Australian Journal of Crop Science AJCS

AJCS 12(12):1975-1982 (2018) ISSN:1835-2707
doi: 10.21475/ajcs.18.12.12.p1405

Effect of Boron (B) and lime on production of watermelon in dystrophic yellow latosol soil

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Abstract

The low concentration of boron in the soil is one of the main challenges for the cultivation of watermelon in regions of the Cerrado biome, due to the appearance of rot apical which may occur due to the lack of boron in the soil or due to boron toxicity by the use of fertilizers without recommendation. There is a narrow range between the appropriate and toxic level pf boron. Therefore, the objective of this study was to evaluate the effect of boron doses on watermelon production in the soils with and without liming. The experiment was carried out in a dystrophic yellow latosol soil, in a randomized block design in subdivide plots: plots (i) liming or without liming and subplots: (ii) boron (0, 2, 4 and 5 $kg.ha^{-1}$), with 8 treatments and 5 replicates. The data were analyzed by regression analysis. The maximum point of the equation was estimated by equating the first derivative of the equation to zero. The diameter, length, weight, number of commercial fruits, bark thickness, percentage of fruits with apical rot, commercial fruits, female flowers, total soluble solids, productivity and profitability were evaluated. The use of boron provided positive effects on the analyzed variables. However, in concentrations higher than 4 kg ha^{-1} its behavior was fitted with a quadratic model (R^2: 0.77 to 0.99). The range was equivalent to 2 to 4 kg ha^{-1} of boron with a specific level of 2.4 $kg.ha^{-1}$, whereas the base saturation rose to 70%, promoted greater productivity for watermelon cultivated in dystrophic yellow latosol under conditions of the closed biome.

Keywords: Fertilization, *Citrullus lanatus* L, Apical rot, Calcium.
Abbreviations: IAA_ indoleacetic acid; B_Boron; Ca_Calcium.

Introduction

The cultivation of watermelon (*Citrullus lanatus* L.) is widespread in countries with high temperatures due to its nutritional value, succulence and good flavor. Moreover, the easy handling combined with the lower cost of production, make watermelon one of the most cultivated fruits in the world, compared to other crops (Oliveira et al., 2012; Bhosale et al., 2017). In Brazil, watermelon cultivation has been extended to the areas of the Cerrado (Carmo et al., 2015), especially due to the high profitability in the off-season period of grain cultivation.

One of the main obstacles to the production of watermelon in the Cerrado is related to the impact of the apical rot caused by calcium (Ca) deficiency and boron (Ferreira et al., 2013), which is related to the low content of organic material in the soil and the reduced amount of B in the mineralogical composition of them. In addition, as the Cerrado soils are acidic, the use of liming is indispensable and has the consequence of raising the pH, culminating in the higher concentration of B in the form of borate anions, which implies a greater adsorption, and consequently less availability to cultures.

B is an essential micronutrient for the cultivation of watermelon because it is related to physiological processes essential for production, such as the formation of the pollen tube, favoring fertilization and fruit formation (Ferreira et al., 2013; Farag et al., 2017). However, the lack of elucidation on the requirement of boron, the adequate dose and the response of the watermelon to its application are still unknown because of the narrow range between the appropriate level and the toxic, which makes the recommendations based on empirical methods of dose response triggering productive impacts such as toxicity or physiological disturbances.

On the other hand, Ca is a nutrient of extreme importance for proper formation of the cell wall (Zeist et al., 2016) and, similarly to B, it is found in deficient amounts in the mineralogical composition of soils of the Cerrado, being supplied by liming. Ca and B present strong soil interaction, and Ca content decreases when there is excess B in the soil, while low Ca contents cause B deficiencies (Malavolta, 1997). The interactions between B and Ca increase the margins of error dose-responses based on recommendation

of dose-responses performed in rural developments, evidencing the need for scientific research.
Now-a-days researches are being developed to reduce the impact of B-induced injury (Farag et al., 2017), watermelon growth on B deficiency (Farag et al., 2016), and the nutrient accumulation process (Schiavon et al., 2017). However, researches related to the ideal level of boron for the specific conditions of watermelon production in the Cerrado are still scarce. In this perspective, the objective of this study was to evaluate the effect of increasing doses (0, 2, 4 and 5 $kg.ha^{-1}$) of boron on watermelon production, in soil with and without liming.

Results and Discussion

Variables related to fruit

A significant effect ($p\leq0.05$) was observed for fruit diameter (FD), peel thickness (PT), percentage of fruits with apical rot (% Fcpa), percentage of commercial fruits (% Fcom), total soluble solids (TSS), commercial fruit total (TFcom), fruit weight (FW) and yield (PRP) for liming factor. The different levels of boron provided a significant effect for all analyzed variables, except for total soluble solids (TSS). There was interaction of liming x level factors for fruit length (FL) ($p\leq0.01$) and productivity (PROD) ($p\leq0.05$). This result indicates that the amplitude of the fruit-yield and productivity responses were different, in presence and absence of liming (Table 1).
The diameter and length of the fruits were affected by the different doses of boron, and it was possible to observe an increase in the FD and FL in the dose 1g $hole^{-1}$ with a reduction for these variables with increase of boron, adjusting (R^2 = 0, 95 and R^2 = 0.77 with liming and R^2 = 0.95 and R^2 = 0.78 without liming for FD and FL, respectively) to a quadratic polynomial model. An increase in the diameter and length of watermelon fruits was observed with the use of boron in the dosage of 2 kg ha^{-1}, which can be attributed to the broad structural function of the cell wall and membrane and enzyme activator in plant metabolism; thus, affecting a better development of the cells of the fruit membrane, resulting in fruits of greater diameter and length (Bhosale et al., 2017) (Fig. 1).
On the other hand, the increase of boron represented a greater thickness of bark (PT), possibly due to the participation of boron in the transport of indoleacetic acid (IAA), ATPase activity, and cell wall synthesis (Goldbach et al., 2001). The increase in the concentration of IAA could specifically promote differential cell elongation and act as a regulator of plant growth, leading to increased fruit skin thickness (Fig. 2). In addition, PT is a parameter that is related to fruit yield, considering the pulp/peel ratio, which tends to be higher in low doses of boron (2 to 4 kg ha^{-1}).
It is also important to emphasize aspects revaccinated by post-harvest practices, where fruits with lower PT are more limited to packaging and transportation processes, because they have a high sensitivity to handling and are easier to suffer damages throughout the handling and transportation procedure, thus depreciation of the fruit with a commercial character and reducing its useful life (Queiroga et al., 2013).

Variables related to flowers and productivity

There was a higher percentage of fruits with apical rot (% Fcpa), when using doses of 0 and 5 kg ha^{-1} (Fig. 2). It was possible to verify that there was a greater Fcpa% ($p\leq0.05$) (Table 1), showing that boron deficiency is a nutritional disorder that causes apical rot, since this physiological anomaly is caused by the lack of Ca and/or B due to the actions in the formation of the cell wall (Marchner, 2012; Yamamoto et al., 2011). It is noted that high boron levels (5 kg ha^{-1}) provided high Fcpa%, which can be attributed by the action of inhibiting the calcium content (contained in liming) by excess boron (Malavolta, 1997). The lack of calcium assimilation (in dose of 5 kg ha^{-}1) may possibly be the reason for the increase of the fruit index caused by apical rot, since the presence of both nutrients is essential to avoid the disorder (Ferreira et al., 2013).
Boron deficiency in the production system causes negative characteristics, such as affected growth points, which consequently tends to reduce the quality of the product. Besides, it causes rapid hardening of the cell wall, because during the formation of carbohydrate complexes there is a loss in distribution of the cellulose micelles, preventing the cell to expand (Malavolta, 1980). The incidence of apical rot has a high relation with the number of fruits per plant and the percentage of commercial fruits. The higher total number of fruits in the plant needs greater demand of calcium (Júnior et al., 2011).
In this study, the percentage of commercial fruits (% Fcom) was adjusted to the quadratic polynomial model in both cases, in relation to the liming factor, when liming was absent (R^2 = 0.99) and present (R^2 = 0.96). In the latter case, it presented the highest ($p\leq0.05$) % Fcom (Fig. 3), due to the limestone action of aluminum neutralization and the promotion of greater absorption of the nutrients contained in the soil, which provided better development of the root system of the plant and also by the supply of calcium and magnesium (Padro et al., 2013). In relation to the different levels of boron, the quadratic polynomial model suggests a response curve interpreted by the increase of the TFcom with the increase of the boron doses until the reduction observed beyond the optimum levels, which could be attributed to the toxicity due to high boron contents. This result is justified by the higher percentage of apical and noncommercial rot fruits (fruit deformity, cracking and smaller size) based on the standard commercialized according to the Company of Warehouses and General Warehouses of Sao Paulo in fruits with doses 0 and 5 kg ha^{-1}, as previously reported.
Fruit weight (FW) presented a response similar to the percentage of commercial fruits; therefore, the use of liming provided heavier fruits with a parabola function, while the concavity turned down, in relation to the FW as a function of the doses of boron (Fig. 3). It is noted that the dose of 2 $kg.ha^{-1}$ promoted an increase of approximately 800 g in the weight of the fruits in relation to the control, in both cases of the liming factor. However, the fruits that received the liming were about 400 g heavier, because calcium is the second mostly required element by the Crimson Sweet watermelon crop (Almeida et al., 2012), suggesting that liming along with 1 g $hole^{-1}$ of boron represents a more efficient amount to guarantee maintenance of control of metabolism disorders and formation of healthy and heavier fruits. The fruit weight margin from dose 4 $kg.ha^{-1}$ is contained in the range of 4 to 7 kg, if framed in the common group (CEAGESP, 2011).
The percentage of female flowers (% FF) was increased proportionally with the increase of the boron level, by which

Table 1. F-value and significance of the factors investigated for fruit diameter (FD), fruit length (FL), peel thickness (PT), percentage of fruits with apical rot (% Fcpa), percentage of commercial fruits (% Fcom), total soluble solids (SST), percentage of female flowers (% FF), total commercial fruit (TFcom), fruit weight (FW) and productivity (PROD).

FV	FD	FL	PT	%Fcpa	%Fcom
	F	F	F	F	F
Liming	149.26**	6.42ns	22.09**	10.14*	11.47*
Level	3.68**	5.26**	2.84*	8.93**	12.33**
C x N	1.66	6.64**	0.91ns	0.58ns	1.45
CV (%)	8.44	7.03	21.54	11.35	6.85
FV	SST	% FF	TFcom	PF	PROD
	F	F	F	F	F
Liming	46.24**	3.04ns	109.03**	169.09**	379.22**
Level	1.56	3.50*	10.46**	5.37**	14.37**
C x N	0.31ns	1.16ns	0.91ns	2.2ns	2.64*
CV (%)	21.23	15.54	10.46	15.72	21.56

**Significant at the 1% probability level; *Significant at the 5% probability level by the F test. Legend: PV: source of variation; C: liming factor; N: value of boron level and CV: coefficient of variation.

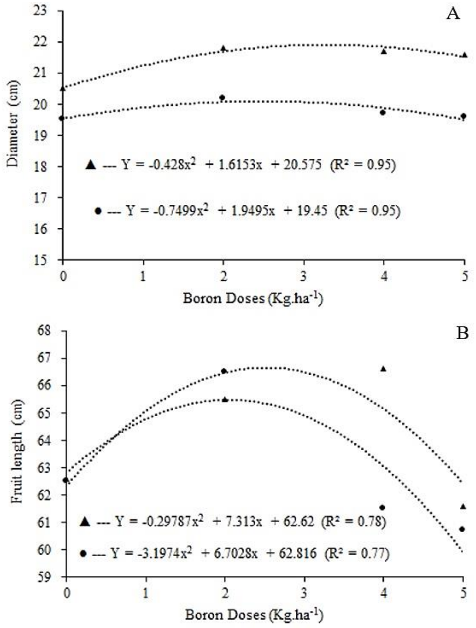

Fig 1. Influence of increasing doses of boron on the diameter (A) and fruit length (B): (●) without liming and (▲) with liming.

Table 2. Linear correlation between the percentage of female flowers (% FF), total fruits per hectare (TF), total commercial fruits per hectare (TFcom) and productivity (PROD).

Variables	% FF	TF	TCF	PROD
%FF	1			
TF	0.56	1		
TFC	0.61*	0.88**	1	
PROD	0.72*	0.67*	0.95**	1

**Significant at the 1% probability level and *: Significant at the 5% probability level by the t test.

Table 3. Economic viability of watermelon cultivation with different levels of boron with or without liming.

Factors C	N	Prod ($kg.ha^{-1}$)	VG (US$)	Liming and boron application cost (US$) Limestone[2]	Borax[3]	Operational[4]	Profitability* ($US\$.ha^{-1}$)
with*	0 $kg.ha^{-1}$	25,187.5	5,047.55	70.29	0.00	49.23	4,927.93
	2 $kg.ha^{-1}$	32,687.5	6,550.55	70.29	4.93	67.83	6,407.49
	4 $kg.ha^{-1}$	30,187.5	6,049.55	70.29	9.87	67.83	5,901.56
	5 $kg.ha^{-1}$	24,062.5	4,822.10	70.29	2.33	67.83	4,671.65
Without	0 $kg.ha^{-1}$	14,875	2,980.94	0.00	0.00	0.00	2,980.94
	2 $kg.ha^{-1}$	15,500	3,106.19	0.00	4.93	18.50	3,082.76
	4 $kg.ha^{-1}$	15,600	3,126.23	0.00	9.87	18.50	3,097.86
	5 $kg.ha^{-1}$	14,812.5	2,968.41	0.00	2.33	18.50	2,937.58

* aiming to increase saturation by base to 70%; [2] considering local price of 18.50 US $ 60 kg bag; [3] considering local price of 2.47 US $ per kg and [4]Operating cost related to the application converted to 1 hectare. Profitability is considering only the costs related to Liming and Boron application. Legend: L: liming factor, B: boron level factor, Prod: productivity, GV: gross value.

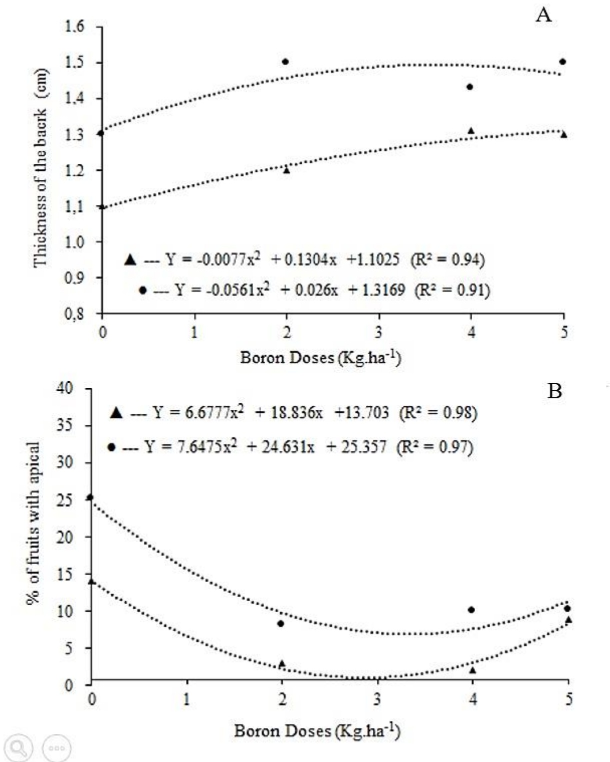

Fig 2. Influence of increasing doses of boron on the thickness of the bark (A), % of fruits with apical (B): (●) without liming and (▲) with liming.

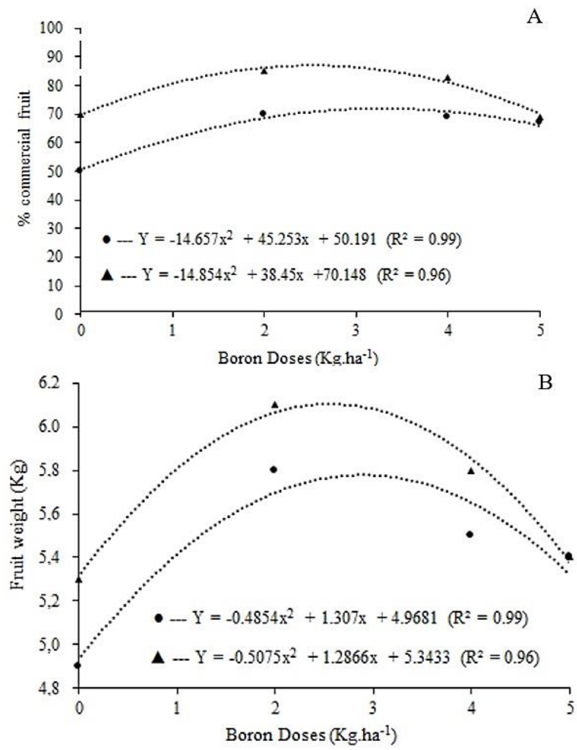

Fig 3. Influence of increasing doses of boron on the % commercial fruit (A) and fruit weight (B): (●) without liming and (▲) with liming.

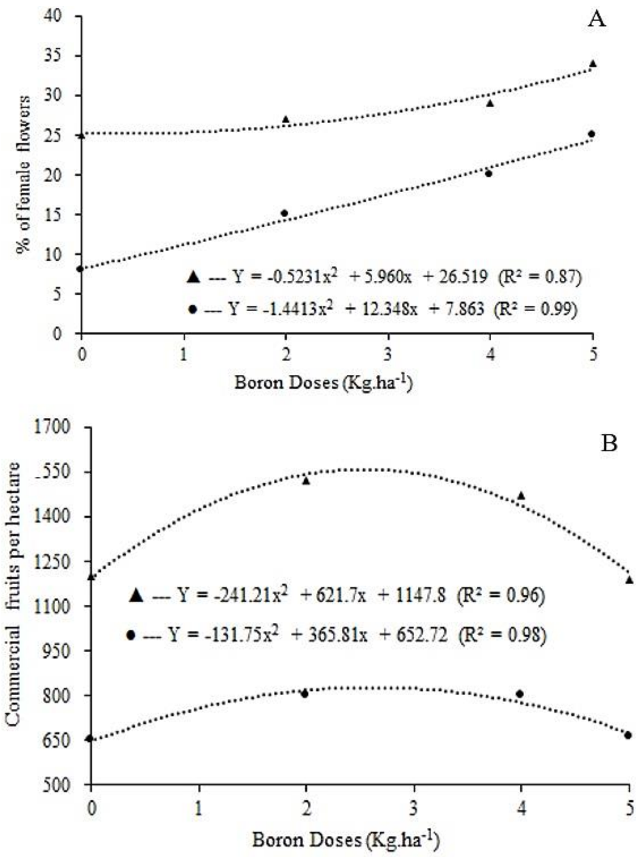

Fig 4. Influence of increasing doses of boron on% of female flowers to (A) and total commercial fruits per hectare (B), total soluble solids, being: (●) without liming and (▲) with liming.

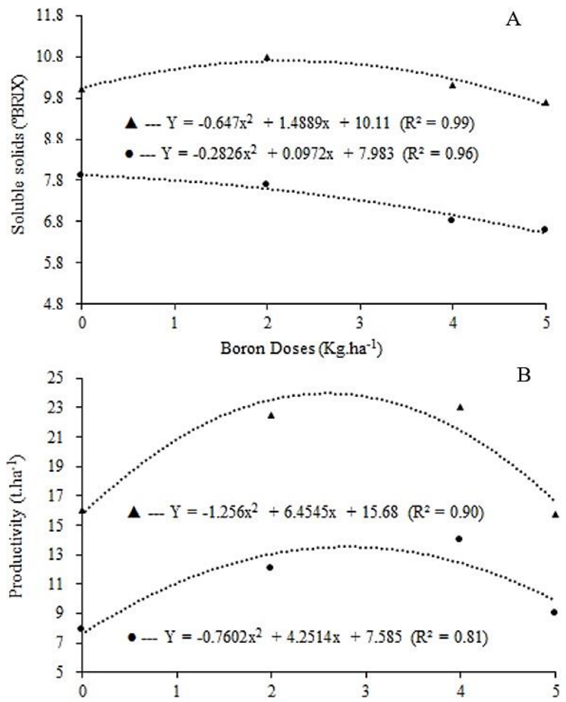

Fig 5. Influence of increasing doses of boron on total soluble solids (A) and productivity in t.ha^{-1} (B), being: (●) without liming and (▲) with liming.

the maximum dose presenting the highest percentage of female flowers. However, the total number of commercial fruits per hectare presented a response curve indicating a reduction in total fruits under 5 $g.ha^{-1}$ dose, but in both cases the liming factor showed a higher percentage of flowers female and commercial fruits compared to production without liming (Fig 4). The highest % FF can be attributed to the close relationship of boron to flowering, especially in pollination and formation of the pollen tube, generating the fruits (Ferreira et al., 2013). However, as highlighted above, there is a reduction in the total number of fruits per hectare, related to the higher rate of abortion of the flowers, since these can impact the fertilization process during pollination due to external factors such as low relative humidity. In addition to this, the lowest number of commercial fruits per hectare can be justified to the highest percentage of fruits with apical rot and non-commercial fruits in the minimum and maximum dose (5 $g.ha^{-1}$) due to impacts related to deficiency of boron in the first dose. Applying the second dose, the boron toxicity was occurred to fruits and reduction of calcium absorption by boron antagonism due to excess boron happened (Malavolta, 1997; Taiz and Zeiger, 2009; Yamamoto et al., 2011) (Fig. 3B). Regardless of the boron doses, the use of liming provided fruits with higher total soluble solids contents (Fig. 5), due to the more beneficial conditions for assimilation of nutrients in the soil, especially due to the reduction of pH and neutralization of aluminum. The edafoclimatic variations on the TSS of the fruits provoked greater dilution of sugars in the final phase of the cultures (Rocha et al., 2011). In Brazil, the TSS value considered ideal for commercialization is 10 ° BRIX. Thus, the fruits of the experiment are within the Brazilian commercial standard.

There was a significant effect ($p \leq 0.01$) on the liming factor due to its benefits such as the improvement of soil chemical properties and the increase of calcium and magnesium exchangeable contents for the plants. Effects on productivity were detected by different doses of boron ($p \leq 0.01$), as well as for interaction ($p \leq 0.05$) between the factors. Therefore, two different equations were presented (Fig. 5). An increase in productivity was observed with the application of the doses of 1 and 4 $kg.ha^{-1}$. The 5 $kg.ha^{-1}$ dose caused a lower number of commercial fruits and fruit weight, due to the impacts of this micronutrient. By means of the equation derivative, it was possible to obtain the ideal dose of boron, using liming and without liming, 2.4 and 2.64 $kg.ha^{-1}$, respectively. The linear correlation analysis showed positive correlations between the percentage of female flowers, total commercial fruits per hectare and productivity ($p \leq 0.05$). It is also worth mentioning the positive correlation between %Fcom and PROD ($p \leq 0.01$) (Table 2). This result evidences the close relationship between % FF with the number of commercial fruits and productivity, since the female flowers are pollinated for fruit formation. Thus, the greater the number of female flowers with the consolidated fertilization process, the greater the number of fruits in the stand situation, and the greater the number of fruits per area, the higher the productivity of the fruit obtained in the area.

Profitability

It is important to highlight that the excess of boron can impair the development of the plant, delay the fruiting and the photoassimilative capacity of the melancholy due to the necrosis in the leaves. This can lead to death of the plant in high degrees of toxicity (Cardozo et al., 2001; Bhosale et al. 2017; Farag et al., 2017).

The treatments presented a positive profitability, with higher values obtained in the treatments that received liming and doses of 2 and 4 $kg.ha^{-1}$ of boron, with respectively 6,407.49 and 5,901.56 US $\$.ha^{-1}$. It is noted that the lack of liming in the cultivation of watermelon in the Cerrado soils may represent a loss of 50% of the potential profitability of the hectare. The investment of approximately 4.93 dollars per hactare for boron applying the dose of 2 kg. ha^{-1} can increase the productivity, and consequently, the profitability (Table 3).

Materials and Methods

Location and characteristics of the experimental area

The research was developed in a rural property located in the city of Chapadinha/Maranhão, Brazil, in the Microregion of Chapadinha, at coordinates 03° 38'44.15 "S and 43° 21'24.05" W, with 100 m above sea level. The local climate is classified as AW (hot and humid), with annual mean temperature of 27°C and annual mean precipitation ranging from 1600 to 2000 mm (Passos et al., 2016). The experiment was conducted during the months of June and November 2017 in an experimental area of 1,500 m² with flat relief and the soil was classified as Dystrophic Yellow Latosol (Santos et al., 2013), with pH in $CaCl_2$ = 4.1; M.O = 27.9 $g.dm^{-3}$; P = 11.4 mg dm^{-3}; H + Al = 0.09; K = 0.29 cmolc dm^{-3}; B = 0.0; Ca = 4.2 $cmolc.dm^{-3}$; Mg = 6.33 cmolc dm^{-3}; SB = 0.64 cmolc dm^{-3}; CTC = 6.97 cmolc dm^{-1}; V (%) = 9.2; gritstone = 45%; fine sand: 20%; clay 11%; silt: 24 and texture = average.

Management and data collection

Initially the glyphosate dehydrating herbicide was applied at the dosage of 5 $L.ha^{-1}$. Afterwards, the soil was prepared with a 20 cm plowing and two gradations. 320 pits with 0.3 x 0.3 x 0.3 m were opened. Later, the area was divided into 40 plots with dimensions of 3.5 x 10 m (35 m²). The recommendations of fertilizers and correctives were carried out as a result of the soil analysis, respecting the delimitation of the treatments to be implanted. Therefore, 114 g of dolomitic limestone per hole (PRNT = 100% and MgO and CaO contents of 10 and 35%, receptively) were ingested in order to raise the saturation by bases to 70% in the pits that in the lottery of the treatments received the liming factor.

After 63 days, planting of the watermelon was planted directly into the field, placing five seeds per hole. The Crimson Sweet cultivar was used, with an average cycle of 85 days after planting, characterized by a rustic plant with vigorous foliage and good tolerance to high temperatures (Carmo et al., 2015). At 15 days after the emergency (DAE), the thinning was done leaving two plants per hole, totally a stand of 640 plants. Nitric (urea), P_2O_5 (single superphosphate) and K_2O (KCl) were applied in sowing, and at 25, 50 and 70 DAE according CFSEMG, (1999). The source of boron (B) was Borax® (11% of B) applied at the time of sowing.

The irrigation system was drip irrigation, consisting of a lateral line per row of plants with self-compensating type drippers, with an average flow of 1.25×10^{-6} m³ s^{-1} spaced by 2.5 m distance between rows of 2 m. Irrigation was carried out daily and the slides were determined on the basis of evapotranspiration of the crop with irrigation carried out three times a day until the beginning of fruiting, after being reduced to twice a day with a leaf of 318.93 mm (Barros et al., 2012), corresponding to efficiently to requirements of the crop.

Phytosanitary control was carried out according to the technical recommendations adopted in the region for the watermelon crop. The preventive application of the organic insecticide was done by the application of Neem oil (*Azadirachta indica*) at the dose of 20 $L.ha^{-1}$. During the cycle of the culture, cultural treatments like the thinning of plants, weeding and combing of the branches were carried out.

At 60 and 90 DAE, the percentage of female flowers (% FF) and total flower numbers (TF) were determined. In the fruiting period, the percentages of apical (% Fcpa) and commercial (% Fcom) fruits were quantified based on the standards established by the Company of Warehouses and General Warehouses of São Paulo - CEAGESP (2011), defined by characteristics such as deformity in the fruit cracks and size below the standard of marketed fruit.

The fruits were harvested at 70, 85 and 100 DAE, which were selected based on the observation of the nearest dry grapevine and the change in color of the fruits, especially on the ground, from white to light yellow (Barros et al., 2012). The total soluble solids content (TSS), peel thickness (PT), length (LL), diameter (LD), weight (LW) and number of $fruits.ha^{-1}$ and crop yield in $t.ha^{-1}$ were measured.

The TSS was determined with the aid of the Whdz analog refractometer KBT001406, with measuring range of 0-32%. The PT was measured by means of a Jakemy qs-150 di-gauge caliper; the LL and LD by means of a tape measure 537B, where the diameter of the fruit was obtained by the mathematical expression: $D = P / \pi$, Where: $\pi = 3.141$ ... and C = Circumference of the watermelon and the weight of the fruits with the help of one of a portable digital scales Crane Scale. The economic viability was calculated by the productivity ratio considering only the total commercial fruits ($kg.ha^{-1}$) with the watermelon kg price in the region, US $ 0.2168, being reduced by the costs related to liming (limestone US $ 18.50 $ for the 60 kg bag) and Borax (2.47 US $ kg for Borax®) and operational cost.

Experimental planning and statistical analyzes

The experimental design was in factorial consisting of eight treatments and four replications, totally 40 plots, with the following factors: (i) liming or without liming, and (ii) several levels of boron (0, 2, 4 and 5 $kg.ha^{-1}$). The plot consisted of two rows of 10m with spacing between rows of 2 m and 2.5m between holes.

The data were submitted to the Shapiro Wilk test to verify the normality of distribution, and were subsequently submitted to analysis of variance with the statistical model: $Yij\ (k) = \mu + Bi + Cj + Nk + CxNjk + Eijk$, where: Yij (k) is dependent variable; μ is the general mean, Bi is the effect of the ith block; Cj is the effect of j-th liming; Nk is the k-th level of boron; CxNjk is the effect of the interaction of the j-th liming with the k-th level of boron and Eijk is the experimental error, assuming Eijk ~ NID (0, σ2).

The exploratory analysis of the data was through regression analysis, where the maximum point of the equation determined the dose of boron corresponded to the highest value of dependent variable which was estimated by equating the first derivative of the equation to zero (Siqueira et al., 2009). Pearson's linear correlation was performed with the t-test at 1% and at 5%. The analyzes were performed using the SAS statistical package (SAS, 2002).

Conclusion

Boron fertilization increased the productivity of watermelon, when the base saturation was increased to 70%. We recommend 2.4 $kg.ha^{-1}$ of boron. However, the acceptable range is 2 to 4 $kg.ha^{-1}$ of boron, because promoting higher productivity and fruits of watermelons with higher quality when cultivated in dystrophic yellow latosol under conditions of the Cerrado biome.

Acknowledgements

The authors thank the Foundation for Research and Development technological of Maranhão – FAPEMA

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