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Plant spacing and boron (B) topdressing fertilisation for purple cabbage crop (*Brassica oleracea* var. capitate) variety purple giant

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Abstract

Brassicas are oleraceous plants of great economic importance, and numerous factors can affect the yield and quality of these vegetables, including plant spacing and fertilisation. Thus, this study aimed to evaluate the effects of plant spacing and boron fertilisation on purple cabbage development and yield. The experiment was performed between march and july at the experimental site of the Mato Grosso do Sul State University (Universidade Estadual de Mato Grosso do Sul - UEMS), Aquidauana unit, located in Aquidauana, MS, Brazil. A randomised block design was adopted, employing a 2 x 5 factorial scheme with four replicates. Two row spacings (0.8 m × 0.4 m and 0.6 m × 0.4 m) and five boron doses (0, 2.5, 5.0, 7.5, and 10.0 kg ha^{-1}) in the form of boric acid applied as topdressing were evaluated for a giant purple cabbage variety. The leaf boron content, plant height, stem diameter, head height and diameter, number of outer and inner leaves, fresh and dry weights of outer and inner leaves, head compactness and classification, and yield were evaluated. The results showed that reducing the row spacing from 0.8 m to 0.6 m increased the purple cabbage crop yield and the boron uptake by the plants. A smaller row spacing (0.6 x 0.4 m) and a boron dose of 6.01 kg ha^{-1} provided the highest cabbage yield.

Keywords: Densification, yield, micronutrient.
Abbreviations: B_boron; PH_Mean values of plant height; SD_stem diameter; HH_head height; HD_head diameter; OLN_outer leaf number; ILN_inner leaf number; OFW_and outer fresh weight; IFW_Mean values of inner fresh weight; ODW_outer dry weight; IDW_inner dry weight; LBC_leaf boron content; COMP_head compactness; SIZE_head size; YIELD_and yield.

Introduction

Among species of the family Brassicaceae, cabbage has the highest economic importance worldwide. Cabbage is one of the most widely used vegetables in cooking because it is nutrient-rich, thus exhibiting a high nutritional value. It is a source of vitamins, minerals, and fibres. Purple varieties are important because they are sources of antioxidants such as anthocyanins. The plant spacing and plant mineral nutrition are among the numerous factors that affect cabbage crop yield and quality. Cabbage, cauliflower, and broccoli are boron-demanding and usually exhibit boron deficiency in Brazil because the majority of Brazilian soils are acidic, which increases the solubility and thus leaching of boron (Malavolta et al., 1991). Boron (B) acts directly in cabbage crop growth and development because it is related to several metabolic processes, such as those involved in cell growth and expansion and the incorporation of calcium into the cell wall, which promotes the biosynthesis of calcium-containing compounds (Alvares et al., 1985) and helps to maintain plasma membrane integrity (Santos et al., 1990). A high population density is generally used for vegetable crop production and is extensively employed for a number of crops. Implementing a closer spacing can contribute to reductions in weeds, improvements in soil protection, increases in fertiliser efficiency, and increases in yield.

Silva et al. (2011) evaluated the spacing between rows and between plants for purple cabbage crops and reported that the yield increases with a decrease in spacing; the minimum yield was obtained at 1.0 m x 0.50 m (20,000 plants ha^{-1}) and the maximum yield at 0.60 m x 0.30 m (54,644 plants ha^{-1}). Silva et al. (2012 and 2014) working with boron doses in cabbage culture observed that boron application influenced the cabbage productivity. Thus, considering the market for cabbage and the use of this vegetable in the human diet and for other purposes, such studies are of paramount importance for crop success, allowing farmers to obtain higher profitability and higher production quality. Therefore, identifying the best spacing and dose of boron which results in better profitability for farmers

This study aimed to evaluate the effect of spacing and boron fertilisation on purple cabbage development and yield.

Results and Discussion

Growth variables

The plant area, plant height, stem diameter, head height and diameter, outer and inner leaf numbers, and outer fresh weight were not significantly affected by the row spacing (Table 1). However, the boron dose significantly affected (Table 1) the head height, and there was a linear increase in head height with an increase in B dose applied (Fig 1A). These results differ from those obtained by Carneiro et al. (1995), who obtained a quadratic fit with an estimated maximum at 14.29 kg ha^{-1} of B.

There was a significant effect of the interaction between boron dose and spacing (Table 1) when the head diameter was evaluated. The response for the closer spacing (0.6 x 0.4 m) can be described by a quadratic polynomial regression (Fig 1B) with a maximum estimated value at 9.93 kg ha^{-1} of B, whereas for the larger spacing (0.8 x 0.4 m), there was a linear increase with an increase in boron dose (Fig 1B). This interaction may be explained by plant competition for space affecting growth and also head brightness. Aquino et al. (2005) reported that reducing the spacing between plants produced heads with smaller diameters and lower mean fresh weights.

Pizzeta et al. (2005) have reported linear increases in cabbage head size and weight in relation to an increase in boron dose. There were no studies in the scientific literature related to the interaction between spacing and boron dose. For outer leaf number, the data fit a positive linear regression (Fig 1C), whereas the inner leaf dry weight data fit a negative linear regression (Fig 1D). Similar results were reported by Silva et al. (2011), who reported mean leaf numbers between 11.43 and 13.98 when evaluating spacing in purple cabbage crop production.

Yield variables

The leaf number and biomass did not differ according to spacing (Table 2). However, an increase in boron dose produced a positive linear effect for outer leaf fresh weight, whereas inner leaf dry weight decreased with an increasing in boron dose (Fig 2A). For leaf boron contents (Table 2), the larger spacing resulted in an 82.7% greater nutrient uptake by the plants compared to the closer row spacing. The leaf boron contents obtained in this study are considerably higher than the ideal range of 25 to 75 mg kg^{-1} reported by Trani and Raij (1996). This higher content may be explained by the adequate soil organic matter content (52 g dm^{-3}), consequently promoting higher absorption of the boron applied to the soil by plants. According to Stevenson (1991), when combined with soil organic matter, boron forms complexes that, when mineralised by microorganisms, release boron in forms available to plants. For leaf boron content, the data fit a quadratic polynomial regression (Table 2) with an estimated maximum at 8.77 kg ha^{-1} of boron (Fig 2B). Thus, applications of up to 8.77 kg ha^{-1} of boron should affect cabbage development and yield, while values above this may not result in an increase in crop characteristics. Silva et al. (2012) and Silva et al. (2014) when evaluating boron doses (0 to 10 kg ha^{-1}) applied for cabbage crop production, reported that the leaf B levels fit a positive linear regression in the leaves depending on the boron dose. Regarding head compactness, the row spacing did not affect this variable (Table 2). However, the boron dose significantly affected the purple cabbage head compactness (Table 2); the response fit a quadratic polynomial regression with an estimated maximum at 7.13 kg ha^{-1} of boron (Fig 2C). This value may be related to the potential crop response to boron application. Silva et al. (2014) working with boron rates in cabbage obtained results next to those found in this work. These results are lower than those obtained by Marouelli et al. (2010), who reported a good head compactness of 3.8, using a grading scale between 1 (low compactness) and 5 (high compactness). Based on head weight, the spacing, the boron dose, and the interaction between the two did not affect the cabbage head classification. Overall, regardless of the treatment, the heads were classified as size 2, i.e., with mean sizes ranging between 500 and 750 g (Table 2). Head size may be related to plant characteristics, cultural practices, and plant spacing. Denser plantings tend to form smaller heads, and consumers prefer smaller head sizes. According to Minami et al. (1998), competition between plants can occur in dense crops, compromising the development of individuals and leading to reductions in yield and/or quality. This impact was not observed on the quality of cabbage heads in this study when the spacing was decreased from 0.8 m to 0.6 m. Pizetta et al. (2005), when evaluating the impact of boron applications on cabbage crops, reported that applications of 6 and 8 kg ha^{-1} of boron reduced the numbers of heads in the classes 1, 2, 3, and 4 (< 1.5 kg) and increased the numbers of heads in classes 5 and 6 (1.5 to 2.5 kg), with 97% of the heads belonging to this last class.

Regarding yield, the 0.6 x 0.4 m spacing between plants produced a 23.7% greater yield (26.660 kg ha^{-1}) than the 0.8 x 0.4 m plant spacing (Table 2). This result indicates that the densification of cabbage plants may provide a more effective use of the crop area without affecting crop quality and yield. According to Silva et al. (2011), a decrease in plant spacing resulted in a higher purple cabbage yield. Žnidarcic et al. (2007) evaluated various spacing combinations for green cabbage and reported that the marketable head weight was greater for the larger spacing (0.30 x 0.40 m).

In this study, the mean crop cycle was 100 days and was unaffected by the row spacing. Stoffella and Fleming (1990) evaluated population densities of cabbage plants ranging from 24.600 to 123.000 plants ha^{-1} and reported that there was an increase in the crop cycle because the vegetable crops required a longer time period to reach the point of harvest.

There was a significant effect of boron dose on cabbage yield (Table 2), and the data fit a quadratic polynomial equation with an estimated maximum at 6.01 kg ha^{-1} of boron (Fig 2D). Silva et al. (2012), evaluating boron doses in cabbage, reported an increase in yield of approximately 10.500 kg ha^{-1} with an increase in boron dose compared to the control. Carneiro et al. (1995) evaluated the cabbage yield for various boron application levels, and the data fit a quadratic equation with an estimated maximum at 10.92 kg ha^{-1} of boron. Dixit and Singh (1997) reported that high doses of boron can cause decreases in cabbage yields.

Table 1. Mean values of plant height, stem diameter, head height, head diameter, outer leaf number, inner leaf number and outer fresh weight obtained for purple cabbage grown at two different row spacings. Aquidauana, MS.

Treatment	PH	SD	HH	HD	OLN	ILN	OFW
Spacings	------------------- cm -------------------				---	---	- g -
0.8 x 0.4m	40.95	2.15	13.61	11.04	10.79	31.95	0.86
0.6 x 0.4m	40.27	2.12	13.10	11.38	10.98	32.99	0.94
Test F	0.825 ns	0.352 ns	3.269 ns	2.482 ns	0.435 ns	1.319 ns	3.430 ns
Regression	--	--	L	--	L	--	L
Interaction	0.484 ns	0.198 ns	0.640 ns	7.424 **	1.670 ns	1.156 ns	0.276 ns
CV (%)	5.78	5.93	6.70	6.06	8.11	8.75	16.56

** significant ($p \leq 0.01$ probability); ns – not significant; L – linear model; (PH) - plant height; (SD) - stem diameter; (HH) - head height; (HD) - head diameter; (OLN) - outer leaf number; (ILN) - inner leaf number; (OFW) - outer fresh weight.

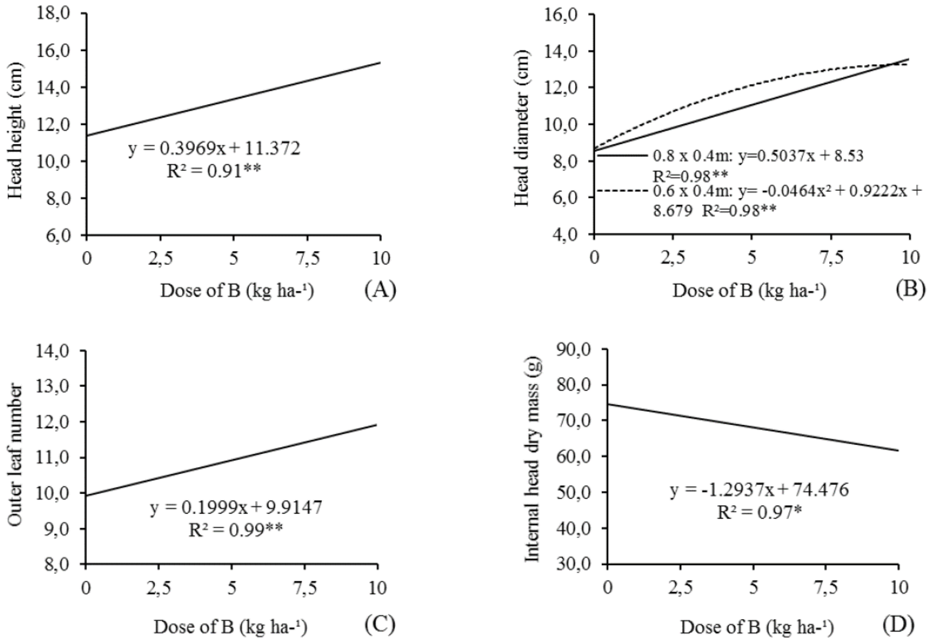

Fig 1. Mean values of head height (A), the interaction between spacing and boron dose for head diameter (B), outer leaf number (C) and internal head dry mass (D) of purple cabbage as a function of boron dose. * significant ($p \leq 0.05$ probability). ** Significant ($p \leq 0.01$ probability). Aquidauana, MS.

The yields obtained in this study (21.550 and 26,660 kg ha^{-1}) are within the range obtained by Lêdo et al. (2000), who evaluated the development of various cabbage cultivars and reported yields between 10,600 and 41.800 kg ha^{-1}. Thus, correct and adequate crop management is of the utmost importance for obtaining satisfactory results and, consequently, economic returns. According to Silva et al. (2011), spacing management enables the farmer to increase crop yields and adjust the size of cabbage to meet the demands of the consumer market.

Materials and Methods

Location and installation of the experiments

The experiment was conducted between march and july at the experimental site of the Mato Grosso do Sul State University, Aquidauana unit, located in Aquidauana - MS, Brazil, at the geographic coordinates of 20° 20' South and 55° 48' West and a mean altitude of 174 metres. The region's climate, according to the Köppen classification scheme, is Aw, defined as a tropical wet and dry climate, with a mean annual rainfall of 1,200 mm, characterised by a rainy season in the summer and a dry season in the winter. The maximum temperature can exceed 40°C and usually occurs from October through February, while the minimum temperatures can vary between –3ºC and 18ºC during the colder months.

The soil of the experimental site is classified as a deep, moderately drained, dystrophic red-yellow Ultisol with a sandy texture (Embrapa, 2006). The soil chemical properties were determined before setting up the experiment, according to the method proposed by Ribeiro et al. (1999), with the following attributes determined for the 0.0-0.20 m layer: pH ($CaCl_2$)= 5.5; H + Al= 21 $mmol_c$ dm^{-3}; Ca= 62 $mmol_c$ dm^{-3}; Mg= 22 $mmol_c$ dm^{-3}; P (resin)= 68 mg dm^{-3}; K= 7.0 $mmol_c$ dm^{-3}; organic matter= 52 g dm^{-3}; CEC= 112 $mmol_c$ dm^{-3}; V%= 81; Cu= 8.0 mg dm^{-3}; Fe= 75.0 mg dm^{-3}; Mn= 20.6 mg dm^{-3}; Zn= 0.9 mg dm^{-3}; and B= 0.32 mg dm^{-3}. For Ribeiro et al. (1999), boron levels between 16 and 35 mg dm^{-3} are considered low. The effects of row spacing and boron fertilisation on the development, production, and quality of cabbage (*Brassica oleraceae* var. capitata cv. "roxo gigante") were evaluated. The experiment had a randomised block design, with ten treatments and four replicates implemented in a 2 x 5 factorial scheme. Two row spacings (0.8 m and 0.6 m, totalling 31,250 plants ha^{-1} and 41,667 plants ha^{-1}, respectively) and five boron doses (0, 2.5, 5.0, 7.5, and 10.0 kg ha^{-1}), applied as topdressing to the soil in the form of boric acid, were evaluated. The plots comprised four 1.6-m-long rows, with plants spaced 0.4 m apart and a row spacing t

Table 2. Mean values of inner fresh weight, outer dry weight, inner dry weight, leaf boron content, head compactness, head size, and yield obtained for purple cabbage grown at two different row spacings Aquidauana, MS.

Treatment	IFW	ODW	IDW	LBC	COMP [1]	SIZE [2]	YIELD
Spacings	--------------- g ---------------			mg kg^{-1}	---	---	kg ha^{-1}
0.8 x 0.4 m	0.59	127.64	69.49	117.60	2.94	2.18	21.550
0.6 x 0.4 m	0.56	127.09	66.51	214.90	2.95	2.12	26.660
Test F	0.591 ns	0.011 ns	0.369 ns	5.576*	0.040 ns	0.158 ns	9.287**
Regression	L	--	L	Q	Q	--	Q
Interaction	0.545 ns	0.265 ns	0.155 ns	2.522 ns	0.516 ns	0.989 ns	0.326 ns
CV (%)	20.99	12.48	22.82	17.90	3.47	21.42	21.99

* significant ($p \leq 0.05$ probability); ** significant ($p \leq 0.01$ probability); ns – not significant; L – linear model: Q – quadratic model; (IFW) - inner fresh weight; (ODW) - outer dry weight; (IDW) - inner dry weight; (LBC) - leaf boron content; (COMP) - head compactness; (SIZE) - head size; (YIELD) - and yield. [1] Means 1. 2. and 3 represent cabbage heads classified as soft. medium. and firm. respectively. [2] 0 = heads ≤ 250 g; 1 = 250-500 g; 2 = 500-750 g; 3 = 750-1.000 g; 4 = 1.000-1.500 g; 5 = 1.500-2.000 g and 6 ≥ 2.000 g.

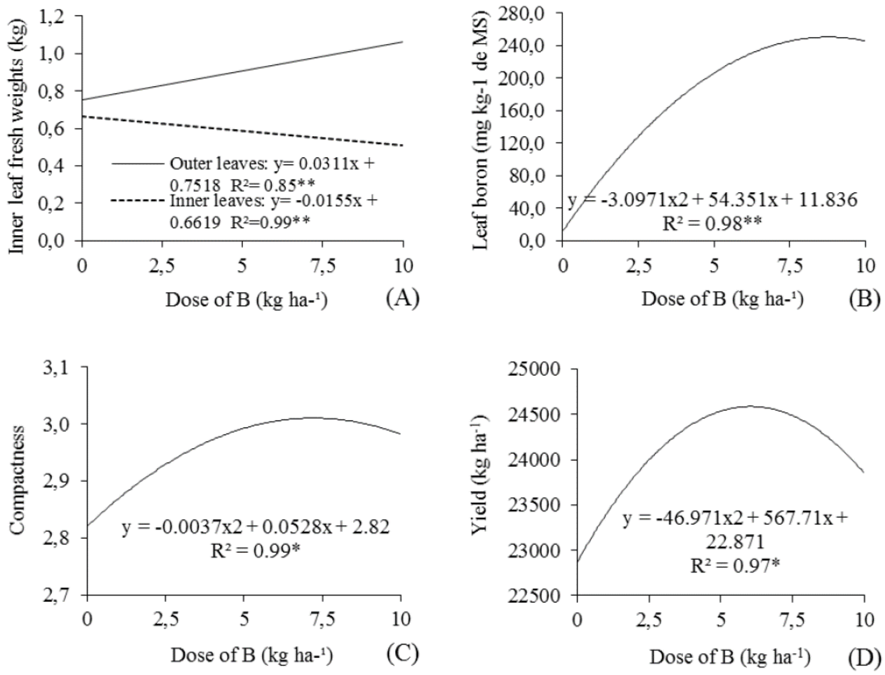

Fig 2. Mean values of outer and inner leaf fresh weights (A), leaf boron content (B), head compactness (C), and yield (D) according to boron doses applied to the purple cabbage crop. * significant ($p \leq 0.05$ probability), ** significant ($p \leq 0.01$ probability). Aquidauana, MS.

that varied depending on the treatment. A basic fertiliser was applied during seedling transplanting, supplying 250 kg ha^{-1} of a 04-20-20 formula. The experimental units comprised twelve plants distributed among four rows; the six plants in the centre of each plot were evaluated, excluding the first and last row of each treatment. The seedlings were sown in 128-cell styrofoam trays with a Plantmax® commercial organo-mineral substrate for vegetables, maintained in an agricultural greenhouse, and watered daily. The seedlings were transplanted when the seedlings had produced four to five true leaves. The boron doses were applied at 15 days after transplanting the seedlings. Weed control was accomplished by manual weeding, and pests were controlled by applying a deltamethrin-based insecticide (0.75 g of the a.i./100 L of water) by spraying. Water was supplied according to the plant demand using a conventional sprinkler irrigation system. Topdressing with 140 kg ha^{-1} of N was accomplished in instalments at 20 and 40 days after transplanting.

Evaluated characteristics

The leaf boron levels and crop yield components were evaluated. For leaf boron content, recently mature leaves (middle) were sampled from each treatment at the onset of head formation, according to Ribeiro et al. (1999). The material was dried in a forced-air oven at 65 °C to a constant weight and then ground in a Wiley mill equipped with a 1-mm mesh sieve. After drying and grinding, the samples were analysed following the methods described by Ribeiro et al. (1997). For yield components, six plants from the useful area of each plot were sampled during the harvest, evaluating the following characteristics: plant height (measured as the distance from the soil surface to the highest portion of the plant); stem diameter (measured at the base of the stem using a calliper); head height and head diameter (measured as the distance between the longitudinal and transverse ends of the head); outer and inner leaf numbers of the leaves that comprise the head by detaching leaves one at a time; fresh and dry weights of the outer and inner leaves measured after being detached and counted (the outer and inner leaves were weighed separately to determine the fresh weight, and to measure the dry weight, the leaves were placed in paper bags, dried in an oven at 65 °C to a constant weight and weighed on a digital scale); compactness (evaluated manually as soft, medium, and firm compactness and assigned a grade of 1, 2, and 3, respectively); head classification (evaluated using a diagrammatic scale and assigned a grade from 0 to 6, where 0 = < 250 g, 1 = 250-500 g, 2 = 500-750 g, 3 = 750-1,000 g, 4 = 1,000-1,500 g, 5 = 1,500-2,000 g, and 6 = > 2,000 g); and yield (commercial heads were used , and the yield was calculated in kg ha^{-1}).

Statistical analysis

The data were subjected to analysis of variance (F test), and the means of the two spacing factor levels were compared by Tukey's test at 5%, while regression curves were fit for the boron dose factor levels.

Conclusion

The results showed that reducing the row spacing from 0.8 m to 0.6 m increased the purple cabbage crop yield and the boron uptake by the plants. A smaller row spacing (0.6 x 0.4 m) and a boron dose of 6.01 kg ha^{-1} provided the highest cabbage yield.

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