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e-mail: info@world-food.net

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Influence of liming and boron on development of young *Swietenia macrophylla* plants grown in Yellow Oxisol

Augusto José Silva Pedroso [1]*, Mário Lopes da Silva Júnior [1]*, George Rodrigues da Silva [2], Orlando Shigueo Ohashi [2], Sannah Mohamad Birani [2], Naísa Castro Leal [2], Vânia Silva de Melo [2], Orivan Maria Marques Teixeira [3], Allan Klynger da Silva Lobato [1], Cândido Ferreira de Oliveira Neto [1], Raimundo Thiago Lima da Silva [4] and Maria de Lourdes Pinheiro Ruivo [5]

[1] Núcleo de Pesquisa Vegetal Básica e Aplicada, Universidade Federal Rural da Amazônia, Paragominas, Brazil. [2] Instituto de Ciências Agrárias, Universidade Federal Rural da Amazônia, Belém, Brazil. [3] Laboratório de Análise de Solo, Empresa Brasileira de Pesquisa Agropecuárias, Belém, Brazil. [4] Centro de Ciências Rurais, Universidade Federal de Santa Maria, Santa Maria, Brazil. [5] Centro de Ciências da Terra, Museu Paraense Emílio Goeldi, Belém, Brazil.
**e-mail: augusto.pedroso@ufra.edu.br, mario.silva@ufra.edu.br*

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Abstract

The aim of this study was to evaluate the development of young *Swietenia macrophylla* plants grown in Yellow Oxisol submitted to different liming and boron doses. Experimental design was completely randomized in factorial arrangement (|4x4|+1), with additional treatment (control), being 4 liming levels (0.5, 1.0, 1.5 and 2.0 t ha^{-1}) combined with 4 boron levels (1, 2, 3 and 4 mg kg^{-1} of substrate). Parameters evaluated were plant height, stem diameter, stem dry matter, aerial part dry matter, root dry matter and aerial part dry matter/root dry matter ratio. The height of young *Swietenia macrophylla* plants was not influenced by liming and boron levels. Maximum yields of leaves and aerial part were obtained with doses of 1.57 and 1.44 t ha^{-1} of liming, respectively. The increase of boron levels negatively influenced the production of root dry matter. For the diameter and dry matter of stem and root significant interaction between liming and boron levels were observed. The better results linked to development of young *Swietenia macrophylla* plants were found at a dose of 1.5 t ha^{-1} of liming and 1.0 mg kg^{-1} of boron.

Key words: *Swietenia macrophylla*, liming, boron, fertilization.

Introduction

The exploration and industrial processing of wood are among the main economic activities in the Amazon, along with mining and farming. Mahogany (*Swietenia macrophylla* King) is the timber species of greatest economic value in tropical America by the beauty of the wood that produces [1].Young plants production is one of the most important phases of the development of arboreal species, mainly in relation to *Swietenia macrophylla*. The use of liming agents is a fundamental practice in the process of plant production, not only to reduce soil acidity, but also as a source of essential nutrients for initial seedling growth, specially, when using material from acid soils poor in nutrients in the preparation of substrate for production of young plants. Some works show the beneficial effect of corrective agents on the growth of *Swietenia macrophylla* [2, 3]. According to Dechen and Nachtigall [4], in conditions of excessive liming, a reduction in the availability of boron can occur.

Among the essential mineral nutrients for plants, boron is the least understood, although in molar terms it is the most requested by the dicotyledonous of all the micronutrients [5]. Boron acts in the division, cell differentiation, metabolism and transport of carbohydrates; it also participates in the synthesis of cell wall, of the reproductive process, affecting pollination, pollen tube growth and production of fruits and seeds [6]. Ramos *et al.* [7] assessing doses and concentrations of boron in plant growth of eucalyptus cultivated in two Oxisols, observed that low doses of boron applied to the soil promotes the highest increase in production of dry matter of plants. Moreira *et al.* [8] have concluded that increasing levels of boron, applied in rubber rootstocks, showed significant effect in the foliar concentrations of B, Mn and Zn, whereas foliar concentrations of N, P, K, Ca, Mg, S, Cu and Fe did not vary significantly in terms of doses of boron. The availability of boron is strongly affected by pH, texture and calcium content of the soil. Thus, the increment of research directed to the nutritional needs and development of *Swietenia macrophylla* is of fundamental importance [2, 9-12].

Based in this overview, the aim of this study was to evaluate the development of young *Swietenia macrophylla* plants grown in Yellow Oxisol submitted to different liming and boron levels.

Materials and Methods

Experimental conditions and plant material: Experiment was conducted in greenhouse conditions at Departamento de Solos of the Universidade Federal Rural da Amazônia in Belém city, Pará State, with climatic type being classified as Afi, and minimum, maximum, and medium temperatures of 23, 36 and 30°C, respectively (1°27'S; 48°26'W; 7 m a.s.l.). The seeds were obtained from arrays of commercial planting of *Swietenia macrophylla* King.

Sampling, type and characteristics of soil: The soil used as substrate was collected in the layer of 0.0-0.2 m depth in Dystrophic Yellow Oxisol [13], medium texture, in the Farm of Empresa Tramontina SA in Aurora do Para city, Para state, Brazil (2°8'S; 47°33'W; 102 m a.s.l.). A composite sample of soil was sent to Laboratório de Solos da Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), for analysis of chemical attributes and particle size distribution (Table 1) [14]. Based on these results the estimation of effective cation exchange capacity (effective CEC) and total CEC pH 7, basis saturation (V%) and aluminium saturation (m%) was performed.

Seed germination and obtaining of seedlings: Seeds were placed to germinate into polyethylene trays where substrate was washed and sterilized white sand. Twenty-five days after germination, complete nutrient solution was used [15] with the purpose of supplying nutrients and uniform plant growth.After the incubation period, 35 days old seedlings were transplanted, one seedling per pot (experimental unit). Throughout the experimental period, soil humidity was kept near 60% of field capacity. Irrigation was done with distilled water according to daily monitoring for this control[18].

Experimental design: Experimental design was completely randomized in a factorial arrangement (|4X4|+1), with an additional treatment (control). There were 4 liming levels (0.5, 1.0, 1.5 and 2.0 t ha^{-1}) combined with 4 boron levels (1, 2, 3, and 4 mg kg^{-1} of substrate) and five replications.

Source and application of liming: The liming utilized was dolomitic limestone (96% PRNT) with doses being calculated based on the results of soil analysis by the method of saturation [16], to enhance to 44 V, 53, 62 and 71%. After applying and blending the liming, the substrate was incubated for a period of 40 days so that the reaction of the limestone could occur, maintaining the moisture content near the field capacity.

Source and application of boron: Boron was applied as a solution, using boric acid as a reagent (H_3BO_3). The choice of the lowest dose was based on the recommendation of 1.0 mg of boron per kg of substrate [17] (as the smallest), and from this it was increased by one unit to the remaining doses to observe the response of plants in relation to this element.

Fertilization of young plants: The basic fertilization was performed 60 days after the transplanting, using urea solutions ($CO(NH_3)_2$), potassium phosphate (KH_2PO_4) and sodium phosphate (NaH_2PO_4) at the rate NPK of 200-500-300 kg ha^{-1} [9]. Nitrogen fertilizer was split in two applications [19] 60 and 105 days after transplanting, respectively. A single application of micronutrients and doses of boron was performed 105 days after transplanting. We used the following reagents as a source of micronutrients: Cu ($CuSO_4$), Fe ($FeCl_3 \cdot 6H_2O$), Mn ($MnCl_2 \cdot 4H_2O$), Mo ($Na_2MoO_4 \cdot 2H_2O$) and Zn ($ZnSO_2 \cdot 7H_2O$). The concentrations (mg kg^{-1} of substrate) were: 1.5 of Cu, 5 of Fe, 5 of Mn, 0.15 of Mo and 5 of Zn.

Parameters of plant development: Height of aerial part was measured with the aid of ruler, considering the extent of the stem base flush with the surface of the substrate to the apical bud. The stem diameter was obtained using a digital pachymeter, measuring close to the surface of the substrate. After the measurements, the plant material was harvested at 270 days of plant age and separated into leaves and stems (aerial parts) and root. Then, these materials were stored in paper bags and dried in a forced air oven at 70°C until constant weight. Once dried, we determined the stem dry matter (SDM), leaves (LDM) and aerial parts (APDM), where APDM = SDM+LDM. The ratio of aerial part/root was obtained by dividing the dry matter of aerial part by root dry matter.

Data analysis: The data were subjected to analysis of variance (ANOVA) with differentiated factorial arrangement, considering the additional treatment and the level of significance determined by F test and means compared by Tukey's test at 5% probability. The Dunnett test ($p<0.05$) was applied when there was significant interaction between factorial arrangement x control. When there were significance by F test of the factorial arrangement ANOVA, variables were subjected to ANOVA of regressions, in order to fit in a model (linear or quadratic). For the procedure of statistical analysis, the programs Assistat, version 7.5 beta [20] and Microsoft Office Excel 2007 were used. For normalization of variable root dry matter values were transformed by square root function. The other variables were not transformed.

Results and Discussion

Plant development induced by liming and boron: In young *Swietenia macrophylla* plants did not show significant difference in height for different treatments, with overall average of 78.1 cm (Table 2), and treatment control also did not differ significantly for this variable. Liming treatments presented significant effects for diameter ($p<0.05$), leaf dry matter, aerial part dry matter, root dry matter and aerial part dry matter/root dry matter ratio ($p<0.01$).

The aerial part dry matter/root dry matter ratio increased with increasing doses of liming, which can be explained by the amount of nutrients available with the liming, which promoted an increase in the production of aerial part dry matter and decreased root dry matter. When there is no restriction of growth, the plants prioritize the development of aerial part, resulting in greater dry matter production of aerial part, which increases the aerial part/root ratio with increasing liming levels [2]. Gonçalves and Mello [21] reported that aerial part dry matter/root dry matter ratio decreases when the amount of photoassimilates in the roots increases, due to low availability of water and nutrients. According to these authors, the greater expenditure of energy for production and root growth reduces the productivity of wood and other forest products.

The effect of boron application was significant only for root dry matter ($p<0.05$). The application of liming isolated, from the dose of 1.0 t ha^{-1}, increased significantly leaf dry matter, aerial part dry matter and aerial part/root ratio (Table 2). The applications of higher boron levels (above 1.0 mg kg^{-1}) adversely affected the production of root dry matter. Opposite result was found by

Table 1. Chemical attributes and clay content of the layer of 0.0-0.2 m in Yellow Oxisol used in this study.

pH	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	$H+Al^{3+}$	CTC pH 7	CTC effect	m	V	OM	Clay
H_2O	mg dm^{-3}	$cmol_c\ dm^{-3}$								%		g kg^{-1}	
5.4	2.0	0.05	0.05	1.8	0.6	0.4	4.21	6.7	2.9	13.8	37.3	21	230

Table 2. Height, diameter, stem dry matter (SDM), leaf dry matter (LDM), aerial part dry matter (APDM), root dry matter (RDM) and aerial part dry matter/ root dry matter ratio (APDM/ RDM), of young *Swietenia macrophylla* plants grown in Yellow Oxisol submitted to different doses of liming and boron levels.

Treatments	Height (cm)		Diameter (mm)		SDM (g)		LDM (g)		APDM (g)		RDM (g)		APDM/RDM (-)	
Liming (t ha^{-1})														
0.5	73.26	a	13.66	ab	31.37	a	36.98	b	68.35	b	15.78	a	4.48	b
1.0	81.10	a	12.73	b	31.36	a	42.42	a	73.78	ab	13.61	b	5.51	a
1.5	79.28	a	13.85	a	34.17	a	45.23	a	79.40	a	14.15	ab	5.68	a
2.0	79.03	a	13.03	ab	30.07	a	43.66	a	73.73	ab	13.78	ab	5.48	a
Boron (mg kg^{-1})														
1.0	78.34	a	13.53	a	34.53	a	41.89	a	76.42	a	15.62	a	5.03	a
2.0	78.25	a	13.33	a	30.11	a	41.24	a	71.35	a	14.16	ab	5.16	a
3.0	79.54	a	13.21	a	31.91	a	42.13	a	74.04	a	14.59	ab	5.17	a
4.0	76.55	a	13.20	a	30.43	a	43.03	a	73.46	a	12.96	b	5.79	a
MSD¹	9.64		0.98		4.63		4.42		7.15		2.17		0.81	
Factorial	78.17	a	13.32	a	31.75	a	42.07	a	73.82	a	14.32	a	5.29	a
Control	77.40	a	13.90	a	31.46	a	42.23	a	73.69	b	14.84	a	4.97	a
MSD²	21.41		2.15		10.29		9.83		0.10		4.81		1.80	
General mean	78.12		13.35		31.73		42.08		73.80		14.50		5.27	
VC (%)	14.8		8.69		17.52		12.61		11.61		8.94		18.5	

MSD¹ – Minimum significant difference applied in the two factors. Means followed by different letters in columns differ significantly between treatments for the same variable by Tukey ($p<0.05$). MSD² – Minimum significant difference for Dunnett test ($p<0.05$).

Matiello *et al.* [22], evaluating the response of Eucalyptus clones to boron in nutrient solution, observed an increase in the production of root dry matter with increasing boron level. Werner [23],working with boron application (0-1.0 mg kg^{-1}) in two soil types of Florida cultivated with *Stylosanthes guianensis,* verified a reduction in dry matter production of roots in plants that received the highest boron levels.

The dose of 1.5 t ha^{-1} of liming, to elevate V in 62%, when compared to the lowest treatment (0.5 t ha^{-1}), provided the greatest dry matter production of leaves and aerial part, but did not differ significantly from the doses of 1.0 and 2.0 t ha^{-1} of liming. Neves *et al*. [24] observed in seedlings of umbu tree, that levels of basis saturation of 68.3 and 70.2% promoted maximum production of leaves and total dry matter. Similar result occurred in young *Swietenia macrophylla* plants evaluated in this study. Tucci *et al.* [25] found that among the doses of 0.5 and 2.0 t ha^{-1} of liming applied in Yellow Oxisol substrate for seedling production of *Ochroma lagopus*, there was no significant effect on height and diameter, thus, the dosage of 0.5 t ha^{-1} showed to be the most economically viable. A similar result was found by Silva *et al.* [2] in young *Swietenia macrophylla* plants, showing that the seedlings did not present difference in height and the highest value of stem diameter was observed with application of 2.5 t ha^{-1} of liming, this being related to increased levels of N and P that favored stem gains in diameter.

The best results are due mainly by the action of lime, which corrects soil acidity and reduces the toxicity of Al by improving conditions for the decomposition of organic matter, processes that lead to an increase of nutrient availability. Studies about the effect of the practice of liming in the substrate, such as Furtini Neto *et al.* [26] on *Senna multijuga* and *Stenolobium stans* seedlings, Tucci *et al*. [27] and Silva *et al*. [28] on *Ceiba pentandra* seedlings, and Souza *et al*. [29] on young *Machaerium nictitans* plants, and Tucci *et al*. [25] on *Ochroma lagopus* seedlings found results on the plant dry matter, similar to those obtained in this work. Moreover, Mann *et al*. [30] on *Acacia auriculiformis* and *Platipodium elegans*, Gomes *et al*. [18] on *Anadenanthera colubrina* and Bernardino *et al*. [31] on *Dalbergia nigra* showed different results, concluding that the seedlings of these species do not respond to limestone. Consequently, these results are important to the extent that emphasizes the variability of forest species in terms of sensitivity to conditions of soil acidity and response to the application of liming, indicating that the responsiveness of native forest species may also be related to their genetic characteristics, regardless of their ecological characteristics [26].

Effects of liming and boron on plant: Analysing interactions (Table 3), it was found that the increased boron levels at the dose of 0.5 t ha^{-1} of liming causes a decrease in the diameter, stem dry matter and root dry matter of young *Swietenia macrophylla* plants. At the dose of 2.0 t ha^{-1} of liming, there was a significant increase in the diameter with increasing boron level. At the level of 1.0 mg kg^{-1} of boron, increasing liming level also caused a decrease in the values of diameter, stem dry matter, and root dry matter (Table 3). In addition, there was no statistical difference in stem dry matter and root dry matter when applied 1.0 t ha^{-1} of liming, independent of boron level.

Stem dry matter suffered a differentiated effect between liming level only at a dose of 1.0 mg kg^{-1} of boron. When comparing the dose of 0.5 and 1.5 t ha^{-1} of liming between the 4 doses of boron, we observed that in the smaller boron level (1.0 mg kg^{-1}) the stem dry matter was higher than that obtained with the highest boron level (4.0 mg kg^{-1}), with values of 37.39 and 41.37 g for boron level of 1.0 mg kg^{-1}, as well as 24.66 and 31.89 g for boron level of 4.0 mg kg^{-1}.

The unfolding of this interaction for the stem dry matter did not differentiate among the four doses of boron for the doses of 1.0 and 2.0 t ha^{-1} of liming. The highest average of stem dry matter occurred in the dose of 1.5 t ha^{-1} of liming, face to the boron level equivalent to 1.0 mg kg^{-1}, presenting average of 41.37 g. Turan *et al.* [32], evaluating the effect of calcium in reducing boron toxicity in wheat plants, observed that the symptoms of boron toxicity decreased when plants were treated with increasing doses of calcium. Thus, in this work there may have occurred toxic effect in treatments that combined the lowest doses of corrective under increasing

Table 3. Interactions between liming and boron linked to diameter, stem dry matter and root dry matter of young *Swietenia macrophylla* plants.

Variables	Liming ($t.ha^{-1}$)	Boron ($mg.kg^{-1}$) 1.0		2.0		3.0		4.0		MSD
Diameter (mm)	0.5	15.43	aA	13.48	abB	13.23	abB	12.50	aB	1.93
	1.0	12.72	bA	11.13	bA	13.21	abA	12.86	aA	1.93
	1.5	14.69	aA	15.00	aA	12.19	bB	13.50	aAB	1.93
	2.0	11.28	bB	12.72	bAB	14.20	aA	13.92	aA	1.93
MSD		1.93		1.93		1.93		1.93		
SDM (g)	0.5	37.39	abA	30.01	aAB	33.44	aAB	24.66	aB	9.27
	1.0	32.00	bcA	29.05	aA	32.87	aA	31.53	aA	9.27
	1.5	41.37	aA	32.04	aB	31.41	aB	31.89	aB	9.27
	2.0	27.37	cA	29.36	aA	29.92	aA	33.62	aA	9.27
MSD		9.27		9.27		9.27		9.27		
RDM (g)	0.5	20.35	aA	14.79	aBC	16.43	aAB	12.12	aC	4.33
	1.0	14.93	bA	12.25	aA	13.84	aA	13.49	aA	4.33
	1.5	15.55	bA	13.59	aA	14.45	aA	13.05	aA	4.33
	2.0	12.18	bA	16.15	aA	13.74	aA	13.21	aA	4.33
MSD		4.33		4.33		4.33		4.33		

MSD – Minimum significant difference ($p<0.05$). Means followed by different letter in columns and capital letter in rows are statistically different between treatments of the same variable, by Tukey's test ($p<0.05$).

levels of boron, however, there was no manifestation of toxic symptoms. On the other hand, in treatments with higher liming levels, the plants responded positively to the boron fertilization.

Interactions between calcium and boron are reported by Gupta [33] who found a negative correlation between these two nutrients, with high concentrations of calcium inducing boron deficiency. According to reports of the author, the application of boron caused a reduction in the concentration of calcium, and when calcium was applied, the boron concentration in the plant decreased. The application of calcium may reduce the availability of boron, resulting in reduction of nutrient absorption [34]. The calcium localized in the cell wall provokes a reduction of permeability of boron in that wall, thereby contributing to reduction of the inhibiting effect of boron on the growth of dry matter of aerial part and root [32].

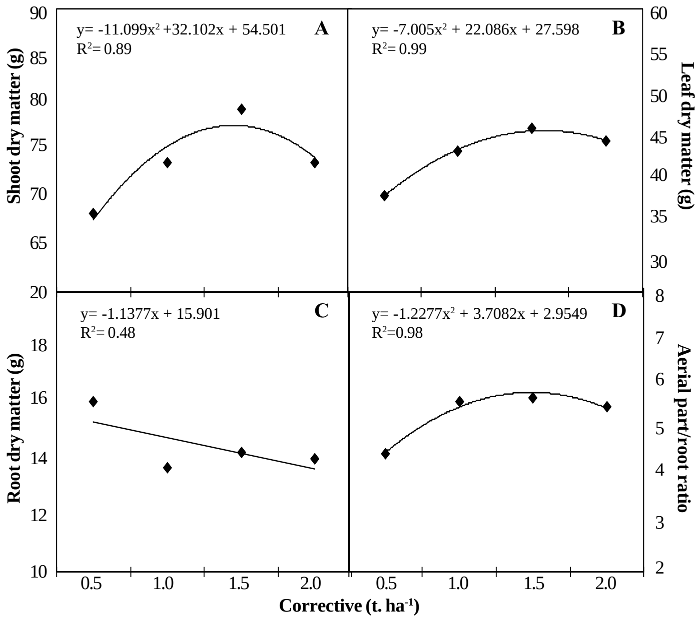

Figure 1. Shoot dry matter (A), leaf dry matter (B), root dry matter (C), and aerial part/root ratio (D) of young *Swietenia macrophylla* plants exposed 4 levels of liming in Yellow Oxysol.

Plant behavior exposed to liming and boron: The variables analysed had different significance for the F test of ANOVA of the regressions. Considering liming level as independent variable, height, diameter and stem dry matter were not statistically significant for models of linear and quadratic regression. To parameters leaf dry matter, part aerial dry matter, and aerial part/root ratio were significant ($p<0.01$) for quadratic regression (Fig. 1).

The average weight of dry root in single doses of liming and boron was significant for linear regression. It is observed that under increasing levels of liming and boron, there is a negative linear behavior of the average values of this variable, ranging from 16.03 g to 13.95 g in liming level, and 15.83 g to 13.10 g boron level (Fig. 1). Moreira *et al*. [8] observed negative effect of high doses of boric acid under the increased number of roots of rootstock rubber. Ramos *et al*. [7], evaluating the response of boron rates on dry matter production and growth of eucalyptus plants, observed that at doses above 2.25 mg dm^{-3} there was a reduction in the production of plant dry matter, indicating the toxic effect of boron. Most of the boron added to soil in the pH range of most agricultural soils is H_3BO_3, which practically does not interact with the soil solid phase, remaining largely in the solution [35]. As its transport to the roots occurs by mass flow [36], the addition of boron levels beyond the need of the plant can lead to toxicity, promoting a reduction in dry matter production of stem and root.

Leaf dry matter and aerial part/root ratio was represented by quadratic equations. The estimated dose for maximum leaf dry matter production was 1.57 t ha^{-1} and the aerial part was 1.44 t ha^{-1} (Fig. 1). However, Silva *et al*. [2] observed that liming positively affected the dry matter of aerial part of young *Swietenia macrophylla* plants, recommending a dose of 0.5 t ha^{-1} as the most economically favorable when using low soil fertility as a substrate.

Conclusions

The development of young *Swietenia macrophylla* plants is positively influenced by the interaction liming x boron, the application of 1.5 t ha^{-1} of liming combined with 1.0 mg kg^{-1} of boron being most favorable. Boron levels separately applied exert a negative influence on production of root dry matter. In addition, the application of liming and boron does not affect the height in this species.

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