International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-9, Issue-8; Aug, 2022
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.98.13

Eucalyptus growth and initial productivity in response to different sources of boron

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Received: 06 Jul 2022,

Received in revised form: 30 Jul 2022,

Accepted: 04 Aug 2022,

Available online: 09 Aug 2022

***Keywords*— boric acid, boron tetraborate, forest nutrition, micronutrients, ulexite.**

***Abstract*— Boron (B) deficiency in forest production systems has been reported in several eucalyptus species. The low biochemical cycling of B and the leaching losses justify the need for effort to get the fertilization of this nutrient right. In this context, the efficiency of three sources of boron with different solubilities was evaluated in a dystrophic Red Latosol, with a sandy loam texture, in eucalyptus crops at juvenile age. Ulexite (10% boron), boric acid (17,2%), and sodium tetraborate (15%) were evaluated, providing 800 g ha^{-1} of B. For comparison, a control without boron was used, totaling four treatments in a randomized block design. To evaluate growth and productivity, total height (Ht) and diameter at breast height (DBH) were analyzed at 12 months, in addition to analysis of plant tissue at the end of this period. There was an influence of borate fertilization on the initial growth of eucalyptus (Clone I 144). Although there was no interaction between the sources of boron in the development of the initial dendrometric attributes, there was variation between the sources in relation to the concentration of boron in the plant tissue.*

I. INTRODUCTION

Eucalyptus plantations have expanded in Brazil in soils with great variation in natural fertility, including areas of the cerrado, where low fertility, sandy textured, high acidity soils are common. At times still with great rainfall irregularity and where constant short mini droughts (veranicos) are observed. Compared to agricultural crops in general, some eucalyptus species have been considered to have a low nutritional requirement, in part due to their ability to develop in these edaphoclimatic conditions [1].

In early stages of growth, typically in sandy soils and in periods of intense water deficit, severe morphological symptoms, characteristic of micronutrient deficiencies such as Zn and B, are frequent. In less adapted genetic materials, the death of the apical meristem is common, conditioning to overbudding and internode shortening, respectively.[1], [2]. In fact, hyposufficient availability of B or limitations of transport in the soil in dry periods, lead to nutritional disorders in plants, since this nutrient has, in general, low phloem mobility [3], suggesting the need to adopt adequate fertility management [4], [5].

On the other hand, there is a great lag in the recommendation of micronutrient doses for forest plantations in general, including eucalyptus, with generally generic recommendations [6]. This may be due to the greater financial expenditure and the greater frequency of responses to the addition of macronutrients in relation to micronutrients.

Despite the "supposed" low nutritional requirement of eucalyptus and high tolerance to Al^{3+} [7], plantations has shown great variation in response to fertilization with micronutrients [8], [9]. For B and Zn, regardless of soil class and genetic material, responses to fertilization have not been observed when there are no water restrictions [1]. In fact, under optimal conditions of humidity, the dynamics of mineralization of organic matter and decomposition of residues, when they exist, associated with low restriction of transport of ions or molecules in the soil, seem to be sufficient for the adequate supply of these nutrients to eucalyptus.

The main sources of B used as fertilizers include borax (Na2B4O5.(OH) 4.10H2O), a colemanite (Ca2B6O11.5H2O), ulexite (NaCaB5O9.8H2O), sasolite (H3BO3), datolite (CaB.(SiO4).(OH)), boracite (Mg3B7O13Cl) e sodium tetraborate (Na2B4O7.5H2O). These sources present wide variations in solubility, so it is expected that they present different rates of B release in the soil, which can significantly affect the availability of the nutrient to plants over time [10]. Ulexite is one of the most used sources of B as a fertilizer and is characterized by its low solubility (1,09 g/100 ml) and variable concentration of B (~ 10%). A recent source on the market is sodium tetraborate, more concentrated in B (~15%) and highly soluble in water (2,65 g/100 ml). More concentrated than tetraborate, boric acid has around ~17,2% B, with a water solubility of 3,45 g/100 ml

Regarding nutritional deficiencies in eucalyptus when there is no adequate supply of B, symptoms of B "hunger" can be seen in leaves, young branches, and apical meristems. Initially, the lack of the nutrient promotes the degeneration of the meristematic tissues, generating malformation of the leaves and stem, directly influencing the shape of the tree. The non-cylindrical or conical shape greatly influences the use of wood, mainly harming the debarking in the production of cellulose, and the stacking of ovens to produce charcoal. The symptom begins with chlorosis on the leaf margins, which can progress to necrosis of the apical buds, known as "dry point" and manifests itself mainly in periods of drought, with accentuated water deficit, being easily observed in commercial plantations, due to decreased mineralization of organic matter, the main source of B in soil [3], [5].

Boron deficiency in forest production systems has been reported in several eucalyptus species. The low biochemical cycling of B in the plant (low mobility) suggests the need for a constant supply of the nutrient to meet the demands of the crop throughout the cycle [3]. As a nutrient that is poorly retained by the soil, it is also subject to leaching losses. Therefore, depending on the soil and climate conditions, cultivation and the clone cultivated, the use of soluble fertilizers can be effective in the short term, so gradual release sources or combinations (soluble sources + low solubility sources) can be more effective for nutrient supply. in the medium and long term [11].

When the importance of fertilization with B (boron) was studied in the adaptive mechanisms related to drought tolerance and the better understanding of the relationships involving nutritional efficiency in different genetic materials and its influence on the selection of tolerant genotypes, a high increase in the efficiency of the water use in plants under drought and supplemented with B, due to the combination of high photosynthetic rate and high concentration of potassium [12].

Additionally, the low phloem mobility limits the internal cycling of the nutrient. Unlike most nutrients, the supply of B is more delicate, since the limits between optimal and phytotoxic levels can be narrow [13], thus requiring greater accuracy in fertilization recommendations. The tolerance of plants to B toxicity seems to depend directly on the translocation rate of the element from the roots to the shoot.

The phytotoxicity of B has been commonly found soon after planting or in the early stages of crop development [14]. Visually, the symptoms are characterized by chlorosis followed by reddening or necrosis of the leaf margins. Among the causes is the application of very soluble sources at planting in an inappropriate location, such as sodium borates or boric acid, or the use of high doses in the first topdressing fertilization [15].

Given this context, the effects of boron fertilizer sources that present different solubilities in a dystrophic Red Latosol with sandy loam texture were evaluated in eucalyptus plantations at juvenile age.

II. MATERIALS AND METHODS

The experiment was installed in the city of Uberlândia, Minas Gerais, located in the geographic coordinates 19º06'17.50''S e 48º20'56.87'' W. According to the Brazilian Soil Classification System, the soil of the experimental area is classified as a dystrophic Red Latosol, with a sandy loam texture. (210 g de argila/kg) with the chemical characteristics shown in Table 1:

Table 1 - Soil chemical characterization of the experimental area at two depths.

Prof.	pH	P	K	Al^{3+}	Ca^{2+}	Mg^{2+}	$H+Al^{3+}$	SB	t	T	V	m
cm	H_2O	---mg dm^{-3}---		---------$cmol_c$ dm^{-3}---------							--- % ---	
0 – 20	5,2	3,41	103,7	0,30	0,44	0,53	1,52	1,23	1,53	2,75	44,74	19,61
20 – 40	4,9	3,04	25,56	0,35	0,27	0,27	1,37	0,61	0,96	1,97	30,74	36,57

Prof.	S	B	Zn	Cu	Mn	Fe	Ca/Mg	Ca/K	Mg/K	O.M
cm		------mg dm^{-3}------								-dag kg^{-1}-
0 – 20	19,80	0,24	2,33	0,04	2,86	8,34	0,9	1,7	1,9	0,52
20 – 40	16,71	0,14	1,15	0,13	1,35	11,43	0,6	3,3	5,2	0,68

P, K, Fe, Zn, Mn e Cu (Mehlich 1 extractor); Ca^{+2}, Mg^{+2}, Al^{3+} (extractor KCl 1 mol L^{-1}); H+Al = potential acidity, t = Cation exchange capacity (t = SB + Al); T = Cation exchange capacity at pH 7,0; SB = Sum of exchangeable bases; V = Base saturation; m = Aluminum saturation; O.M = Organic matter (Colorimetric Method) [16].

The local climate is characterized as Cwb according to the Koppen classification, with dry winters and rainy summers [17]. The area has an average altitude of 803 m. The average temperature of the hottest month during the experiment was 26.01 °C and the annual rainfall in 2021 was 1186.06 mm. It is also noteworthy that in the period from December 2021 to January 2022, rainfall was above the historical average for the region, with approximately 499.67 mm of rainfall in just two months. (Figure 1).

The following sources of boron were used: Ulexite with a concentration of 10% boron (granulated fertilizer), boric acid with a concentration of 17% boron (powdered fertilizer) and sodium tetraborate with a concentration of 15% B (granulated fertilizer). The experimental design was randomized blocks, with a total of 4 treatments, each treatment with a source of boron and a control treatment (without addition of B). 6 replicates per treatment were used. The plots consisted of 4 rows with 5 plants, with a useful plot of 2 rows and 8 plants.

The plants received in the bed of the planting furrow at a depth of 40 cm: 380 kg ha^{-1} of the NPK formulated 9:18:15 + 135 kg ha^{-1} of Simple Superphosphate (SS) + 06% S + 03 Cu kg ha^{-1} + 03 Zn kg ha^{-1} (1,5 kg ha^{-1} of Zn ($ZnSO_4$); 1,0 kg ha^{-1} of ($MnSO_4$); 1,5 kg ha^{-1} ($CuSO_4$).

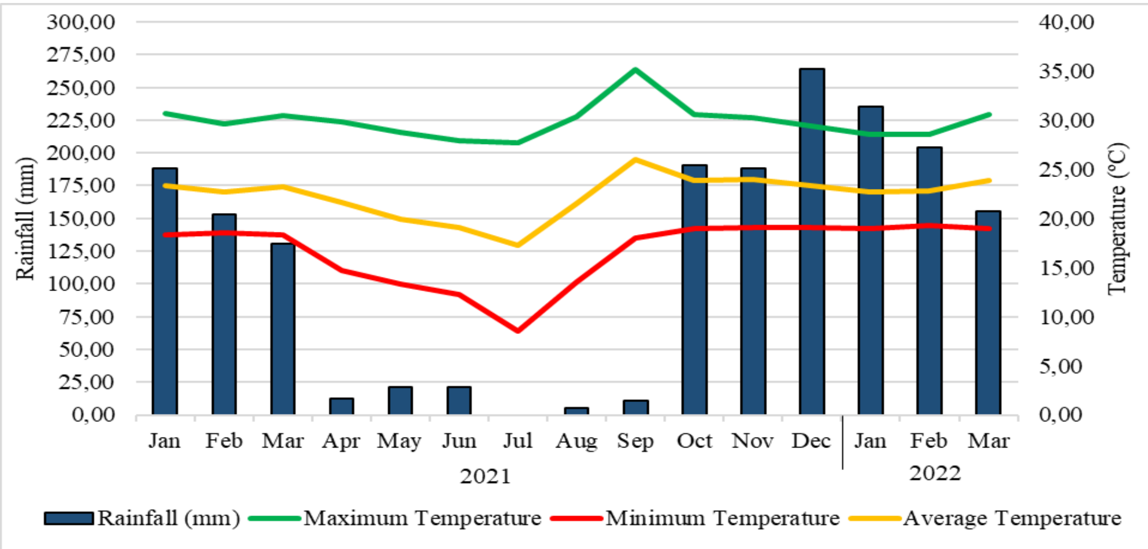

Fig.1: Minimum (°C), average (°C) and maximum (°C) temperatures and precipitation (mm) during the experiment.

In turn, the boron used in planting was applied in two covettes lateral to the seedling, at a dose of 800 g ha-1 of B, each treatment with its respective source, except for the control treatment. The application took place in the first week of planting. The planting was carried out in February 2021 at a spacing of 3,4 m x 2,3 m. Each seedling received an irrigation of 2 liters of water per basin/hole after planting. The genetic material used was the clone of E. urophylla x E. grandis, named I 144, demanding in boron.

Every 15 days after planting until 3 months of age, visual evaluations were carried out in order to verify possible symptoms of B toxicity in the plants.

In the evaluation of growth, the height and diameter at breast height were measured at 1,3 m (DBH) of the eucalyptus at 08 and 12 months after planting the seedlings, using a wooden ruler and tape measure, respectively. Diameter data were grouped through prior analysis and empirical criteria into six diameter classes with 2,0 cm intervals for distribution checks.

For plant tissue analysis, mature leaves indicative of nutrition ("sample leaves") were collected at the end of February 2021, two in each quadrant of the middle third of the tree canopy, around 200 leaves from each plot.

In the determination of N and B, in addition to P, K, Ca, Mg, S, Zn, Cu, Fe and Mn, Malavolta and EMBRAPA methodologies were used, respectively [18], [19].

Data were submitted to analysis of variance. For analysis of plant diameter and height data, Tukey test was used up to 5% probability.

III. RESULTS AND DISCUSSION

3.1. Boron toxicity after planting

No symptoms of boron toxicity or deficiency were observed at 30, 60 and 90 days after planting the seedlings. The rainfall data show the occurrence of mild rains in the months following planting (Figure 1). As can be seen, there were occurrences of intense drought in the months of July, August, and September. It is also added that there were low temperatures in the dry season and even frost in the vicinity of the experimental area, which may have hampered the diffusion of boron to the vicinity of the radicella.

It should also be noted that in August, the relative humidity remained below 12% for more than 10 consecutive days. Prolonged droughts reduce the level of assimilable boron, both due to the absence of diffusion of the nutrient in the soil and the reduction of mineralization of organic matter [20]. In addition, these climatic conditions considerably reduce the photosynthetic rate and consequently the absorption of nutrients [21].

3.2. Initial plant growth in height

The evaluation of plant height in mid-October did not show a statistically significant difference for the three sources tested, with a difference only for the control with reduced growth, in the absence of boron (Table 2).

Some authors verified that the critical level of boron, that is, the content of the available nutrient in the soil necessary to obtain at least 90% of the productivity, must be around 0,31 mg dm-3[15]. This value is above that found in the soil at the time of implantation. This justified the low increase in height of the control treatment that did not receive boron addition at planting.

Table 2: Average plant height variation considering boron sources at 8 months.

Boron sources	Height (m)	ANOVA (95%)
Control	0,43	b
Boric acid	0,67	a
Ulexite	0,65	a
Sodium tetraborate	0,66	a

From mid-October to the following February, there was abundant rainfall (Figure 1), promoting intense plant growth. Boric acid treatment had a 9,8-fold increase in height at 12 months of age compared to 8 months, while sodium tetraborate had a 10-fold increase in height at the eighth month assessment. On this occasion, the plants reached more than 4.5 meters in height in all treatments, except for the control, exceeding the expectation of 1,8 to 2,2 meters after the second year of planting, as is common in Brazil. On this occasion, the control plants continued with an average height statistically lower than the three sources of boron tested, as shown in Table 3.

Table 3: Average plant height variation considering boron sources at 12 months.

Boron sources	Height (m)	ANOVA (95%)
Control	6,34	b
Boric acid	6,56	a
Ulexite	6,58	a
Sodium tetraborate	6,60	a

It is noteworthy that despite the control having a lower growth than the other treatments, it had a notable increase in height. Some authors observed that in eucalyptus stands after 9 months, plants may develop fine roots more than 2 meters deep [22]. With precipitation above the historical average, the complementation arising from atmospheric deposition of nutrients is also added [23], [24]. Thus, it is inferred that these aforementioned factors contributed to the height development of the Control treatment.

3.3. Evaluation of the average diameter of plants

The diameter of the plants, after the first year, showed no difference between the control without boron and the other treatments (Table 4). In fact, one of the functions of boron is the formation of the cell wall, with more pronounced effects on growth in height than in diameter.

Table 4: Variation of the average diameter of the plants, in the sources of boron at 12 months of age.

Boron sources	DBH (cm)	ANOVA (95%)
Control	6,12	a
Boric acid	6,16	a
Ulexite	6,18	a
Sodium tetraborate	6,19	a

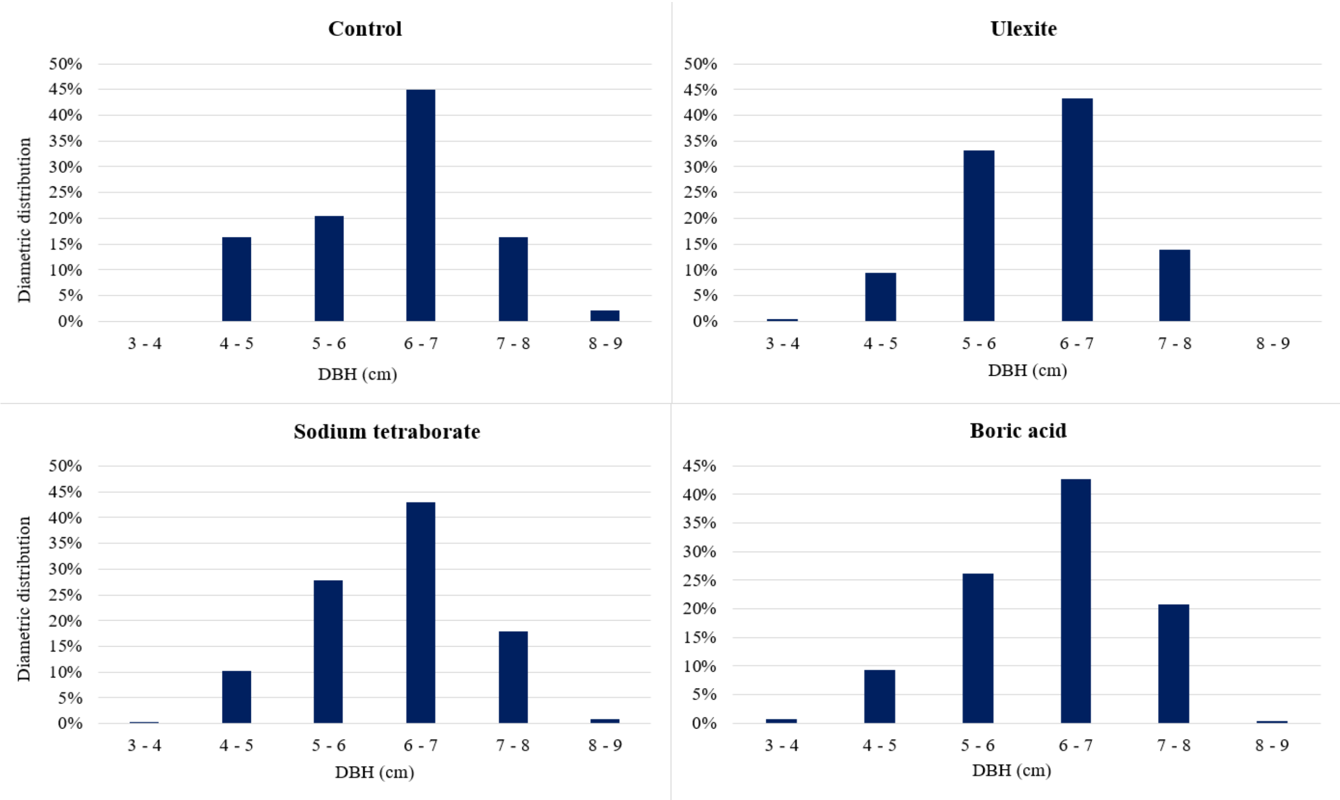

Figure 2: Diametric distribution for each boron source at 12 months of age.

The data set of the diameters of all trees in the different treatments presented a variation from 3,50 cm to 8,28 cm, with an amplitude of 4,77 cm. The distribution of the number of trees per class showed a tendency towards a normal distribution with mean, median and mode values close to each other, being 6,16 cm, 6,21 cm, and 6,68 cm, respectively, influenced by the presence of more individuals in the 4th class (Figure 2).

The diametric distribution curve has negative asymmetry in all treatments, which demonstrates that there are more individuals in the largest classes. The diameter production curve will be steeper, the more productive the site, and thus the earlier the maximum current annual increase in diameter will occur, and the higher these values will be when compared to less productive sites [25].

However, the Control treatment is the one with the highest percentage of individuals in the 3-4 cm and 4-5 cm classes, totaling 16%. Some authors also observed that in less productive sites it is to be expected that a higher concentration of trees is found in lower classes [26], [27] which was not observed in this experiment.

3.4. Nutritional deficiency

At 12 months, some plants with dieback were found, as shown in Figure 3. This behavior did not have a pattern of occurrence between treatments. It was to be expected that it would be more frequent in the control plots, since the soil had only 0,12 mg/dm3 of boron, indicated below the critical level for this nutrient in the soil [15]

However, satisfactory precipitation between the 8th and 12th month seems to have facilitated the diffusion of boron in the soil for most plants, including the control. However, it should be noted that the “dieback” occurred in the middle of the rainy season, regardless of the source of boron, demonstrating that the initial dose of 800 g ha-1 of B was not satisfactory to avoid deficiency of this nutrient (Figure 3). This behavior also contradicts the expectation that 10% of the final dose of boron should always be provided at planting[15], without observing climatic variations such as optimal precipitation and robust initial growth (“optimal start up”).

There were also some tortuosities between 2,0 and 2,5 meters, indicating a possible boron deficiency, but this symptom was not frequent in all plants of the different treatments.

The result of the leaf analyzes even before the dosages were complemented for each boron source showed that the boron concentrations in the leaves were identical for the Ulexite and the Control.

However, there was a statistical difference between the treatments with Tetraborate and Boric Acid in relation to the Control, and there was greater absorption of boron in the first two sources.

Fig.3: Loss of apical dominance observed at 12 months.

This can be explained by the higher solubility of these sources compared to ulexite in that condition of good precipitation in sandy-clay soil.

Thus, even though there were optimal humidity conditions, there was not enough ulexite dissolution and/or mass flow to supply boron to the plants in quantity to meet the demand (Table 5). Similar results were obtained by other authors comparing ulexite with more soluble sources, verifying that the low initial availability and slow release in the soil [28], [29].

Table 5: Nutrient concentrations in eucalyptus leaves, at 12 months of age, according to the variation of the Boron source and in the control. Equal letters in the column do not differ from each other.

Treatments	N g/kg	P g/kg	K g/kg	Ca g/kg	Mg g/kg	S g/kg	B Mg/kg	Cu Mg/Kg	Fe Mg/kg	Mn Mg/kg	Zn Mg/kg
Ulexite	18,45 ab	1,23 a	7,68 a	9,90 a	2,25 a	0,92 a	27,89 ab	6,17 a	87,52 a	567,66 a	22,86 a
Boric acid	19,33 a	1,33 a	8,23 a	10,87 a	2,38 a	1,05 a	30,41 a	6,24 a	83,60 a	581,76 a	14,96 a
Sodium tetraborate	19,35 a	1,32 a	8,32 a	10,44 a	2,40 a	1,01 a	30,45 a	6,30 a	78,96 a	487,74 a	15,09 a
Control	17,61 b	1,22 a	7,64 a	10,09a	2,24 a	0,89 a	23,00 b	6,10 a	73,42 a	513,48 a	13,44 a

A synergistic effect between nitrogen and boron is observed in eucalyptus. The combination of boron with nitrogen favored a better assimilation of the macronutrient, which may partially contribute to increase the synthesis and accumulation of carbohydrates and proteins [30].

The nutritional concentrations observed in the experimental area at 12 months for all sources are in sufficiency ranges that represent a relative growth of 90% according to the methodology proposed by some researchers [31], [32].

IV. CONCLUSION

1. The absence of boron negatively influences the height of clone I 144 in the initial stage of development
2. There was no difference in diameter and height in relation to boron sources in the initial growth of eucalyptus.
3. The less soluble source provided a lower concentration of boron in leaves at 12 months.

4. A synergistic interaction between boron and nitrogen was observed in the eucalyptus leaf until the end of the first year of cultivation.

ACKNOWLEDGEMENTS

We thank the operational team at Fazenda Água Limpa at the Federal University of Uberlândia, and the teams at Eldorado Brasil and the Rio Tinto group (US Borax).

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