	3175a	39.60a	2033a
V18	93.43a	3136a	37.76a	2138a
R1	93.47a	3005a	33.31a	2045a
R3	90.97a	2959a	33.01a	2042a
Boron doses (kg ha^{-1})				
0	---$^{(1)}$	3075	---$^{(1)}$	2125
1	---$^{(1)}$	3254	---$^{(1)}$	2081
2	---$^{(1)}$	3103	---$^{(1)}$	2061
3	---$^{(1)}$	2956	---$^{(1)}$	2085
4	---$^{(1)}$	2965	---$^{(1)}$	2115
5	---$^{(1)}$	3155	---$^{(1)}$	2086
F-value				
Phenological stage (A)	0.19^{ns}	0.54^{ns}	0.36^{ns}	0.60^{ns}
Boron doses (B)	16.39**	0.63^{ns}	10.87**	0.13^{ns}
A x B	0.06^{ns}	1.52^{ns}	1.20^{ns}	1.92^{ns}
CV (%)	18.47	20.76	26.71	13.68

Means followed by the same lowercase letter in the column for each factor studied do not differ by the Tukey test at 5% probability. **= Significant at 1% probability; ns = not significant; $^{(1)}$ = Significant regression for the effect of boron doses. CV (%) = Coefficient of variation.

Brito Neto et al. (2011) highlight the response of this element, stating that crops have shown increases in their yields due to boron supply. Bonacin et al. (2009) found that boron doses from 0 to 4 kg ha^{-1} did not influence crop yield, maintaining the average at 2559 kg ha^{-1}. Foloni et al. (2010) pointed out that sunflower plants are highly responsive to B fertilization in corrected soils where the B content is below 0.26 mg dm^{-3}.

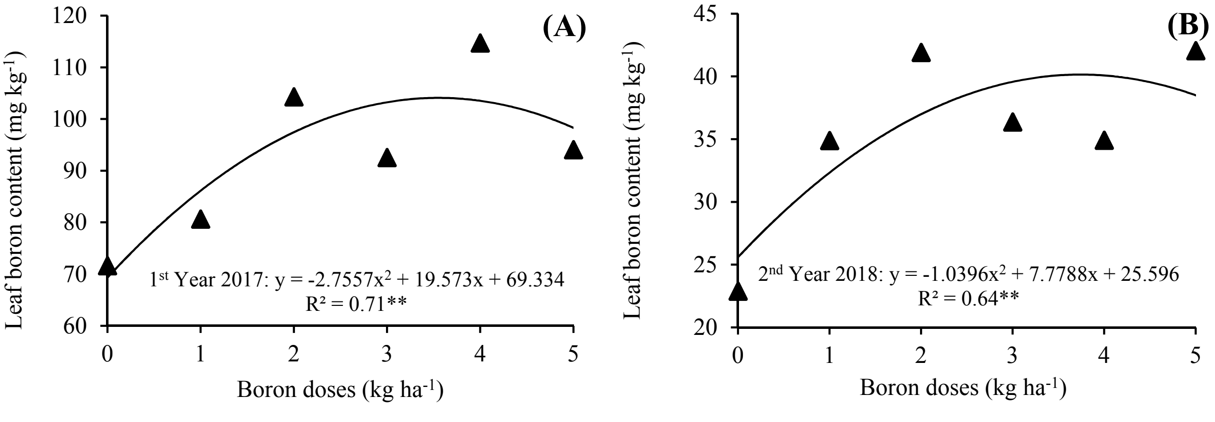

Figure 4. Leaf boron content in sunflower plants in the first crop season (off-season 2017) (A) and the second crop season (off-season 2018) (B) according to the boron doses. Ipameri-GO, 2018. **= Significant at 1% probability

Rainfall in the experimental area during the 2017 and 2018 crop seasons was between 271.8 and 310.4 mm over the crop cycle (Figure 1). Despite the low volume of total rainfall during the crop cycle, the higher yield in 2017 may be associated with the higher rainfall concentrated in April and May, when the plants were in reproductive development, when the sunflower need for water is greatest. In 2018 (second crop season) occurred the opposite of 2017, with rainfall concentrated in March, at the start of plant development, when the sunflower needs less water (Figure 1). In the period of greatest water demand by the crop (flowering and achene filling), the volume of rain was lower and isolated, a factor that may have contributed to the low yield of the crop in 2018.

4. Conclusions

The boron application at different phenological stages did not influence the parameters evaluated in the sunflower crop.

Boron doses between 3.38 and 3.74 kg ha^{-1} influenced the characteristics of leaf boron content, plant height, and 1000-achene weight.

Most of the parameters assessed, including crop yield, were influenced by crop seasons due to rainfall distribution during the crop cycle. The 2017 off-season had the best results.

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Authors contributions

Prof. Dr. Cleiton Gredson Sabin Benett, Prof. Dr. Katiane Santiago Silva Benett and Amanda Tavares da Silva were responsible for study design and revising. Amanda Tavares da Silva, Marina Gabriela Marques, Anne Silva Martins, Willian Gonzaga da Silva, Natália Arruda, Yago César Rodrigues Morais were responsible for data collection. Prof. Dr. Cleiton Gredson Sabin Benett, Prof. Dr. Katiane Santiago Silva Benett and Amanda Tavares da Silva drafted the manuscript and Prof. Dr. Cleiton Gredson Sabin Benett, Prof. Dr. Fabricio Rodrigues and Natália Arruda revised it. All authors read and approved the final manuscript.

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Competing interests

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