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Does the application of boron in different stages of soy crop affect its productivity?

A aplicação de boro em diferentes estádios da cultura da soja afetam sua produtividade?

Eduardo Schanoski de Souza[1] (ORCID 0000-0002-5775-3623), Matheus Silva Romam[1] (ORCID 0000-0001-7452-5457), Bruna Ferrari Schedenffeldt[2] (ORCID 0000-0002-2099-3690), Elias Silva de Medeiros[1] (ORCID 0000-0002-9694-4019), Paulo Vinicius da Silva[1*] (ORCID 0000-0003-4647-5602), Munir Mauad[1] (ORCID 0000-0003-4119-5783)

[1]Federal University of Grande Dourados, Dourados, MS, Brazil. *Author for correspondence: munirmauad@ufgd.edu.br
[2] Federal University of São Carlos, Araras, SP, Brazil.

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ABSTRACT

Soybean is one of the most demanding annual crops in boron (B), however, there is a divergence regarding the best phenological stage to carry out this application via foliar. Therefore, the objective of the present work was to evaluate the influence of different times of foliar application of B, with and without splitting, on flowering, productivity, and components of soybean production. For this, an experiment was carried out in the field, the experimental design used was in randomized blocks, with seven times of foliar applications of B (control, 100% 15 V4, 100% R1, 100% R3, 50% V4 + 50% R1, 50% V4 + 50% R3 and 50% R1 + 50% R3) and four replications, totaling 28 experimental plots. The number of flowers, number of beginning pod, B content in plants, weight of 1000 grains (g) and productivity were analyzed. The highest B content was observed with applications in the V4 (50%) + R1 (50%) and V4 (50%) + R3 (50%) stages, that is, part in the vegetative stage and part in the reproductive stage. The application of B did not result in a significant difference in relation to the number of inflorescences per plant. There was no significant effect of the times of foliar application of B for the variable of number of pods per plant, number of inflorescences and productivity. For weight of 1000 grains (g) higher values were found in V4, R1 and R3 and in the control. Therefore, the foliar application of boron in the stages V4 (50%) + R1(50%) and V4(50%) + R3 (50%) increased the levels of B in the plant, while in R1+R3 it provided the highest number of beginning pods. However, there was no effect of boron application for grain yield regardless of the time of application.
KEYWORDS: foliar fertilization; phenology; boron; soybean.

RESUMO

A soja é uma das culturas anuais mais exigentes em boro (B), no entanto, existe uma divergência em relação sobre qual melhor estádio fenológico para efetuar essa aplicação via foliar. Logo, o objetivo do presente trabalho foi avaliar a influência de diferentes épocas de aplicação foliar de B, com e sem parcelamento no florescimento, produtividade e componentes da produção da soja. Para tal, foi realizado um experimento em campo, o delineamento experimental utilizado foi em blocos ao acaso, com sete épocas de aplicações foliares de B (testemunha, 100% 15 V4, 100% R1, 100% R3, 50% V4 + 50% R1, 50% V4 + 50% R3 e 50% R1 + 50% R3) e quatro repetições, totalizando 28 parcelas experimentais. Foram analisados o número de flores, número de canivete, teor de B nas plantas, peso de 1000 grãos (g) e a produtividade. O maior teor B foi observado com aplicações nos estádios V4 (50%) + R1 (50%) e V4 (50%) + R3 (50%) isto é, parte no estádio vegetativo e parte no estádio reprodutivo. A aplicação de B não resultou em diferença significativa em relação ao número de inflorescências por planta. Não houve efeito significativo das épocas de aplicação foliar de B para a variável de número de vagens por planta, número de inflorescências e produtividade. Para peso de 1000 grãos (g) foram encontrados maiores valores em V4, R1 e R3 e na testemunha. Portanto, a aplicação foliar de boro nos estádios V4 (50%) + R1 (50%) e V4 (50%) + R3 (50%) aumentou os níveis de B na planta, enquanto em R1+R3 proporcionou o maior número de canivetes. No entanto, não houve efeito da aplicação de boro para a produtividade de grãos independente da época de aplicação.
PALAVRAS-CHAVE: adubação foliar; fenologia; boro; soja.

INTRODUCTION

Soybean cultivation is one of the *main commodities of* Brazilian agribusiness, showing area growth of 3.8% in the 2021/2022 crop compared to the 2020/2021 crop, reaching 38.5 million acres and an estimated production of 140.5 million tons, representing an increase of 2.3% compared to the last harvest (CONAB 2022).

The large area of soybean production in Brazil is mainly found in the Cerrado biome, which presents soils with medium and sandy texture (SANTOS & ALBUQUERQUE FILHO 2020) with low organic matter content and lower water retention capacity. Consequently, they are soils often deficient in nutrients due to low degradation of organic matter, as in the case of boron, an important micronutrient in soybean (SILVA et al. 2021).

Soybean is one of the most demanding annual crops in B (TRAUTMANN et al. 2014), especially at the beginning of the reproductive phase (CARVALHO & NAKAGAWA 2012). It is a nutrient with low mobility in the plant, due to its complex shape and low solubility, making it difficult to redistribute, requiring the supply of B constantly during the vegetative and reproductive period of the plants (MASCARENHAS et al. 2014).

Boron participates in processes of sugar transport, lignification, cell wall structure, carbohydrate and RNA metabolism, respiration, cell wall synthesis and plasma membrane integrity (CAMACHO-CRISTÓBAL et al. 2018). Its availability is essential for pollen grain germination and pollen tube growth, and also to increase flower collection, granulation, i.e., grain formation and to interfere with the retention of newly formed pods (RAIJ 2011, GUPTA & SOLANKI 2013).

And one way to provide nutrients to plants is through the foliar fertilization technique, a method that has been widely recommended due to the development of high concentration soluble fertilizers, associated with agricultural pesticides in spray tanks (GAZZIERO 2015). Foliar application of nutrients has the function of increasing or maintaining the concentration of nutrients in leaves during the grain filling period (TAIZ et al. 2017).

Research results demonstrate a great variability regarding the best time for application of boron fertilization in soybean plants. According to ROSOLEM & BOARETTO (1989) the stage from R1 to R5 is the one with the highest demand for nutrients by soybean plants. RAIMUND et al. (2013) indicate the stage of V6 and R5 as recommended for the application of boron leaf in soybean crop due to the high demand for filling and grain formation, however SILVA et al. (2020) with the application of leaf B in stages V4 and R1 did not observe significant difference for soybean grain yield.

Given the significant importance and divergence of information in the literature regarding boron fertilization for soybean development, it is necessary to understand the phenological stage suitable for fertilizer application in soybean crop, especially in Cerrado conditions. Thus, the objective of this study was to evaluate the influence of different times of leaf application of B with and without installment in flowering, productivity, and components of soybean production.

MATERIAL AND METHODS

The work was conducted at Chácara Andrade, located in the city of Fátima do Sul, MS, (latitude of 22° 26'S, longitude 54°28'W and altitude of 430 m). The climate, according to the Köppen classification, is of type Aw (ALVARES et al. 2013) tropical monsoon, with rainy summer. The soil of the experimental area is classified as dystrophic Red Latosol of the sandy franc type (SANTOS et al. 2013), and presented the chemical characteristics presented in Table 1.430 m

Table 1. Chemical parameters for fertility purposes of sample (0-20 cm) of Dystrophic Red Latosol.

Dystrophic Red Latosol										
P Resin	M.O.	pH	K	Ca	Mg	H+Al	B	SB	CTC	V
mg/dm^3	mg/dm^3	Ca/Cl_2	------ cmolc/dm^3 -----				mg/dm^3	-- cmolc/dm^3--		%
7.35	9.03	4.8	0.08	1.85	0.49	0.03	0.23	2.42	2.45	45.1

Each experimental unit consisted of six lines with 4 m length each, spacing of 0.45 m between them, totaling 9 m^2. The 4 central lines of the plots were considered as a useful area, discarding 0.5 m from each end.

Before sowing the area was desolated with glyphosate (3.5 L ha^{-1}), chlorimuron (80 g ha^{-1}) with the addition of nitrogen (1.2 l/ha) and 3 days after the application of paraquat (3 L ha^{-1}), a product in which it presented its application and commercialization regulated in October 2017, during which time the experiment was developed. Sowing was performed on October 21, 2017, using the cultivar BMX Potencia of high size, indeterminate growth habit, maturation group 6.7 and sowing density of 14 seeds meter. Sowing fertilization consisted of the application of 250 kg ha^{-1} of formulated 02-20-18. The seeds were treated at the property using Orgamon® (4 mL kg^{-1}) and Standak Top® (pyraclostrobin + methyl thiophanate + fipronil) (2 mL kg^{-1}), germination occurred on 10/26/2017.

The leaf applications of B were prepared Bravo Boro 10 - For Plant – 0.5 kg ha^{-1} syrups, the recommended base followed the soil lysine order to establish the production components. This dose followed the recommendation of a package leaflet for application, being performed as follows: (1) full dose treatment (100%), i.e., 0.5 kg ha^{-1} applied at a single time and (2) the dose 0.5 kg ha^{-1}, applied in installments in two applications, and these were divided into two applications of 50% (Fractional applications occurred in different phenological stages). The applications were made with a pressurized costal spray with CO_2, equipped with an application bar with 4 flat jet nozzles, fan type, spaced at 0.50 m, which provided volume of syrup equivalent to 200 L ha^{-1}.

The first boron application occurred when 50% of the plot plants had the third trifoliate leaf fully developed, characterizing the V4 stage, and so on for each phenological stage.

During the conduction of the experiment there was the presence of soybean caterpillar (*Anticarsia gemmatalis*, Lepdoptera, Noctuidae), apple caterpillar (*Heliothis virescens,* Lepdoptera, Noctuidae) and brown bedbug (*Euschistus heros,* Hemiptera, Pentatomidae) which were controlled with additive applications (0.75 kg p.c. ha^{-1}) when pests reached the level of economic damage.

The number of flowers and the number of beginning pods were determined by selecting 5 plants randomly in the useful area of the plot. The plants were marked with a tape, and the counts of each structure were made at intervals of 5 days. The number of flowers was determined by counting all flowers emitted by the plants during the period from 05/12/2017 (R1) to 04/01/2018, when there was no longer emission of flowers by the plants. The counting of the number of pods in the beginning pod stage began on 12/20/2017 (R3) and lasted until 09/01/2018 when the plants were no longer in this phenological stage. The experimental design used was in randomized blocks (four blocks), with seven stages of leaf application of B (Control, 100% V4, 100% R1.100% R3, 50%V4 + 50% R1, 50% V4 + 50% R3 and 50% R1 + 50% R3). This design was subdivided in time (Epochs); thus, the treatment design was divided into a plot subdivided into time. The amounts of beginning pods and leaves were evaluated in seven stages during five and seven seasons, respectively.

At the time of harvest (R8), the following determinations were made: B content in the plant collecting 5 random plants in the useful area of the plot. For this, the plants were dried in a greenhouse of forced circulation at 65 ºC for 72 h. The aerial part (stem and leaf) was ground in a Wiley mill and sent to the analysis laboratory to determine the nutritional status of boron in the plants according to the methodology proposed by MALAVOLTA et al. (1997). The number of pods per plant was determined in 10 plants in the useful area of the plot. Average number of grains per pod was obtained by counting the number of grains of the pods of 10 plants and divided by the total number of pods.

The weight of 1000 grains was determined following the methodology proposed by BRASIL (2009), which were weighed on a precision scale (0.001 g), according to the criteria established in the RAS and the results were expressed in grams. Grain yield was obtained by collecting plants contained in 1m² of the useful area of the plot, manually trodden, and the resulting grains were clean and weighed. The grains were standardized at a humidity of 13% and then transformed into kg ha^{-1}.

Statistical analyses of the data were performed with the aid of the R program (R CORE TEAM 2021). The results were submitted to variance analysis and the means compared by the Tukey test at the level of 5% probability, when the Stage was studied. For the quantitative factor epoch, regression analysis was conducted.

RESULTS AND DISCUSSION

Statistical analyses showed that there was no effect of the Stage x Epoch interaction when the boron content variables and the number of beginning pods and flowers ($p>0.05$) were evaluated. There was a stage effect for the B content in the plant and number of Beginning pods (Table 2). The highest content was observed with application in stages V4 (50%) + R1 (50%) and V4 (50%) + R3 (50%) that is, part in the vegetative stage and another in the reproductive stage, differing from the other time of application. While the lower content was found in the witness that differed from the other treatments.

Table 2. Boron content in the plant (ppm), number of flowers, number of beginning pods in soybean plants as a function of the time of application of B via foliar. Chácara Irmãos Andrade, MS, 17/18.

Treatment(1)	Boron	Flowers	Beginning pods
Witness	19.52 e*	26.87	36.29 bc
V4	25.78 c	23.16	33.36 c
R1	21.42 d	28.22	39.68 ab
R3	21.46 d	28.90	37.55 abc
V4+R1	29.32 a	25.08	33.78 bc
V4+R3	27.50 b	27.95	39.04 abc
R1+R3	20.86 d	28.46	42.62 a
	F(2) Value		
	570.61*	1.48 ns	6.52**
CV (%)	8.34	38.18	21.46

*Averages followed by equal letters do not differ from each other by the Tukey test at 5%.
(1)**, significant to 5%; ns, not significant to 5% by F-test.

Cultivars of indeterminate growth such as the one used in this study present a lower proportion of the vegetative phase (33.4%) than the cultivars of determined growth (42%), a fact associated with the overlap of the vegetative and reproductive phases and, consequently, their early flowering (ZANON et al. 2015) which indicates a higher proportion of the growth cycle in the reproductive phase. Thus, as part of the fertilization was performed in V4, the physiological activities of the soybean plant were enhanced, as in the case of the photosynthetic rate and the efficient use of water, as reported by FUJIYAMA et al. (2019). On the other hand, the applications in R1 and R3 favored the supply of B to the reproductive phase, which presented a higher proportion of the total cycle in the reproductive period.

According to ZANON et al. (2015), cultivars of indeterminate growth continue to grow and increase their size until near the beginning of grain filling. Therefore, it was found that the application of B in stages R1 and R3 contributed to the supply of the vegetative and reproductive organs that develop after the beginning of flowering in cultivars with this growing habit. However, B is an element of low mobility in phloem, which requires the need for supply and availability during the vegetative (CALONEGO et al. 2010) and reproductive (AHAMAD et al. 2009) soybean stage.

Although B has great importance in the participation of the reproductive process of plants through germination and growth of pollen tube, seed fixation in reproductive structures (AHMAD et al. 2009) there was no significant difference ($p>0.05$) between the stages when the number of inflorescences per plant was evaluated (Table 2). However, the analysis of variance showed that there was effect of Epoch ($p<0.05$). Thus, the regression was adjusted between the days after sowing and the number of inflorescences per plant (Figure 1).

The regression adjustment resulted in an R^2 of 61%, indicating that 61% of the variability of the number of flowers is explained by the adjustment of the model. The adjustment reveals that the maximum expected amount of 47 leaves occurs in 60 days after sowing.

The R3 stage is characterized by the beginning of the development of the pods, also known as the beginning pods phase, where the pods are up to 5 mm long. This stage is of significant importance for the definition of plant yield components, such as the number of pods per plant. In this sense, the highest number of beginning pods was observed for the R1+R3 treatment that differed from the application in V4 and V4+R1 (Table 2).

The application in the R1 + R3 stages presented the best results, probably due to the fact that the soybean plant presented different demands per boron according to its development, and the reproductive stages are the most important. Similar results were obtained in a study developed by VARANDA et al. (2018), in which the best responses to boron application in the flowering phase on soybean agronomic variables was in R1 and R4, beginning of the reproductive phase, in the edaphoclimatic conditions of off-season in the irrigated floodplain.

On the other hand, the lower number of beginning pods was found with applications in stages V4 and V4+R1, which can be attributed to the fact that although the highest nutrient absorption rates occur in flowering and grain filling intake, for most of them, the highest amounts are absorbed after flowering (ROSOLEM & BOARETTO 1989), with the split applications of 500g of B in the V4 stage(ROSOLEM & BOARETTO 1989), with the split applications of 500g of B in the V4 stage and R1 not enough to attribute significant gains in the formation of beginning pods. This information corroborates data obtained by KAPPES et al. (2008), where the application of up to 400 g ha^{-1} boron in the cultivar M-SOY 8411 did not significantly influence the formation of pods per plant.

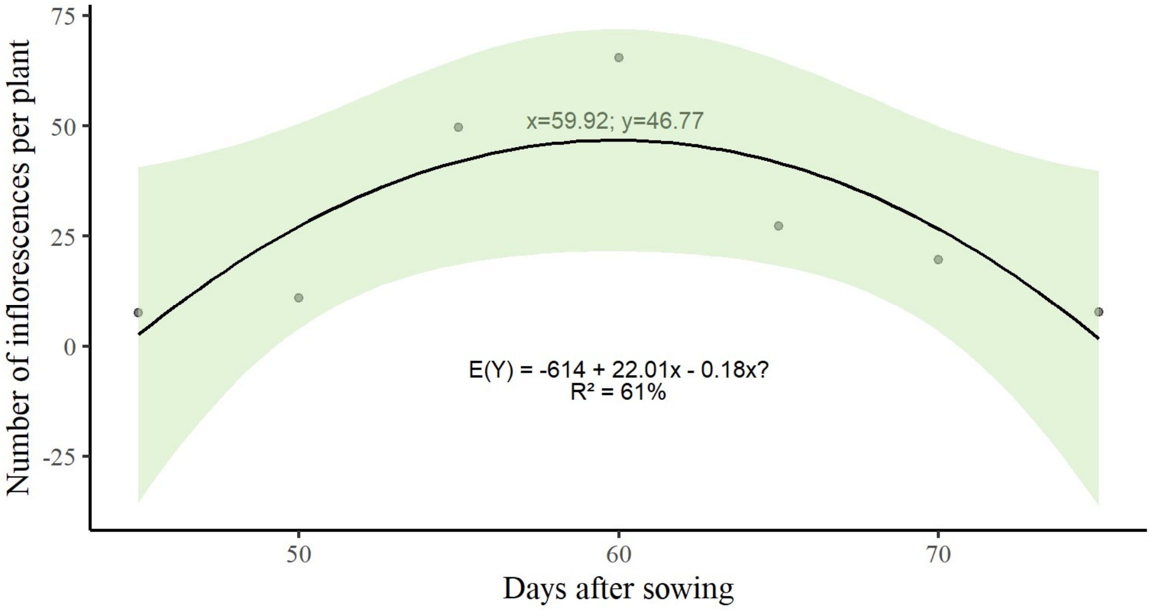

Figure 1. Number of inflorescence per plant as a function of leaf application of boron in different stages of soybean crop development. Chácara Irmãos Andrade, MS, 17/18.

There was no significant effect of leaf application times of B for the variable number of pods per plant (Table 3), and the highest number of pods per plant observed for application in R1 + R3 (0.5 + 0.5 kg ha^{-1} of B) produced 48 pods per plant, while the smallest number was observed for the V4+R3 treatment with 38 pods produced per plant. These results are in agreement with SILVA et al. (2020) that evaluating doses, methods, and times of application of B for the cultivar Msoy7730 IPRO of soybean did not observe significant response on the number of pods per plant. While GOMES et al. (2017) did not observe a significant response to this variable when studying different times of leaf application of B as a function of phenological stage for conventional (BRS 7980) and transgenic (Msoy7739) cultivars.

As for the number of pods per plant, the number of grains per pod did not present significant differences due to the time of leaf application of B (Table 3). These results corroborate those reported by SILVA et al. (2020) for cultivar Msoy7730 IPRO and CALONEGO et al. (2010) with cultivar BRS 214 RR. The absence of significant results for the variables number of pods per plant and number of grains per pod may be related to the initial b content in the soil (0.23 mg dm^{-3}) being considered average according to RAIJ et al. (1997), therefore being sufficient for absorption by plants. Thus, there was no increase in these analyzed parameters.

The weight of 1000 grains (g) was influenced by the time of leaf application of B, with the highest values observed in treatments V4, R1 and R3 and in the control (Table 3). These data do not corroborate those found in the literature, such as SANTOS et al. (2019) who reported the increase in the mass of 1000 grains when foliar B was used in stage V6 and R2. While VARANDA et al. (2018) observed an increase in the mass of one hundred seeds with boron application in R2 and R4, in contrast, in the present study, the increase occurred in R1 and R3 that did not differ statistically from control and V4.

There was no effect of B application on soybean yield (Table 3). A possible explanation for the absence of response to soybean yield as a function of leaf application of B is the fact that both the number of pods per plant and the number of grains per pod did not respond significantly to the application of B (Table 3).

According to ZUFFO et al. (2018) the number of pods per plant is the component of production with the greatest influence on productivity and presents a direct estimate of 0.885, while the number of grains per pod is the second component of production that also influences productivity, whose direct estimation value is 0.541. Thus, these two components did not present significant difference, hence they did not increase in grain yield.

Table 3. Number of grains per plant (GP), pod per plant (VP), grains per pod (GV), weight of one thousand grains (PMG) and yield (P) of soybean variety POTENCIA RR under different times of foliar boron application. Chácara Irmãos Andrade, MS, 2017/18.

Treatment[(1)]	Pod/Plant	Grain/Pod	PMG	Productivity

	-------------- nº -------------		---- g ---	---- kg ha^{-1}---
Witness	44 a	2.36 a	134.96 a	4102 a
V4	46 a	2.31 a	134.44 a	3859 a
R1	42 a	2.28 a	129.10 abc	4111 a
R3	43 a	2.37 a	132.04 ab	4219 a
V4+R1	38 a	2.39 a	126.35 bcd	3375 a
V4+R3	40 a	2.27 a	125.22 cd	3839 a
R1+R3	48 a	2.16 a	122.12 d	4258 a
		F[(2) values]		
	1.49 ns	0.41ns	13.76*	0.896 ns
(CV%)	13.38	10.41	2.08	16.35

[(1)]Averages followed by equal letters do not differ from each other by the Tukey test at 5%.
[(2)]**,* and significant to 1% and 5%,**: not significant.

The absence of a significant response to grain yield in soybean is reported by several authors (CALONEGO et al. 2010, GOMES et al. 2017, SOUZA et al. 2018, SILVA et al. 2020, RATKE et al. 2020). One factor that should be considered is the distinct demand of each cultivar, because genetic factors are related to the efficiency of nutrient use by plants (FAGERIA et al. 2009). However, according to FIOREZE et al. (2018), another point to be considered is the "umbrella" effect during leaf application, a fact that can hinder the passage of drops to the middle and lower third of the plant, reaching only the upper leaves.

In the literature, the responses to boron foliar fertilization for soybean culture have been inconsistent. NAKAO et al. (2018) did not find significant effects of the application of different doses of B on nutritional levels, production components and yield of soybean seeds. The same was reported by ENDERSON et al. (2015) who, while working with foliar fertilization of micronutrients in 23 sites in the USA, using the nutrient in isolation (B, Fe, Mn, Cu) or in mixtures, observed an increase in B contents in leaf tissue and grains, but not in soybean yield. In this sense, the use of this technique opens discussions about its real effectiveness for the crop, and more research is needed on the correct management in the different production systems.

CONCLUSION

The foliar application of boron in stages V4 (50%) + R1 (50%) and V4 (50%) + R3 (50%) increased b levels in the plant, while in R1+R3 it provided the highest number of beginning pods. However, considering the productive characteristics of soybean, significance was found in the weight of 1000 grains (g) for applications in V4, R1 and R3 in isolation, while for grain yield, regardless of the time of application, there was no influence of boron application.

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