

Management of boron fertilization in eucalyptus cultivated in the low altitude Cerrado region in Entisol

Thiago de Souza Celestrino¹, Salatiér Buzetti¹, Marcelo Carvalho Minhoto Teixeira Filho¹, Rodolfo de Niro Gazola¹, Raíssa Pereira Dinalli Gazola¹, Alexandre Costa da Silva¹, Paulo Henrique Müller da Silva², Antônio Leonardo Campos Biagini¹

¹ Universidade Estadual Paulista Júlio de Mesquita Filho, Faculdade de Engenharia de Ilha Solteira, Ilha Solteira, SP, Brasil. E-mail: thiagocelestrino@yahoo.com.br (ORCID: 0000-0002-8380-237X); sbuzetti@agr.feis.unesp.br (ORCID: 0000-0003-2569-4750); mcmt Teixeirafilho@agr.feis.unesp.br (ORCID: 0000-0003-2303-3465); mgazola@gmail.com (ORCID: 0000-0003-0640-5175); raissadinalli@gmail.com (ORCID: 0000-0002-3207-6291); Alexandre_C_Silva@cargill.com (ORCID: 0000-0001-5755-1282); leobiagini10@gmail.com (ORCID: 0000-0002-7233-6895)

² Instituto de Pesquisas e Estudos Florestais, Piracicaba, SP, Brasil. E-mail: paulohenrique@ipef.br (ORCID: 0000-0002-2926-8719)

ABSTRACT: This study aimed to compare the residual effect from boron (B) sources in the planting furrow as well as foliar applications of B, and the top dressing reapplication of micronutrient in boron nutrition, wood productivity and the tree fork of the eucalyptus cultivated in an Entisol. The experiment was assembled in a subdivided plots scheme, arranged in a factorial scheme of 3 x 2 x 2, with the first factor being: 0 kg ha⁻¹ of B, 1 kg ha⁻¹ of B using borogran fertilizer or 1 kg ha⁻¹ of B using boric acid fertilizer in the furrow; with or without B application via leaves (boric acid); and the last factor 2, it refers to the subplots that received or not the top dressing application of B in the soil at 34 months after the planting at the 1 kg ha⁻¹ dose of B (boric acid). Boron sources, at a 1 kg ha⁻¹ dose, as well as the foliar nutrient applications, at 4 and 10 months after planting, reduced the tree fork percentage of eucalyptus trees. The 1 kg ha⁻¹ application of B in the eucalyptus plantation (I144 clone) was not enough in a soil with average B content, being necessary the top dressing reapplication of this nutrient, with positive reflexes in the B content in the soil, and consequently, in the B foliar concentration and wood productivity.

Key words: *Eucalyptus* spp.; fertilizer solubility; micronutrient

Manejo da adubação boratada na cultura do eucalipto cultivado na região do Cerrado de baixa altitude em Neossolo Quartzarênico

RESUMO: Objetivou-se comparar o efeito residual de fontes de boro (B) no sulco de plantio, bem como das aplicações foliares de B, e as reaplicações do micronutriente em cobertura, na nutrição boratada, produtividade de madeira e bifurcação do eucalipto cultivado em Neossolo Quartzarênico Órtico. O experimento foi montado em esquema de parcelas subdivididas, dispostos em esquema fatorial de 3 x 2 x 2, sendo o primeiro fator: 0 kg ha⁻¹ de B, 1 kg ha⁻¹ de B utilizando o fertilizante borogran ou 1 kg ha⁻¹ de B utilizando o fertilizante ácido bórico, no sulco de plantio; com a aplicação ou não de B via foliar (ácido bórico); e o último fator 2, se refere às subparcelas que receberam ou não a aplicação de B em cobertura no solo aos 34 meses após o plantio, na dose de 1 kg ha⁻¹ de B (ácido bórico). As fontes de boro, na dose de 1 kg ha⁻¹, bem como as aplicações foliares do nutriente, aos 4 e 10 meses após o plantio, reduziram a porcentagem de bifurcação das árvores de eucalipto. A aplicação de 1 kg ha⁻¹ de B no plantio de eucalipto (clone I144) não foi suficiente em solo com teor médio de B, sendo necessária a reaplicação do nutriente em cobertura, com reflexos positivos no teor de B no solo, e consequentemente, na concentração de B foliar e produtividade de madeira.

Palavras-chave: *Eucalyptus* spp.; solubilidade de adubos; micronutriente

Introduction

In 2016, the area planted with forests in Brazil for industrial purposes was of 7.84 million hectares, where 72.7% corresponded to eucalyptus plantations, mainly located in the States of Minas Gerais (24%), São Paulo (17%) and Mato Grosso do Sul (15%) (Indústria Brasileira de Árvores - Ibá, 2017). Known by the high wood production capacity, the eucalyptus cultivation in Brazil, according to Gonçalves et al. (2015), presents an average $40 \text{ m}^3 \text{ ha}^{-1} \text{ year}^{-1}$ increment of wood with bark, ranging from 25 to $60 \text{ m}^3 \text{ ha}^{-1} \text{ year}^{-1}$, depending on the edaphoclimatic conditions. Therefore, among the many reasons for this productive level, it is worth noting the investments from forest sector companies in genetic improvement research, providing site-specific allocation of the genotypes, in addition to forest management techniques (Ibá, 2015).

Correctives and fertilizers applications have been becoming almost mandatory practices in forest management, with noted gains in wood productivity due to these applications (Laclau et al., 2010; Gonçalves, 2011). One of the reasons for the fertilizers usage is the forest expansion in regions of the Cerrado biome, whose characteristics are the predominance of marked nutritional restriction, high levels of aluminum in the soil and low water availability.

Research on the fertilizers usage in forest essences has mainly focused on primary nutrients (nitrogen [N], phosphorus [P] and potassium [K]), being them targets for dosage calibration in eucalyptus cultivations (Gazola et al. 2015). For that matter, there is a lack of micronutrients in forest plantations, where, with the insertion of more nutrient-demanding clones, there was a greater frequency of symptoms from nutrient deficiency (Rodrigues et al., 2012). Among them, boron (B) deficiency is the most limiting in eucalyptus wood productivity, being quite common in coarse soils with low organic matter (O.M.), since this is the main source of B (Gonçalves et al., 2015). Such conditions predispose to nutrient deficiency in the plant, not possibly supplying crop requirements throughout the vegetative cycle (Portela et al., 2015).

When detected a necessity of a B application via fertilizer in the soil, the selection of the used source, associated with the soil conditions, will result in a greater or lesser fertilization interaction effect on the nutrient deficiency (Moraes et al., 2004). Therefore, regarding B application in the eucalyptus cultivation, authors have forebode the use of less soluble sources in soils with sandy texture, where there is greater losses by leaching and/or the greater dose splitting, when using more soluble sources (Silveira et al., 2002; Gonçalves et al., 2015).

In Cerrado soils that have low O.M. content, boron fertilization is common in the planting furrow, at the cultivation planting stage, and occasionally the B application via leaves has been employed in regions of prolonged dry period, in order to attenuate the effect of the lower B uptake by the roots during this period (José et al., 2009). However, there

is still controversy regarding the B usage via leaves, due to its immobility in the phloem (Faquin, 2005), thus suggesting further studies that prove the efficiency of foliar fertilization in eucalyptus forests.

Among the functions that B has in the plant, it is possible to highlight the cell elongation, sugar transport, nucleic acid synthesis, hormonal responses, membrane integrity and functioning, cell cycle regulation and the synthesis of pectin, lignin and cellulose (Marschner, 1995; Reguera et al., 2009). Trees submitted to conditions of low B availability display a smaller root lengthening, becoming thick and short, which reduces the volume of soil explored by them (Marschner, 1986). Another typical symptom from B deficiency is the death of the leader, with the oversprouting of lateral buds along the trunk, due to the death and dominance loss of the apical bud (Silveira et al., 2002).

In this context, it is important to verify if the B application into the planting, with sources from different solubilities, is sufficient to meet the cultivation requirements during the cycle, or if it is necessary to reapply the nutrient through top dressing. Therefore, this study aimed to compare the residual effects from B sources in the planting furrow, as well as the foliar B applications, and the micronutrient top dressing reapplication, boron nutrition, wood productivity and tree fork in the eucalyptus.

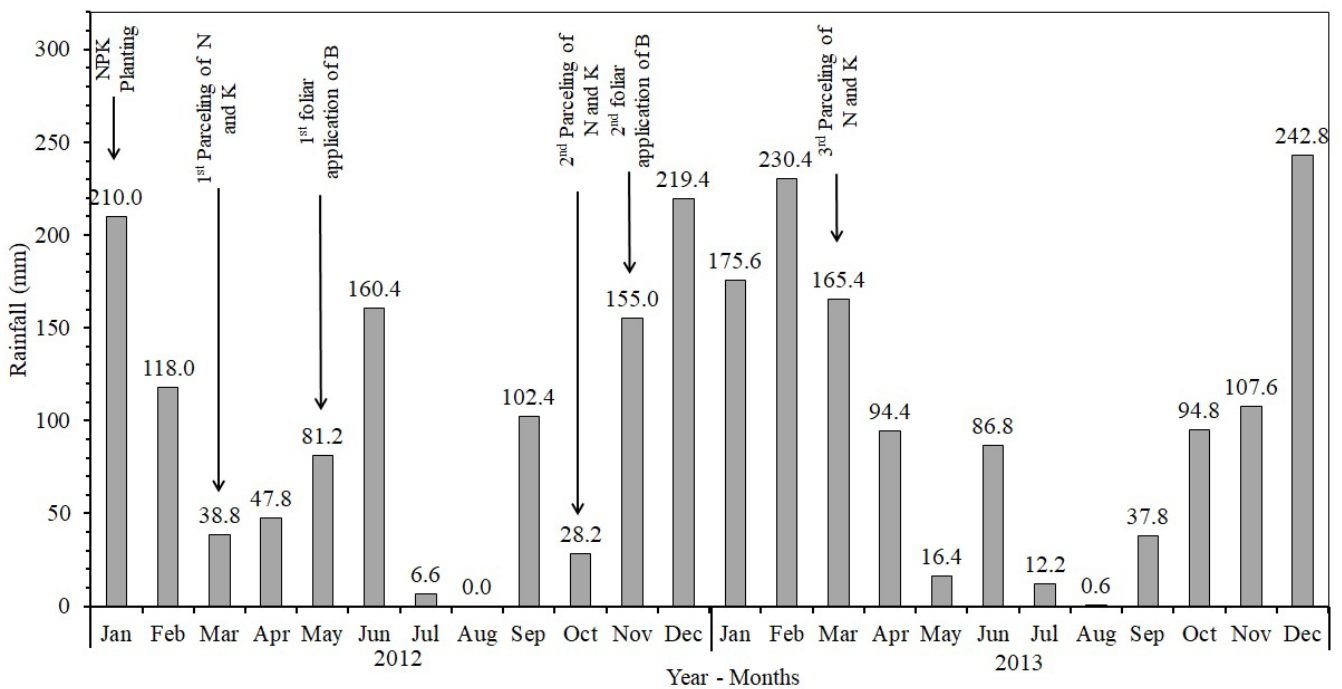
Materials and Methods

The experiment was implemented in January 2012, at the Renascença Farm, municipality of Três Lagoas - MS, with $20^\circ 34'S$ latitude, $51^\circ 50'O$ longitude and 305 m of altitude, approximately. The climatic classification of the region is Aw, according to Köppen, defined as tropical humid with a rainy season in summer and a dry one in winter. The mean rainfall and temperature are 24.2°C and 1241 mm per year, respectively. The mean annual rainfall during the conduction period of the experiment was 1207.2 mm (Figures 1 A and 1 B).

The soil was classified as Entisol, according to the Brazilian soil classification system (Santos et al., 2013). The soil granulometric analysis was carried out before the experiment install, in stratified layers of 0.00-0.20 m; 0.20-0.40 m; 0.40-0.60 m; 0.60-0.80 m; 0.80-1.00 m and 1.00-1.20 m (Table 1).

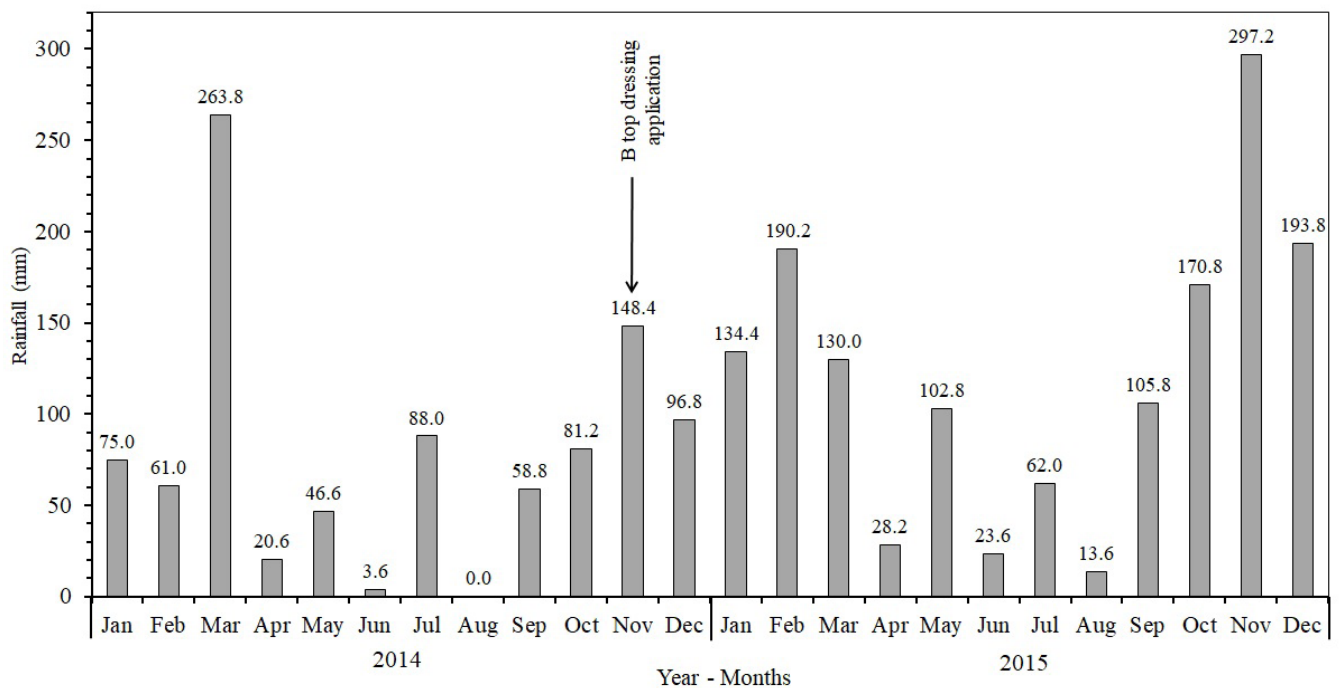
The soil chemical attributes were determined before the experiment install (September/2011), at 0.00-0.20 m and 0.20-0.40 m depths, according to the proposed methodology by Raji et al. (2001) (Table 2). We found that the soil, initially, had low nutrients and O.M. contents, as well as an average B content before the installation, according to the interpretation limits of soil nutrient elaborated by Raji et al. (1997).

In September 2011, based on soil chemical analysis and the area history, which was a degraded pasture cultivated with *Urochloa brizantha* (Syn. *Brachiaria*) for 20 years and with high weeds infestation, there was a need of a dolomitic limestone application at a 1500 kg ha^{-1} dose with 80% RTNP (relative total neutralizing power) applied to the soil surface,



Source: Weather Station of Três Lagoas - MS

Figure 1 A. Monthly rainfall (mm) and applications periods of the fertilizers during the experiment conduction, Três Lagoas, 2012/2013.



Source: Weather Station of Três Lagoas - MS

Figure 1 B. Monthly rainfall (mm) and applications periods of the fertilizers during the experiment conduction, Três Lagoas, 2014/2015.

and in order to improve the subsurface conditions, gypsum at 500 kg ha⁻¹ dose was applied to the soil surface. In this same month, the initial ant combat was held by using granulated bait (1.5 g ha⁻¹ of the active ingredient (a.i) sulfluramide).

The land systematization (felling and removal of native trees, total mechanical mowing, opening of roads, and

construction of fences) for the cultivation install was performed in December 2011. There was combat against ants in pre-planting, following the recommendations used in commercial areas from Cargill/SA Company.

In January 2012, 6 L ha⁻¹ of herbicide (2880 g ha⁻¹ of glyphosate a.i) were applied in order to eradicate weeds. Soil

Table 1. Granulometric analysis of the experimental area soil. Três Lagoas/MS, 2011.

Depths (m)	Clay	Silt		Total Sand
		g kg ⁻¹		
0.00-0.20	85	17		898
0.20-0.40	104	20		876
0.40-0.60	114	17		869
0.60-0.80	121	18		861
0.80-1.00	130	21		849
1.00-1.20	145	24		831

Source: Elaborated by the author.

preparation was also performed, which consisted of subsoiling in the planting row, employing a subsoiler until the mean depth of 0.45 m. The planting was held on January 28, 2012, using seedlings from the clone I144 (spontaneous hybrid of *Eucalyptus urophylla*) with spacing of 3.0 m x 2.5 m. Two weeks after planting, 150 g ha⁻¹ of pre-emergent herbicide (112.5 g ha⁻¹ of isoxaflutole a.i) was applied.

The planting fertilization was undertaken in January 2012, in a manual way over a continuous fillet, in the planting furrow with NPK, by using 150 kg ha⁻¹ from the 10-27-10 formula associated to 30 kg ha⁻¹ of P₂O₅ from triple superphosphate (45% P₂O₅), following the criteria used by Cargill/SA Company for commercial plantations. Cu and Zn fertilizations at 1 kg ha⁻¹ were also employed in the planting, using fertilizers from copper and zinc sulphate, respectively. Nitrogen and potassium top dressing fertilizations were performed manually in a semicircle, at 2, 9 and 14 months after planting. Each nitrogen fertilization used ammonium nitrate at the 40 kg ha⁻¹ dose of N and potassium chloride at the 50 kg ha⁻¹ dose of K₂O. Therefore, during the 14 months after planting, there was a supply of 135 kg ha⁻¹ of N, 70 kg ha⁻¹ of P₂O₅ and 165 kg ha⁻¹ of K₂O.

For the experiment maintenance in the year 2012, other activities were carried out: a) chemical control of weeds in the space between rows: March and November, with 2880 g ha⁻¹ of glyphosate a.i being applied; b) chemical control of weeds in the row: May 2012, with pre-emergent herbicide application, using 112.5 g ha⁻¹ of isoxaflutole a.i; c) maintenance control of leaf-cutting ants: June and September, with application of granulated formicide bait (0.3 and 1.5 g ha⁻¹ of sulfluramide a.i, respectively).

In the experiment maintenance in 2013 the activities were: a) chemical control of weeds in the space between rows: January and November, with application of 2880 g ha⁻¹

of glyphosate a.i; b) leaf-cutting ants control: May and July, with application of granulated formicidal bait (0.3 and 1.5 g ha⁻¹ of sulfluramide a.i, respectively); c) manual mowing in November 2013. Maintenance activities in the years 2014 and 2015 were: a) control of leaf-cutting ants: May and July, with application of granulated formicide bait (0.3 and 1.5 g ha⁻¹ of sulfluramide a.i, respectively).

Experimental design and treatments

The experiment was assembled in a subdivided plots scheme, arranged in a factorial scheme of 3 x 2 x 2, with each subplot being composed of 24 trees, distributed in three rows with eight trees each. From the total, we considered 18 useful trees, excluding one from each end of the rows.

The treatments arranged in a factorial scheme already implanted with the two B sources (boric acid and borogran), provided in the planting furrow (0.40-0.45 m depth), and the applications or not of B via leaves, were subdivided by the top dressing reapplication or not of B (Table 3). Therefore, the first factor refers to the 3 levels of B application in the planting furrow, with: 0 kg ha⁻¹ of B; 1 kg ha⁻¹ of B using borogran fertilizer (low solubility, 10% of B) and 1 kg ha⁻¹ of B using boric acid fertilizer (high solubility, 17% of B), both manually applied over a continuous fillet in the planting furrow. The 1 kg ha⁻¹ dose of B is in agreement with the recommendation proposed by Gonçalves et al. (1997) in soils with medium levels of B.

The second factor refers to two levels of B application via leaves. One level consisted of the non-application and the other from two foliar B applications at four and ten months after planting, using boric acid (0.5%) in the 250 L ha⁻¹ volume of each syrup. These applications were performed in the morning, using a backpack sprayer with 20 liters capacity, with a fan-type nozzle and working pressure of 6 kgf cm⁻². The third factor, included in the subplots, had 2 levels referring to the top dressing reapplication or not of B in at 34 months after planting, manually, in the crown projection. For the B application, we used the boric acid fertilizer at the 1 kg ha⁻¹ dose of B. The treatments are exemplified in Table 3.

Evaluations

The B levels in the soil were quantified at 36 months after planting, and soil samples were collected in a mug-type manual auger at the 0.0-0.20 m and 0.20-0.40 m depths. In each subplot, we took five simple samples in the planting row (average distance between two trees) and, later, homogenized

Table 2. Chemical attributes from the experimental area soil before the experiment install, Três Lagoas/MS. 2011.

Depth (m)	P _{resin} (mg dm ⁻³)	OM (g dm ⁻³)	pH (CaCl ₂)	K	Ca	Mg				SB
						(mmol _c dm ⁻³)				
0.00-0.20	1	7.4	4.2	0.2	4.2	1.9	17	4.3	6.3	
0.20-0.40	1	6.8	4.2	0.3	1.6	1.1	18	4.5	3.0	
	CEC (mmol _c dm ⁻³)	V (%)	m	S-SO ₄ ²⁻	B	Cu	Zn	Mn	Fe	
0.00-0.20	23.3	27	25	4.7	0.27	0.4	0.2	1.5	13	
0.20-0.40	21.0	14	25	4.0	0.20	0.5	0.2	1.4	20	

The used cationic micronutrients extraction method was DTPA, and for boron was hot water.

Table 3. Treatments in the 3 x 2 factorial scheme in subdivided plots (2), Três Lagoas/MS.

Treatments	Application mode			kg ha ⁻¹ of total B
	Factor 1	Factor 2	Factor 3	
Treatment 1	No application	No application	No application	0.0
Treatment 2	Borogran	No application	No application	1.0
Treatment 3	Boric Acid	No application	No application	1.0
Treatment 4	No application	Boric Acid	No application	0.425
Treatment 5	Borogran	Boric Acid	No application	1.425
Treatment 6	Boric Acid	Boric Acid	No application	1.425
Treatment 7	No application	No application	Boric Acid	1.0
Treatment 8	Borogran	No application	Boric Acid	2.0
Treatment 9	Boric Acid	No application	Boric Acid	2.0
Treatment 10	No application	Boric Acid	Boric Acid	1.425
Treatment 11	Borogran	Boric Acid	Boric Acid	2.425
Treatment 12	Boric Acid	Boric Acid	Boric Acid	2.425

Source: Elaborated by the author.

them for the removal of a portion referring to the composite sample. The same was done in the space between rows of each subplot, since the top dressing application of B was performed in the crown projection. The samples were sent to the oven and subsequently, after drying, sieved in a 2 mm mesh. The chemical analysis of B was performed at the Soil Fertility Laboratory from UNESP/Ilha Solteira, using the described methodology by Raji et al. (2001).

The B foliar concentrations were performed at 30, 36 and 42 months after planting, with the collection of mature leaves from the branches located in the upper third of the crowns, directed to the four cardinal points from the antepenultimate leaflet of the branches (Malavolta et al., 1997). The leaves were dried in a forced ventilation oven (65 °C) for 72 hours and then milled in the Wiley type mill to determine the B foliar concentration in the Laboratory of Plants Nutrition from UNESP/Ilha Solteira, according to the proposed methodology by Malavolta et al. (1997).

The volume of the wood with bark was estimated at 30, 36 and 42 months after planting, by determining the trees height and the diameter at breast height (DBH) of each useful tree from the subplots, using Eq. 1 and 2:

$$V_i = \frac{\pi \cdot (DBH_i)^2 \cdot ff \cdot H_i}{4} \quad (1)$$

$$V_{tb} = \left(\frac{\sum V_i}{A_i} \right) \cdot 10000 \quad (2)$$

in which: V_i = volume of wood with bark of each tree (m³); DBH_i = diameter at breast height of each tree (m); H_i = total height of each tree (m); ff = form factor, with the 0.5 value being assigned due to the absence of regionally defined factors for the studied clone; A_i = useful area of subplots (m²); V_{tb} = total volume with estimated bark (m³.ha⁻¹).

The percentage of trees forks was performed at 30, 36 and 42 months after planting, by counting and observing all the useful trees of the subplots. After the evaluations, the results were processed by the statistical software SISVAR (Ferreira,

2011). In order to evaluate the effect of the treatments (independent variables) on the dependent variables, the results were submitted to the analysis of variance, and the means compared by the Tukey test, adopting the significance level of 5%.

Results and Discussion

During the conduction of the experiment, there was no interaction between the B sources, foliar applications of B and top dressing application on the B contents in the planting row and the space between rows (Table 4). The B application in the planting furrow positively influenced the B soil content, in the row, at 36 months after planting (Table 4). We verified in the 0.0-0.20 m layer, in the row, the highest B content in the soil with the borogran application, when compared to the control group. In this layer, both sources did not differ in numerical terms, however, the B content in the soil from the most soluble source is in the lower limit of the range considered average for the cultivation (0.21-0.6 mg dm⁻³), according to limits elaborated by Raji et al. (1997). In the Entisol, Celestrino (2014), at 24 months after the B application, found positive correlation (Pearson), $r = 0.97^{**}$, in the 0.0-0.20 m layer, between the B content in soil and the plants height. Thus, the B suppression in the planting or doses below the required by the cultivation may be the bottleneck for its productivity, especially in sandy soils with low O.M. content. In this study, at 36 months after planting, B contents in the soil, in the row, 0.0-0.20 m layer, are considered low for the cultivation, according the interpretation limits proposed by Raji et al. (1997), which indicates, possibly, the absorption of B, since the initial contents were considered as average for the cultivation.

In deep layers (0.20-0.40 m), the application of borogran provided higher B contents in the soil, in the row, when compared to the treatments (control group and boric acid). Therefore, possibly the fertilization with more soluble sources makes the greater initial availability of the nutrient in the soil solution possible, which favors its absorption by the tree, whereas, sources with less solubility gradually provide the nutrient, resulting in higher B contents in the soil. However,

Table 4. Boron content in the soil in the row and in space between rows of eucalyptus planting, at depths of 0.0-0.20 and 0.20-0.40 m after 36 months of planting, in function of boron treatments, Três Lagoas/MS. 2015.

Treatments	B content (mg dm ⁻³)			
	Rows		Space between rows	
	0.0-0.20 m	0.20-0.40 m	0.0-0.20 m	0.20-0.40 m
Factor 1				
Control group	0.18 b	0.22 b	0.25 a	0.20 a
Boric Acid (1 kg ha ⁻¹ of B)	0.21 ab	0.23 b	0.24 a	0.19 a
Borogran (1 kg ha ⁻¹ of B)	0.27 a	0.36 a	0.28 a	0.21 a
D.M.S. (5 %)	0.06	0.10	0.09	0.09
Factor 2				
No foliar	0.22 a	0.25 a	0.24 a	0.21 a
With foliar (0.450 kg ha ⁻¹ of B)	0.22 a	0.30 a	0.27 a	0.20 a
D.M.S. (5 %)	0.04	0.07	0.06	0.06
Factor 3				
No boron top dressing	0.22 a	0.30 a	0.22 b	0.18 a
With boron top dressing (1 kg ha ⁻¹ of B)	0.23 a	0.24 a	0.30 a	0.23 a
D.M.S. (5 %)	0.04	0.07	0.06	0.06
C.V. (%)	26.54	26.08	30.84	30.15

Means followed by the same letter in the column do not differ by the Tukey test, at 5% of probability.

the B contents in the soil, in the row, regardless of the source, are presented as average values (0.21-0.60 mg dm⁻³ of B), according to the interpretation limits proposed by Raij et al. (1997).

The top dressing B application, at 34 months after planting, positively influenced B contents in the soil, in the space between rows, 0.0-0.20 m layer, providing an average increment of 36% when compared to the non-application of the nutrient (Table 4). This higher B content in the soil, in the space between rows, is due to the application site (crown projection). However, although the source (boric acid) allows the nutrient to descend to the soil profile, there was no difference in deeper layers (0.20-0.40 m) between the nutrient application and non-application. The possible explanation is due to the time interval between the nutrient application (34 months after planting) and soil collection (36 months after planting). The B contents in the soil, in the space between rows, were in the range considered average for the cultivation (0.21-0.60 mg dm⁻³ of B), according to the interpretation limits proposed by Raij et al. (1997).

During the conduction of the experiment, there was no interaction effect between B sources, B foliar applications and top dressing application on the nutrient foliar concentrations at 30, 36 and 42 months after planting (Table 5).

At 36 months after planting, the borogran source provided a higher foliar B concentration, when compared to the control group, however, with concentrations similar to the application of boric acid (Table 5). That way, based on B contents in the soil, in the row (Table 4), the highest foliar concentration of B from the borogran source is due to the higher B content in the soil. However, at 30 and 42 months after planting there was no difference between the sources and the control group, resulting in similar concentrations. According to Mattiello et al. (2009), restricted water conditions reduce the B absorption by the plant, since water is the main vehicle in the process of transporting the nutrient from the soil to the root.

Table 5. Concentration of foliar boron at 30, 36 and 42 months after the planting in function of the treatments, Três Lagoas/MS. 2014/15.

Treatments	Foliar B concentration (mg kg ⁻¹)		
	30 months	36 months	42 months
Factor 1			
Control group	31.91 a	50.52 b	32.48 a
Boric Acid (1 kg ha ⁻¹ of B)	33.64 a	57.97 ab	34.14 a
Borogran (1 kg ha ⁻¹ of B)	38.53 a	60.87 a	36.27 a
D.M.S. (5 %)	10.07	10.16	4.30
Factor 2			
No foliar	30.33 b	52.34 b	35.46 a
With foliar (0.450 kg ha ⁻¹ of B)	39.05 a	60.56 a	36.13 a
D.M.S. (5 %)	6.68	6.85	2.90
Factor 3			
No boron top dressing	-	48.86 b	32.66 b
With boron top dressing (1 kg ha ⁻¹ of B)	-	64.05 a	35.93 a
D.M.S. (5 %)		6.85	2.90
C.V. (%)	18.33	17.55	12.23

Means followed by the same letter in the column do not differ by the Tukey test, at 5% of probability.

When in forest sites in Uruguay, Ferrando & Zamalvide (2012) evaluated the effect from B sources with different solubilities (ulexite and sodium borate) at the 4 g plant⁻¹ dose of B, and concluded that both sources provide foliar concentrations of B within the range considered suitable for cultivation. In this study, there was no difference between sources, since both provided adequate concentrations of foliar B for eucalyptus, according to the range considered adequate by Gonçalves (2011), 30-60 mg kg⁻¹ of B.

The B applications via leaves, even after 20 and 26 months of the last application, resulted in greater foliar concentrations of B (Table 5), however, regardless of these applications; the concentrations were within the adequate range elaborated by Gonçalves (2011), 30-60 mg kg⁻¹ of B. According to José et

al. (2009), the foliar application of B is a used strategy mainly in dry times, aiming at the lower absorption of the nutrient by the root. In this study, at 30 months after planting, we verified that the non-foliar application of B resulted in a foliar concentration close to the lower limit of the range considered adequate by Gonçalves (2011). It is also possible that, in the long term, the higher foliar concentration of B from the applications provides greater transfer of B to the soil by the deposition of the leaf litter. According to Schumacher & Viera (2015), nutrient cycling is fundamental for the continuous circulation of nutrients in the ecosystem.

The top dressing application of B, resulting in higher B levels in the soil (Table 4), positively influenced the foliar concentration of B at 36 and 42 months after the planting (Table 5). Considering the adequate range developed by Gonçalves (2011), 30 and 60 mg kg⁻¹ of B, the top dressing application of B provided average B contents above this range at 36 months after planting, without characterizing toxicity symptoms in the experimental area. There was a 31% increase in foliar concentration of B, which resulted in a beneficial effect for the cultivation, as it resulted in volumetric gains of wood at 36 months after planting (Table 6).

During the conduction of the experiment, there was no interaction between B sources, foliar and top dressing application of B on the estimated volume of wood with bark (Table 6). We noted that the B sources in the planting furrow, as well as the control group, did not differ significantly in the volume measurements of the wood with bark, which is plausible, given the proximity of the foliar concentrations of B observed between treatments (Table 5). Therefore, 1 kg ha⁻¹ of B, regardless of the B source, is not enough to increase the volume of wood with bark until 42 months after the planting, in a soil with an average B content initially. In a Red Latosol with

Table 6. Mean values of the wood volume with bark from eucalyptus as a function of boron treatments. Três Lagoas/MS. 2014/15.

Treatments	Volume (m ³ ha ⁻¹) in the evaluated ages		
	30 months	36 months	42 months
Factor 1			
Control group	98.0 a	133.4 a	172.7 a
Boric Acid (1 kg ha ⁻¹ of B)	104.0 a	143.8 a	171.7 a
Borogran (1 kg ha ⁻¹ of B)	98.6 a	147.2 a	177.5 a
D.M.S. (5 %)	14.76	15.5	28.9
Factor 2			
No foliar	103.7 a	144.9 a	182.2 a
With foliar (0.450 kg ha ⁻¹ of B)	96.5 a	138.1 a	165.7 a
D.M.S. (5 %)	10.0	10.5	19.5
Factor 3			
No boron top dressing	-	134.6 b	160.8 b
With boron top dressing (1 kg ha ⁻¹ of B)	-	148.4 a	187.1 a
D.M.S. (5 %)	-	10.5	19.5
C.V. (%)	16.97	12.62	19.12

Means followed by the same letter in the column do not differ by the Tukey test, at 5% of probability.

clayey texture and average B content, Paula (2009) evaluated effect from doses, sources and forms of B application in eucalyptus clones, and found that the application of 4 kg ha⁻¹ of B, regardless of the source (boric acid and ulexite), provided a higher volumetric increase than the control group, possibly indicating that the B dose in this study was underestimated.

For this matter, in order to verify possible responses of the cultivation to top dressing nutrient applications, the experimental plots were subdivided and it was verified that the 1 kg ha⁻¹ application contributed to the increase in the soil B contents (Table 4), as well as foliar nutrient concentration (Table 5), and wood productivity, with an increase of 14 and 26 m³ ha⁻¹ of wood with bark, respectively, at 36 and 42 months after planting (Table 6). However, this beneficial effect can be attributed by the B application in the control subplot or by the B application in subplots that already received 1 kg ha⁻¹ of B from the sources in the planting. This can also be explained by the fact that there was no significant interaction between the studied factors.

The beneficial effect of B on wood productivity can be explained by its role in plants, as it acts on cell wall formation, cell division and elongation, as well as the metabolism of N and plant hormones, which are fundamental for the plants growth (Dechen & Nachtigall, 2006). There are studies in the literature that have noticed the positive effect of B on the height and/or diameter at breast height (DBH) growth in trees, positively influencing the volume of eucalyptus wood (Barros et al., 1992; Oliveira et al., 2000; Barretto et al., 2007; Paula, 2009; Leite et al., 2010).

We verified at 30, 36 and 42 months after planting that the applications of the B sources were enough to reduce the percentage of trees forks in the order of 13-14% and 8-9%, in applications of boric acid and borogran, respectively, when compared to the control group (Table 7). However, considering

Table 7. Percentage of eucalyptus trees forks in function of the treatments, Três Lagoas/MS, 2014/15.

Treatments	% of tree fork in the evaluated ages		
	30 months	36 months	42 months
Factor 1			
Control group	25.04 a	28.67 a	29.40 a
Boric Acid (1 kg ha ⁻¹ of B)	11.46 b	15.62 b	15.85 b
Borogran (1 kg ha ⁻¹ of B)	16.67 b	20.32 b	20.61 b
D.M.S. (5 %)	6.44	5.72	5.82
Factor 2			
No foliar	21.00 a	25.02 a	25.39 a
With foliar (0.450 kg ha ⁻¹ of B)	14.44 b	18.05 b	18.52 b
D.M.S. (5 %)	4.77	3.87	3.94
Factor 3			
No boron top dressing	-	22.94 a	23.36 a
With boron top dressing (1 kg ha ⁻¹ of B)	-	20.14 a	20.55 a
D.M.S. (5 %)	-	3.87	3.94
C.V. (%)	30.93	30.60	30.50

Means followed by the same letter in the column do not differ by the Tukey test, at 5% of probability.

the percentage of tree fork even with the B applications in the planting under different sources, the cultivation could possibly benefit from higher dose applications than the one applied in the planting. Paula (2009) while studying doses, sources and B application modes in eucalyptus clones, verified the intensity reduction of the symptoms from dieback using doses of 8 and 10 kg ha⁻¹ of B. According to the author, there are differences in susceptibility to B deficiency due the genetic material, as well as to its growth rate, influenced by the production environment.

In the current study, we found no difference between the B sources about the percentage of the trees fork (Table 7). However, Paula (2009) found that the application of more soluble sources, such as boric acid, was more efficient in preventing B deficiency symptoms in clone "A", since this source met the cultivation requirement in the rainy season, an era marked by intense vegetative growth.

Foliar B applications reduced the percentage of tree forks until 42 months after planting (Table 7); however, there was no interaction between soil and foliar application, according to results obtained by Celestrino et al. (2015) at 24 months after planting. The authors also observed that even with the omission of B at planting, foliar applications (total of 0.425 kg ha⁻¹ of B) were sufficient to reduce 35% of tree forks, when compared to the control group. According to José et al. (2009), the foliar application of B may be an alternative for rapid recovery of plants with symptoms from B deficiency.

Although the late top dressing application of B is positive for eucalyptus productivity and nutritional status of the cultivation, there was no difference in the percentage of tree forks, since there is no way to regress its severity. According to Gonçalves et al. (2015), the symptoms from B deficiency occur mainly in the first and second year of cultivation growth, due to the lower volume of soil explored and lower biogeochemical cycling. Therefore, during the initial phase of the cultivation, it is necessary to supply the nutrient properly so that it does not impair nutritional management in order to obtain high productivities.

Conclusion

Boron sources, at a 1 kg ha⁻¹ dose, as well as the foliar nutrient applications, at 4 and 10 months after planting, reduced the tree fork percentage of eucalyptus grown on sandy soil.

The application of 1 kg ha⁻¹ of B in the eucalyptus plantation (I144 clone) was not sufficient in a soil with average B content, being necessary the top dressing reapplication of the nutrient, with positive reflexes on the B content in the soil, and consequently, in the concentration of foliar B and wood productivity.

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