DOSES, METHODS AND TIMES OF APPLICATION OF BORON IN SOYBEAN UNDER FIELD CONDITIONS

DOSES, MÉTODOS E ÉPOCAS DE APLICAÇÃO DE BORO NA SOJA SOB CONDIÇÕES DE CAMPO

Renan Cesar Dias da SILVA[1]; Geovani Soares da SILVA JUNIOR[2]; Adilson PELÁ[3]; Regina Maria Quintão LANA[4]; José Geraldo Mageste da SILVA[4]
1. Institute of Agrarian Sciences, Federal University of Uberlândia, MG, Brazil; 2. Agronomist, Cargill, Brazil; 3. University State de Goiás, Ipameri, GO, Brazil; 4. Institute of Agrarian Sciences, Federal University of Uberlândia, MG, Brazil

ABSTRACT: The boron (B) fertilization in soybean is important to ensure great yields. Boron correction must be applied in deficient soils repairing losses, exports and leaching. The objective of this study was to evaluate the effects of doses, methods and times of application of B in soybean B content and yield. The field experiments were conducted during the 2015/16 and 2016/17 cropping seasons and set as a randomized block design with nine treatments (0, 0.5, 1, 1.5, 2 kg ha^{-1} of B, 0.5 kg ha^{-1} of B mixed with NPK (02-28-18) in furrow during sowing, foliar application with 0.3 kg ha^{-1} of B in V4 soybean stage, foliar application with 0.3 kg ha^{-1} of B in R1 soybean stage, and foliar application of 0.15 kg ha^{-1} in V4 plus 0.15 kg ha^{-1} of B in R1 soybean stage) and four replications. Boric acid was the B source and the variables analyzed were: B leaf content, B exported in seeds, number of pods per plant, number of seeds per pod, weight of 100 seeds (g) and productivity (kg ha^{-1}). The levels of B in leaf were between 30.1 and 43.8 mg kg^{-1} and between 65.0 and 92.6 mg kg^{-1} in the 2015/16 and 2016/17 growing season, respectively. Exports of B in seeds were estimated between 166 and 248 g ha^{-1} and between 208.9 to 260.8 g ha^{-1} in the 2015/16 and 2016/17 growing season, respectively. Great productivity (3,820 kg ha^{-1}) was observed in the 2016/17 growing season, with an estimated dose of 0.95 kg ha^{-1} of B.

KEYWORDS: Boric acid. Foliar fertilization. *Glycine max*. Micronutrient.

INTRODUCTION

Soybean is considered one of the most important crops in the world due to its high protein content and several uses, enabling the formation of large industrial sectors destined for its processing to oil, meal and feed. In recent decades, there has been a significant increase in the productive capacity of the Brazilian soybean areas, mainly as a consequence of scientific advances and the adoption of new technologies for cropping.

Among these technologies there are the production and use of high quality seeds and foliar mineral fertilization (PESKE; BARROS; SCHUCH, 2012; SUZANA et al., 2012;). Special attention has been devoted to the management of micronutrients in the soybean culture. Boron (B) is a micronutrient which its deficiency in agriculture is quite common, especially in Cerrado (Savanh-like biome) soils, and there still gaps regarding the best time and quantity that must be applied during soybean cycle.

The soybean plant presents variable B requirements according to its cycle phase (vegetative or reproductive) (SANTOS et al., 2008). Plants need the micronutrients for innumerous physiological processes during their development, during cell division, in the metabolism of nucleic acid, in the germination of pollen grains and growth of the pollen tube, in the synthesis of amino acids and proteins and in the internal transport of sugars, starches, nitrogen (N) and phosphorus (P) (MASCARENHAS et al., 2014).

Boron is an essential element for plants because it acts as an enzymatic regulator and in the process of structuring and membrane functioning (input and output of solutes), in the formation of cell wall, synthesis and transport of carbohydrates, protein synthesis, N fixation, photosynthesis and plant growth, as well as provide plant resistance to diseases (FERNANDES, 2006). In addition, B fertilization improves flower fertilization, seed formation, the meristem growth, cell differentiation, maturation and division and interferes with the retention of newly formed pods (PRADO, 2008). However, the limit between deficiency and toxicity to this element is very narrow, requiring greater care in the management of B fertilization.

The B deficiency is general in the Brazilian soils, especially in those soils found in the Cerrado region, in sandy soils with low organic matter content and where water stress regularly occurs (TIRLONI et al., 2011). Boron is regularly exported

Received: 01/05/2019
Accepted: 30/01/2020

http://dx.doi.org/10.14393/BJ-v36n6a2020-48015

by crops and the use of fertilizers and lime also contributes to the insolubilisation of micronutrients (SOARES; CASAGRANDE; ALLEONI, 2008). According to Hansel; Oliveira (2016), the conditions that favor the B deficiency are dry seasons, elevated precipitation, low organic matter content and soil pH in the range between 5 and 7.

For the majority of plant species B is a non-mobile element and, as a consequence, the first signs of symptoms of B deficiency arise in regions of growth and increased demand like meristems. The low B mobility due to its complex forms and low solubility make it difficult to be redistributed from more mature plant tissues. Thus, B is necessary in constant supply during the vegetative and reproductive stages of the plants (MASCARENHAS et al., 2014). The B application via soil or foliar is widely used in many crops as a strategy to improve the survival of flowers, fruit quality and stress tolerance. However, the effectiveness of B fertilization to improve these factors is variable in the literature (ROSS et al., 2006; KHAYYAT et al, 2007).

The nutritional requirement of crops, in general, becomes more intense with the beginning of the reproductive stage. This increased demand is due to the fact that the nutrients are essential to the formation and the development of new reserve organs (MALAVOLTA, 2006; GALLI et al., 2012). The best results tend to be found when the B application is performed in V6 to R5 soybean stages, where the plants need to absorb great amounts of B for seed formation and filling (RAIMUNDI; MOREIRA; TURRI, 2013).

According to Martin et al. (2014), the B methods of application to plants involve the application of B fertilizers via soil, prior or together with crop sowing, or via foliar, alone or together with agricultural pesticides. However, the efficiency of foliar application can be compromised by climatic conditions and by foliar absorption efficiency, which varies for each plant species (MARTIN et al., 2014). Therefore, the objective of this study was to evaluate the soybean plant boron content and yield in function of doses, times (moment of application) and methods of application.

CONTENTS

The field experiment was conducted during the 2015/16 and 20162/17 cropping seasons in the Goiás State University, Ipameri Campus, located at the coordinates: 17º43'20" South and 48º09'44" West, at an altitude of 800 m above sea level. The soil is classified as dystrophic Red-Yellow Latosol (SANTOS et al., 2013). The climate of the region is a transition between tropical climate with a dry winter (Aw) and humid subtropical climate with a dry winter and hot summer (Cwa) according to the Köppen (ALVARES et al., 2013). Precipitation data was recorded by a weather station in Ipameri during both seasons (Figure 1).

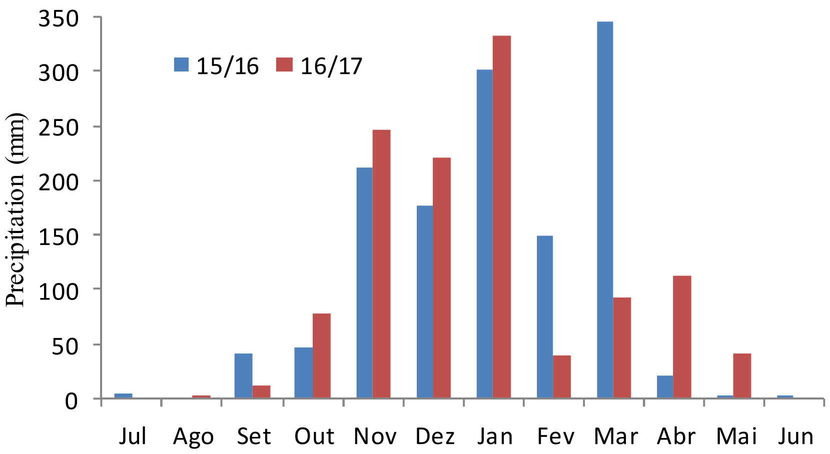

Figure 1. Precipitation (mm) in Ipameri county in 2015/16 and 2016/17 cropping season

The experimental design was set as randomized blocks with nine treatments (0 (T1), 0.5 (T2), 1 (T3), 1.5 (T4), 2 (T5) kg ha^{-1} of B; 0.5 kg ha^{-1} of B mixed with NPK (02-28-18) in furrow during sowing (T6); foliar application with 0.3 kg ha^{-1} of B in V4 soybean stage (T7); foliar application with 0.3 kg ha^{-1} of B in R1 soybean stage (T8), and foliar application of 0.15 kg ha^{-1} in V4 plus 0.15 kg ha^{-1} of B in R1 soybean stage (T9)), and four replications. The application mode was in total area for T1 up to

T5, located in the sowing furrow (T6) and spray on leaves (T7, T8 and T9). The application time was prior to sowing for T-1 up to T-6; in the vegetative stage V4 when the plants showed the fourth leaf fully expanded (T-7); in the reproductive stage R1 at the beginning of the flowering (T-8), and application in divided doses in V4 and R1 soybean stage (T-9).

The experimental plot consisted of six lines of five (5) meters long, spaced by 0.45 m between rows, considering useful area (3.6 m^2) the two central lines, avoiding 1 m at each end. Soil chemical analyzes indicated: pH ($CaCl_2$) = 4.8; P (Mehlich) = 5.6 mg dm^{-3}; soil organic matter (SOM) = 2.9 dag kg^{-1}; K = 46 mg dm^{-3}; Ca = 1.2 cmolc dm^{-3}; Mg = 0.4 cmolc dm^{-3}, H+Al = 3.8 cmolc dm^{-3}; B = 0.34 mg dm^{-3}; Cu = 0.5 mg dm^{-3}; Fe = 43.0 mg dm^{-3}, Mn = 2.3 mg dm^{-3}; Zn = 1.4 mg dm^{-3} (SILVA, 2009); the soil texture analysis indicated 32% of clay, 16% silt and 52% sand. Dolomitic limestone (2.0 t ha^{-1}) was applied 60 days before sowing aiming to increase the soil base saturation to 60%. The sowing fertilization was performed according to soil analysis (ALVAREZ et al., 1999). Fertilizers were applied in the furrow (450 kg ha^{-1} of NPK 02-28-18) corresponding to 9 kg ha^{-1} of N, 126 kg ha^{-1} of P_2O_5 and 81 kg ha^{-1} of K_2O.

The sown occurred in the second half of November of each cropping season (2015/16 and 2016/17) in no-tillage system, with the soybean variety MO7739 IPRO, medium cycle (116 days), aiming a plant population of 260,000 plants ha^{-1}.

The cultural management was performed in a preventive manner to control diseases, pests and weeds. In desiccation and in post-emergence glyphosate (620 g L^{-1}) herbicide was applied at the doses of 3 and 2 L ha^{-1}, respectively. The seed treatment was performed with Maxim Advance (fungicide) (acilalaninato 20 g L^{-1}, thiabendazole 150 g L^{-1}, fludioxonil 25 g L^{-1}) at the dose of 100 mL of commercial product for each 100 kg of seeds, with Cruiser (insecticide) (350 g L^{-1} of Tiametoxan) at the dose of 200 ml of commercial product for each 100 kg of seeds, and with inoculants (*Bradyrhizobium japonicum*) at the dose of 250 g of commercial product for each 100 kg of seeds.

Foliar diseases were controlled with triflostrobina (150 g L^{-1}) and protioconazol (175.0 g L^{-1}) (fungicides) at the dose of 0.4 L ha^{-1} of the commercial product at the beginning of the flowering; eighteen (18) days after, azoxystrobin (200 g L^{-1}) and cyproconazole (80 g L^{-1}) (fungicides), at the dose of 0.3 L ha^{-1} of the commercial product. The occurrence of bedbugs at the grain filling stage was controlled with imidacloprid (100 g L^{-1}) and beta-cyfluthrin (12.5 g L^{-1}) (insecticides) at the dose 1 L ha^{-1} of the commercial product. All applications were performed with spray equipment pressurized with CO_2 (3.0 bars), using black cone nozzle and flow rate of 100 liters per hectare.

At full soybean flowering, leaves of the third trifoliate from the apex were collected without petioles from four (4) plants per plot at random. The samples were gently washed with distilled water and dried in an oven at 60 ºC with forced ventilation for 48 h prior to the determination B content. The extraction was performed by the method of dry digestion in oven and the determination of B was performed by spectrophotometry with azomethine-H (SILVA, 2009).

The harvest was performed manually in the second half of March. Ten (10) plants from the useful area were evaluated for the following parameters: number of pods per plant, number of seeds per pod, weight of 100 seeds and productivity (kg ha^{-1}) with seed moisture at 13%. The B seed content was assessed similarly to the B leaf content to estimate the quantity of B exported (SILVA, 2009).

The data were submitted to analysis of variance by F test, and when differences were significant the averages of the treatments where compared by the Scott-Knott test ($p < 0.05$) and regression for the 0 – 2 kg ha^{-1} doses (Treatments T1 to T5).

The leaf and seed B content were not significantly influenced by B fertilization in both crop seasons (Table 1). The B in leaf in the 2015/16 cropping season ranged from 30.12 to 43.83 mg kg^{-1} indicating that all treatments were within the proper B in leaf range - from 21 to 55 mg kg^{-1} (SOUZA; LOBATO, 2004). In the 2016/17 cropping season the contents of B were greater than those observed in the previous harvest, ranging between from 65 to 92.6 mg kg^{-1}, an observation related to the greatest rainfall the occurred in the vegetative stage of development (Figure 1).

Boron is a nutrient that moves in soil through mass flow, depending on soil water availability which greatly contributes to improve nutrient absorption when precipitation is great.

The results observed in this study did not demonstrated toxicity symptoms regardless of the treatment performed. According to Furlani et al. (2001), B deficiency in soybean is observed when the leaf content is lower than 25 to 30 mg kg^{-1}, and the toxicity appears for contents above 83 mg kg^{-1}, depending on the cultivar and environmental conditions.

The results obtained in this study corroborate with the results found by Rosolem (2007), which reported B foliar values ranging from 25 to 55 mg kg^{-1} as appropriated for great yields. Rosolem; Zancanaro; Bíscaro (2008), studying B in soybean crops for a period of three years, verified that the levels of B in leaf corresponded to B fertilization of 7.5 kg ha^{-1} of B fertilizer. In other study including soybean, Fageria (2000) found that the limit of B toxicity is 155 mg kg^{-1}, which was 41% above the greatest value found in this study, indicating that no B toxicity happened in both crop seasons evaluated.

Table 1. Boron content in leaves from plants in full flowering and boron exported with the harvested grains in function of doses and methods of application in the 2015/16 and 2016/17 crop season.

	2015/16		2016/17	
Boron Dose	Foliar Boron	Grain Boron	Foliar Boron	Grain Boron
kg ha^{-1}	mg kg^{-1}	g ha^{-1}	mg kg^{-1}	g ha^{-1}
0	35.6 a	144.8 a	78.0 a	219.1 a
0.5	30.1 a	201.3 a	92.6 a	301.9 a
1	34.2 a	260.0 a	65.0 a	202.1 a
1.5	37.2 a	203.0 a	78.3 a	213.8 a
2	36.7 a	187.0 a	91.5 a	224.0 a
0.5 + NPK	32.2 a	166.0 a	75.6 a	209.8 a
0.3 V_4	34.7 a	210.0 a	81.2 a	211.2 a
0.3 R_1	41.0 a	248.0 a	88.0 a	260.8 a
$0.15V_4$+$0.15R_1$	43.8 a	187.0 a	78.9 a	245.7 a
0 – 2 kg ha^{-1}				
Linear Reg.	ns	ns	ns	ns
Polynomial Reg.	ns	ns	ns	ns
CV (%)	16.6	25.4	21.7	35.0

CV: coefficient of variation. Averages followed by the same letter in column do not differ by the Scott Knott test ($p > 0.05$).

The B export in seeds was not influenced by the B treatments (Table 1), with values raging between 144.8 and 248.0 g ha^{-1} and between 208.9 and 302.1 g ha^{-1} of B in the 2015/16 and 2016/17 cropping season, respectively. The quantities exported demonstrate that virtually all the doses tested, regardless of the season or method of application, are sufficient to compensate the loss of B with the harvest. However, Rosolem et al. (2012) demonstrated that a linear adjustment better described the increments of B in cotton plants.

There were no differences for the number of pods per plant between doses and application times. The doses from 0 to 2 kg ha^{-1} applied before sowing were lower than the applications at R1, V4+R1 or B + NPK (Table 2). These times and methods of application showed better results in the 2015/16 cropping season, which did not occur in the 2016/17 season, where no differences were observed among methods and doses of B application. The greatest number of pods per plant was observed for the foliar application of 0.3 kg ha^{-1} of B applied at the reproductive stage R1, reaching 83.2 pods per plant, followed by treatments V4+R1 and B + NPK, with 69.75 and 65.75 pods per plant, respectively, in the 2015/16 season. In the 2016/17 cropping season these treatments did not differ, with the foliar applications of B in R1, V4+R1 and B + NPK presenting 47.0, 42.2 and 41.0 pods per plant, respectively. The fact of having produced a great number of pods per plant in the season 2015/16 did not reflected in increased productivity.

In both seasons no significant differences were found for the number of seeds per pod and weight of 100 seeds (Table 2). This is probably due to the initial percentage of B in the soil which was sufficient for the range of productivity verified. Similar results were observed by Seidel; Basso (2012), applying a product based on Ca and B in soybean, the weight of 1000 seeds showed no difference for applications in stages R2, R3 or R4, possibly due to the adequate amount of B in the soil and good water availability during the crop cycle.

Table 2. Number of pods per plant, seeds per pod, weight of 100 seeds and productivity in function of doses and methods of boron application.

	2015/16				2016/17			
Boron Dose kg ha^{-1}	Pod per Plant	Seed per Pod	100 seeds Weight	Yield Kg ha^{-1}	Pod per Plant	Seed per Pod	100 seeds Weight	Yield Kg ha^{-1}
0	50,9 c	2,14 a	15,7 a	2806 a	49,2 a	1,97 a	17,5 a	3353 a
0.5	58,1 c	2,09 a	16,0 a	2643 a	49,5 a	1,98 a	16,8 a	3717 a
1	57,6 c	2,07 a	15,7 a	2935 a	46,0 a	2,10 a	16,9 a	3746 a
1.5	54,7 c	2,03 a	15,2 a	2817 a	42,5 a	2,09 a	17,1 a	3756 a
2	50,4 c	2,07 a	16,0 a	2758 a	45,5 a	1,98 a	17,3 a	3202 a
0.5 + NPK	65,8 b	2,06 a	15,2 a	2921 a	41,0 a	2,10 a	17,1 a	3797 a
0.3 V_4	51,0 c	2,14 a	15,2 a	2716 a	41,0 a	2,11 a	17,1 a	3419 a
0.3 R_1	83,2 a	1,95 a	16,0 a	2964 a	47,0 a	2,00 a	16,7 a	3470 a
$0.15V_4+0.15R_1$	69,8 b	2,04 a	16,5 a	2995 a	42,2 a	2,12 a	17,2 a	3574 a
0 – 2 kg ha^{-1}								
Linear Reg.	ns	ns	ns	ns	ns	ns	ns	ns
Polynomial Reg.	ns	ns	ns	ns	ns	ns	ns	*
CV (%)	13,03	7,02	7,10	8,03	14,3	8,63	3,35	8,60

CV: coefficient of variation. Averages followed by the same letter in column do not differ by the Scott Knott test ($p > 0.05$).

Kappes; Golo; Carvalho (2008), assessing foliar application in soybean crop, observed that the time most suitable for B application is the R5 stage, differing from what was found in this study which verified the R1 stage as the best period for B application for the number of pods per plant in the 2015/16 crop season and not observed differences between the treatments (times, methods and doses of B in the 2016/17 crop season).

The B fertilization treatments were not able to affect the number of seeds per pod when applied before sowing, together with the NPK fertilizer, in vegetative or reproductive stages. Seidel; Basso (2012) found no differences when Ca and B were applied to soybean crop for the number of seeds per pod at the R2, R3 and R4 stages, similarly to the results found in this study. However, Bevilaqua Filho; Possenti (2002) observed that the Ca and B application positively affected the number of seeds per pod in common bean.

Calonego et al. (2010) concluded that foliar B fertilization does not interfere with the 100 seeds weight and yield of soybean, corroborating the results found in this study. Rosolem; Boaretto (1989) reported that the largest supply of nutrients to the soybean crop is between R1 and R5. Therefore, since B is not translocated in soybean plant via phloem, it should be reapplied in the flowering or post-flowering stage for improved effects on yield.

The soybean productivity was similar among treatments in both seasons, however the soybean productivity was superior in 2016/17, which could be explained by the great rainfall occurred in that period, and since no water deficiency occurred during critical soybean stages it is assumed that B was always available to soybean crop development.

In the 2016/17 crop season there was a quadratic adjustment of the B doses applied before sowing (0 – 2 kg ha^{-1}) for the variable productivity where the 0.95 kg ha^{-1} of B resulted in a grain yield of 3,820 kg ha^{-1} (Figure 2), which was above the national average of 3,362 kg ha^{-1} (CONAB, 2017).

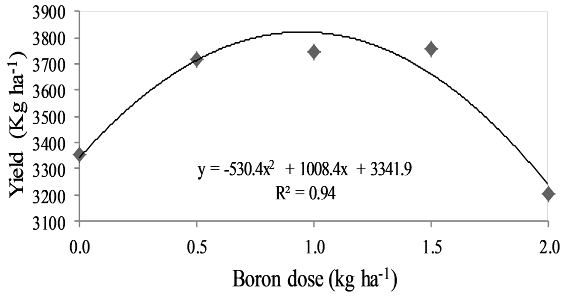

Figure 2. Sobean productivity in function of boron doses appliedin the soil in pre-swin.

According to Silva et al. (2017), studying B application and soil water retention capacity, found that the dose of 1 mg dm^{-3} of B resulted in an additional production of 7 grams plant^{-1} at a soil water retention capacity of 70%.

The similarity of results among treatments (times, methods and doses of B application) can be attributed to the initial B quantity in the soil of the area, which was 0.34 mg dm^{-3}, which is enough to supply the demands required by soybean plants. According to Seidel; Basso (2012), the similarity of results for soybean yield in different foliar applications of Ca and B could also be justified by their contents in the soil (0.38 and 0.25 mg dm^{-3}, respectively) which were able to attend the crop demands for these elements resulting in great crop productivity for all treatments.

The number of pods per plant is superior when boron is applied at the dose of 0.3 kg ha^{-1} in R1 soybean stage.

The number of pods per plant is superior when boron is applied at the dose of 0.3 kg ha^{-1} in R1 soybean stage.

The application of boron in different doses, times and methods do not influence most of the agronomic components evaluated.

Boron deficiency or toxicity in the leaf analyzes were not identified.

Great soybean productivity (3,820 kg ha^{-1}) was observed in the second season for the 0.95 kg ha^{-1} boron dose.

ACKNOWLEDGMENT

The State University of Goiás to Pro-Rectory for Research and Graduate Studies (PRP) for the opportunity of academic training and financial support with the grant of scholarship.

RESUMO: A fertilização de boro na soja é importante para garantir boas produtividades, corrigir solos deficientes e repor perdas, exportação ou lixiviação. O objetivo deste estudo foi avaliar os efeitos de doses, avaliar modos e épocas de aplicação de B na produtividade da soja. Os experimentos foram implantados na Fazenda Experimental da UEG, Campus Ipameri, nas safras 2015/2016 e 2016/2017 com delineamento em blocos ao acaso, com nove tratamentos e quatro repetições. 0,0; 0,5; 1,0; 1,5; 2,0 kg ha^{-1} de boro, - 0,5 kg ha^{-1} de B junto com NPK 2-28-18 no sulco de semeadura; aplicação foliar com 0,3 kg ha^{-1} de boro em V4; aplicação foliar com 0,3 kg ha^{-1} de boro em R1; aplicação foliar de 0,150 kg ha^{-1} em V4 mais 0,150 kg ha^{-1} de boro em R1. Foi utilizado como fonte o ácido bórico. As variáveis respostas analisadas foram: teor na folha, exportação pelos grãos, número de vagens por planta, número de grãos por vagem, massa de 100 grãos e produtividade. Os teores de B encontrados ficaram entre 30,12 e 43,83 mg kg^{-1} na folha de soja na safra 2015/2016 e entre 65,0 e 92,6 mg kg^{-1} na safra 2016/2017. As exportações de Boro foram estimadas entre 166 e 248 g ha^{-1} e 208,9 a 260,8 g ha^{-1} na primeira e segunda safra, respectivamente. Houve maior produtividade na segunda safra (3820 kg ha^{-1}) com dose estimada de 0,95 kg ha^{-1}

PALAVRAS-CHAVE: Adubação foliar. Ácido bórico. *Glycine max.* Micronutriente.

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