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ORIGINAL ARTICLE

Nutrient requirements of paricá (*Schizolobium parahyba* var. *amazonicum*): optimizing seedling quality for reforestation programs

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ABSTRACT

Amazonian reforestation programs emphasize the use of species native to the region. However, reforestation using native species requires the production of high-quality seedlings. The present study aimed to evaluate the development and quality of seedlings of paricá (*Schizolobium parahyba* var. *amazonicum*), a species native to the Amazon with high potential for reforestation activities. We carried out a greenhouse experiment in which seedlings were subjected to treatments with varying presence of major and micronutrients in the substrate, and evaluated the effect on functional attributes (plant height, stem diameter, specific leaf area, shoot and root dry matter) and physiological response (chlorophyll *a*, *b* and carotenoid concentrations). Our results showed that nutrient omission significantly affects paricá seedling growth. Considering the assessed biometric and physiological variables, the highest nutritional requirements of seedlings were for N, P, K, micronutrients, Mg and S, while seedling quality was maintained in the absence of Ca. Overall, this species shows efficient use of available nutrients and potential for growth in soils with low concentrations of bases. Therefore, for the production of high-quality paricá seedlings, major and micronutrients should be added and lime is essential, but the good seedling performance under Ca omission suggested that this element does not need to be added to the soil.

KEYWORDS: soil fertility, Amazonian species, deficiency symptoms, nutrient omission, biometric variables

Exigências nutricionais do paricá (*Schizolobium parahyba var. amazonicum*): otimizando a qualidade de mudas para programas de reflorestamento

RESUMO

Os programas de reflorestamento da Amazônia enfatizam o uso de espécies nativas da região. No entanto, o reflorestamento com espécies nativas requer a produção de mudas de alta qualidade. O presente estudo teve como objetivo avaliar o desenvolvimento e a qualidade de mudas de paricá (*Schizolobium parahyba* var. *amazonicum*), espécie nativa da Amazônia com alto potencial para atividades de reflorestamento. Realizamos um experimento em casa de vegetação no qual mudas foram submetidas a tratamentos com presença variável de macro e micronutrientes no substrato, e avaliamos o efeito sobre os atributos funcionais (altura da planta, diâmetro do caule, área foliar específica, matéria seca da parte aérea e raiz) e resposta fisiológica (concentração de clorofila *a*, *b* e carotenóides). Nossos resultados mostraram que a omissão de nutrientes afeta significativamente o crescimento do paricá. Considerando as variáveis biométricas e fisiológicas avaliadas, as maiores exigências nutricionais das plântulas foram para N, P, K, micronutrientes, Mg e S, enquanto a qualidade das plântulas foi mantida na ausência de Ca. De modo geral, esta espécie apresenta uso eficiente dos nutrientes disponíveis e potencial de crescimento em solos com baixas concentrações de bases. Portanto, para a produção de mudas de paricá de alta qualidade, devem ser adicionados macro e micronutrientes e o calcário é essencial, mas o bom desempenho das mudas sob omissão de Ca sugere que este elemento não precisa ser adicionado ao solo.

PALAVRAS-CHAVE: fertilidade do solo, espécie amazônica, sintomas de deficiência, omissão de nutrientes, variáveis biométricas

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INTRODUCTION

The rehabilitation of deforested areas due to human action requires the development of adequate reforestation programs that consider ecological and environmental aspects such as the functionality and adaptability of target species to local soil conditions (Moratelli *et al*. 2007). The lack of knowledge about nutrient demands of most species native to Amazonia hinders the development of effective reforestation projects in the region (Damschen *et al*. 2012.

In the Itacaiúnas River watershed (Brazilian Amazon), where copper, nickel, manganese, gold and iron mines are located (Sahoo *et al*. 2020), there is a forest deficit of 3275 km^2 caused mainly by illegal deforestation and urban expansion (Nunes *et al*. 2019). Considering the importance and potential of native species in generating ecological benefits and improving the use of environmental resources during reforestation, it is essential to understand the nutritional demands of Amazonian species and their adaptive mechanisms. This knowledge is paramount to achieving the effective management of soil fertilization in reforestation projects in the Amazon region (Schwartz *et al*. 2015).

Pioneer species have a strong ability to colonize different environments, mainly due to their high nutritional efficiency, a phenomenon that is directly related to the ability to translocate nutrients from senescent leaves to growing tissues (Machado *et al*. 2016). *Schizolobium parahyba* var. *amazonicum* (Huber ex Ducke) Barneby (Fabaceae), known in northern Brazil as paricá, is a tree species native to the Amazon region with high potential for reforestation activities due to its rapid growth. Its wood production capacity is of 20 to 30 m^3 ha^{-1} $year^{-1}$ and there is a widespread use of its timber (Miranda *et al.* 2016). This species represents a regional alternative for the reforestation of degraded areas (Cordeiro *et al*. 2015).

Despite its potential, the use of paricá in plantations in the Amazon remains a risky activity due to the lack of information on its nutrient, water and light requirements and the appropriate silvicultural treatments to enhance seedling production and cultivation (Gomes *et al*. 2019; Oliveira *et al*. 2019). The assessment of seedling performance involves the response of biometric and physiological parameters such as plant height, shoot and root dry matter, and chlorophyll concentration to soil conditions to which they are sensitive (Grossnickle 2012; Amaral *et al.* 2020).

In this context, we evaluated the effect of different nutrient omission treatments on the development of paricá seedlings, namely on nutrient provision, functional traits (specific leaf area, shoot and root dry matter) and physiological response (pigment synthesis). Our aim was to contribute to the production of high-quality seedlings of this species and enhance its use in reforestation programs.

MATERIAL AND METHODS

Seeds of paricá (*Schizolobium parahyba* var. *amazonicum*) were collected at Carajás National Forest (Floresta Nacional de Carajás – FLONACA) (6°3′32.33″S, 50°10′23.27″W), Parauapebas, Pará state, Brazil. FLONACA has an area of 4000 km^2 and is protected by federal law. The climate of the region is Aw according to the Köppen classification, i.e., tropical, hot, and humid, with annual rainfall above 2000 mm, a dry season between May and October and a rainy season between November and April (Alvares *et al*. 2013).

The experiment was conducted in a greenhouse using a Quartzarenic Neosol according to the Brazilian soil classification (Santos *et al*. 2018). Five soil samples were collected in the 0-20-cm layer after removing all vegetation and organic debris from the surface. After air drying, the samples were sieved through a mesh of 2 mm to perform chemical and physical analyses for soil characterization. Soil pH was determined by pH electrode in a soil:water suspension (1:2.5 ratio) (Teixeira *et al*. 2017). Available P, K, B, Zn, Fe, Mn, and Cu were extracted by the Mehlich-1 solution (0.05 mol L^{-1} HCl, 0.0125 mol L^{-1} H_2SO_4), where P was determined by colorimetry, K by flame photometry and the other elements by inductively coupled plasma-atomic emission spectrometry (ICP-AES Spectro Genesis, Kleve, Germany). Exchangeable Ca, Mg, and Al were extracted using 1 mol L^{-1} KCl extracts added to lanthanum oxide and quantified using ICP-AES. The soil sand, silt, and clay proportions were quantified using the Bouyoucos densimeter method (Teixeira *et al*. 2017). The results of the soil physical and chemical analyses are presented in Table 1.

Ten soil management treatments were established using the missing element technique: complete fertilization with added lime (Complete), complete fertilization without lime (Complete - Lime), no fertilization and no lime (Control), omission of nitrogen (-N), omission of phosphorus (-P), omission of potassium (-K), omission of calcium (-Ca), omission of magnesium (-Mg), omission of sulphur (-S) and omission of micronutrients (-Micronutrients). Before paricá cultivation, limestone (32% CaO and 15% MgO) was applied to the treatments with lime. The soil was incubated for 30 days

Table 1. Physical and chemical attributes of the soil used for paricá (*Schizolobium parahyba* var. *amazonicum*) seedling cultivation in a greenhouse experiment of missing element treatments.

pH_{H2O}	K	Ca	Mg	Al	P	B	Mn	Fe	Cu	Zn	sand	silt	clay
	----------------cmol$_c$ kg^{-1}----------------				------------------mg kg^{-1}------------------						--------------%-------------		
4.9	0.01	0.2	0.1	1.1	1.4	0.3	21.7	4.2	3.2	2.6	74	3	23

and, during this period, soil moisture was maintained at field capacity. Complete fertilization consisted of the application of 200 mg of N, 200 mg of P, 150 mg of K, 50 mg of S, 0.5 mg of B, 1.5 mg of Cu, and 5 mg of Zn per dm^3 of soil. Pots filled with 2 dm^3 of soil were used, and a completely randomized experimental design was employed, with five replicates per treatment. Before the beginning of the experiment, seeds were submitted to dormancy breaking using the mechanical scarification method and three seeds were planted in each pot. After germination, only one seedling was allowed per pot. During plant growth, soil moisture was maintained at field capacity using distilled water daily.

After 75 days of cultivation under these treatments, stem diameter and seedling height were measured. Shoots and roots were harvested separately and washed in running water three times and in distilled water two times. Each plant part was then dried in an oven at 60 °C until constant weight. Shoot dry matter (SDM) and root dry matter (RDM) were obtained using a precision scale (Mettler Toledo, 1 mg precision). The materials were then ground in a Wiley mill (Retsch, Düsseldorf, Germany) to determine the concentration of major nutrients and micronutrients. For nutrient determination, samples of 250 mg of plant tissue were mixed with 2 mL of 65% HNO_3 (MERCK®, Darmstadt, Germany), 2 mL of H_2O_2 and 5 mL of Milli-Q water (Master System MS 2000, Gehaka, São Paulo-Brazil) and then digested in a microwave oven (Mars Xpress, CEM Corporation, Matthews, NC, USA) at 80 ºC for 3 min, 150 ºC for 5 min and 180 ºC for 10 min. The digested extracts were filtered using slow-filtering blue-band filter paper. The filtered extract was transferred to 50-mL Falcon tubes, and the final volume was adjusted with Milli-Q water. Major and micronutrient levels were determined by inductively coupled plasma-optical emission spectrometry (ICP-OES).

The Dickson quality index (DQI) was calculated using the following equation (Dickson *et al.* 1960):

$$DQI = \frac{\text{TDM (g)}}{\frac{H\ (cm)}{SD\ (mm)} + \frac{SDM\ (g)}{RDM\ (g)}}$$

where TDM = total dry matter; H = height; SD = stem diameter; SDM = shoot dry matter; and RDM = root dry matter.

The DQI is considered a valuable morphological measure that integrates height, diameter, shoot, and root biomass, providing realistic results regarding the quality of seedlings (Silva *et al.* 2020).

Leaf area was determined by scanning the fresh leaves using a scanner (HP PSC 1310, Reading, UK) and the free software ImageJ (Rasband 2007). The leaves (including those used to determine leaf area) were then dried to constant weight, and specific leaf area (SLA) was calculated as the ratio between the mean leaf area and the mean dry weight.

During harvest, the third pair of fully expanded leaves was collected from the seedlings to determine chlorophyll *a* and *b* and carotenoid concentrations according to Lichtenthaler and Wellburn (1983). Samples (0.5 g) were placed in an agate mortar and homogenized with a pestle adding 5 mL of 80% acetone and then refrigerated at 4 °C. The homogenate was filtered, and the precipitate was washed with cold acetone until total chlorophyll extraction. The absorbance was measured at 663 nm, 645 nm and 470 nm.

Statistical analysis

The data were submitted to a one-way analysis of variance (ANOVA), and the means were compared using the Scott-Knott test. Differences were considered significant when $p \leq 0.05$. Previously to ANOVA, the data were submitted to tests of normality (Shapiro-Wilk) and homogeneity of variance (Levene), to verify the fulfillment of the premises for parametric analysis. The analyses were performed using the software R version 3.6.2 (R core team 2020). The barplot graphics were performed using the software SigmaPlot 11 (Systat Software 2008).

RESULTS

Visual symptoms of deficiency and growth of seedlings

Visual symptoms of nutritional deficiency in seedlings were first manifested in the treatment -P at 28 days of cultivation. Further deficiency symptoms were observed in the treatments -N, -Micronutrients, -K and -S at 32, 40, 50 and 54 days of cultivation, respectively (Figure 1). The plants in the remaining treatments showed no visual symptoms of nutritional deficiency during the cultivation period.

The older leaves of seedlings under the -N treatment initially became light green, subsequently progressing to intense yellowing. At the end of the experiment, these plants had reduced biomass, with a decrease of 55% and 25% in SDM and RDM, respectively, compared to the Complete treatment (Figure 2). The omission of P promoted a 63% and 37% reduction in SDM and RDM, respectively, compared to the Complete treatment. Potassium deficiency manifested as chlorotic spots in older leaves that eventually merged and evolved to necrosis on the edges. The omission of K promoted a 58% and 26% reduction in SDM and RDM, respectively, compared to the Complete treatment. Calcium omission did not promote a noticeable reduction in both SDM and RDM. Magnesium omission caused a reduction of 37% and 6% in SDM and RDM, respectively. Sulphur deficiency manifested as the yellowing of younger leaves, and its omission reduced SDM by 42% relative to the Complete treatment, but did not compromise RDM. The Complete - Lime treatment, caused

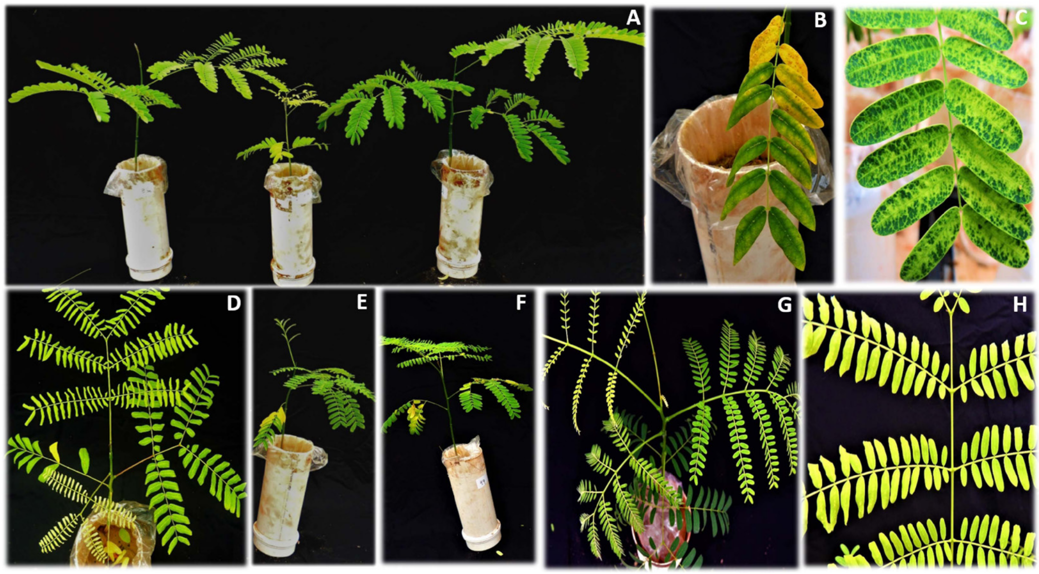

Figure 1. Images of growth and nutritional deficiency symptoms in paricá (*Schizolobium parahyba* var. *amazonicum*) seedlings submitted to missing element treatments. A – complete fertilization scheme, control (no fertilization) and Ca omission (from left to right); B – phosphorus omission; C – potassium omission; D – nitrogen omission; E – phosphorus omission; F – potassium omission; G – micronutrient omission; H – sulphur omission. This figure is in color in the electronic version.

reduction in SDM and RDM of 33% and 30%, respectively, compared to the Complete treatment. The omission of micronutrients caused the greatest reduction observed in SDM (69%) and RDM (54%).

The height of the seedlings was significantly lower in the treatments Control, -P, -K, and -Micronutrients. Stem diameter was significantly lower in the treatments Complete - Lime, -N, -P, -K, and in the Control. DQI showed that the treatments -N, -P, -K, -Mg, -S, and -Micronutrients significantly impaired seedling quality and development, similarly to the Control. Remarkably, seedling height, stem diameter, SDM, RDM and DQI were all significantly higher in the treatments Complete and -Ca (Figure 2).

Nutrient content and photosynthetic parameters

Nutrient content and photosynthetic parameters of the seedlings varied significantly among treatments. Generally, treatments with nutrient omission resulted in significantly lower nutrient content of the respective nutrient in root and shoot tissues (Table 2). Slight reductions in leaf nutrient contents in the Complete treatment may have resulted from dilution effects on some leaf nutrients due to higher shoot growth. In contrast, in the Complete - Lime treatment, SDM was reduced in comparison with the Complete treatment, showing a nutrient concentration effect for all nutrients in shoots except Ca and Mg, which were not applied in this treatment. Such nutrient concentration effects were not observed in the roots. The cationic micronutrients Cu and Mn had significantly higher concentrations in shoots (and Mn in roots) of the Complete - Lime treatment than in the Complete treatment (Table 2).

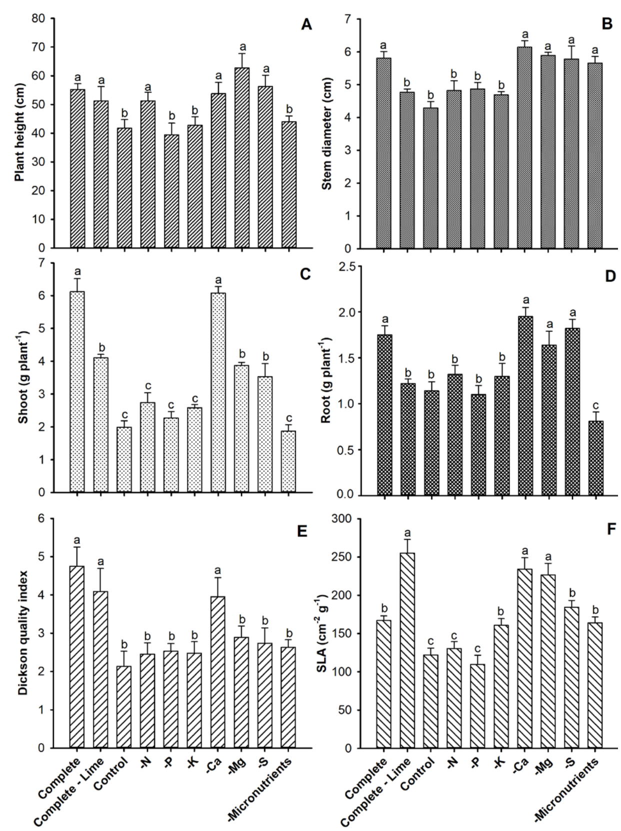

Figure 2. Biometric parameters of paricá (*Schizolobium parahyba* var. *amazonicum*) seedlings subjected to different missing element treatments. A – plant height; B – stem diameter; C – shoot dry matter; D – root dry matter; E – Dickson quality index; F –specific leaf area. Columns represent the mean and bars the standard deviation of five replicates. Different letters above bars indicate significant differences between means according to the Scott-Knott test (5% significance level).

Table 2. Major nutrient and micronutrient content in shoots and roots of paricá (*Schizolobium parahyba* var. *amazonicum*) seedlings subjected to different missing element treatments.

Treatment	Nutrient contents in shoots								
	g kg^{-1}						mg kg^{-1}		
	N	P	K	Ca	Mg	S	B	Cu	Mn
Complete	15.2 ± 0.1b	3.5 ± 0.2a	14.3 ± 1.3b	4.8 ± 0.8c	1.7 ± 0.1b	1.6 ± 0.2b	32.2 ± 2.1a	3.1 ± 0.6c	23.4 ± 1.2d
Complete - Lime	26.5 ± 1.1a	3.6 ± 0.2a	19.3 ± 1.5a	3.6 ± 0.4c	0.9 ± 0.1c	2.0 ± 0.5a	39.6 ± 3.4a	9.8 ± 0.7a	68.3 ± 5.8a
Control	8.0 ± 0.8c	0.7 ± 0.2c	4.9 ± 0.9c	8.0 ± 0.9a	1.4 ± 0.2b	0.8 ± 0.2c	12.7 ± 1.1c	3.0 ± 0.6c	3.6 ± 0.4f
-N	7.0 ± 0.4c	2.3 ± 0.6b	12.8 ± 1.2b	3.6 ± 0.4c	0.8 ± 0.1c	1.1 ± 0.3b	26.1 ± 1.7b	2.8 ± 0.8c	9.1 ± 0.7e
-P	30.5 ± 1.3a	0.5 ± 0.1c	13.3 ± 1.4b	6.8 ± 0.7b	1.5 ± 0.3b	1.9 ± 0.7a	31.0 ± 2.3a	4.6 ± 0.9b	31.3 ± 1.7c
-K	26.2 ± 1.2a	4.2 ± 0.6a	3.5 ± 0.7c	9.2 ± 0.9a	3.4 ± 0.3a	2.0 ± 0.4a	29.8 ± 1.3a	5.3 ± 0.6b	31.8 ± 1.6c
-Ca	15.6 ± 0.8b	2.7 ± 0.4b	14.3 ± 1.5b	1.9 ± 0.1d	2.0 ± 0.5b	1.3 ± 0.4b	28.3 ± 1.7b	7.8 ± 0.9a	49.6 ± 3.5b
-Mg	18.8 ± 0.9b	3.8 ± 0.6a	20.3 ± 1.6a	9.5 ± 0.5a	0.8 ± 0.3c	1.4 ± 0.4b	27.1 ± 1.1b	3.0 ± 0.3c	36.8 ± 4.8c
-S	21.9 ± 0.7a	3.7 ± 0.8a	17.3 ± 1.8b	8.3 ± 0.8a	1.8 ± 0.5b	0.8 ± 0.3c	34.7 ± 2.1a	2.9 ± 0.3c	27.4 ± 2.1d
-Micronutrients	23.5 ± 1.2a	4.2 ± 0.7a	15.6 ± 1.3b	6.6 ± 0.7b	2.2 ± 0.5b	1.9 ± 0.5a	6.7 ± 0.8d	1.6 ± 0.2d	10.1 ± 1.4e
Treatment	**Nutrient content in roots**								
	g kg^{-1}						mg kg^{-1}		
	N	P	K	Ca	Mg	S	B	Cu	Mn
Complete	13.1 ± 0.8c	3.2 ± 0.7a	18.6 ± 1.4a	3.9 ± 0.7a	2.3 ± 0.4b	3.2 ± 0.3a	16.9 ± 1.3a	22.2 ± 2.5b	31.1 ± 2.3c
Complete - Lime	18.3 ± 1.4a	3.5 ± 0.9a	20.6 ± 1.5a	3.5 ± 0.5a	1.2 ± 0.1c	2.0 ± 0.2b	18.0 ± 1.4a	20.7 ± 2.4b	99.1 ± 7.6a
Control	8.7 ± 0.7b	1.3 ± 0.4c	6.3 ± 0.9c	5.4 ± 0.7a	1.9 ± 0.2b	1.0 ± 0.2b	15.7 ± 1.5a	7.1 ± 0.9c	13.2 ± 1.4d
-N	14.1 ± 0.9c	2.7 ± 0.4b	17.3 ± 1.7a	4.6 ± 0.9a	1.7 ± 0.3b	2.5 ± 0.4b	20.1 ± 1.6a	57.2 ± 4.4a	94.3 ± 8.5a
-P	21.9 ± 1.8a	0.3 ± 0.01d	14.1 ± 1.2b	5.0 ± 0.7a	1.8 ± 0.5b	2.4 ± 0.3b	19.1 ± 1.4a	26.2 ± 2.1b	57.3 ± 3.2b
-K	18.8 ± 1.4a	2.2 ± 0.3b	2.0 ± 0.6d	4.6 ± 0.6a	3.8 ± 0.7a	3.1 ± 0.2a	18.4 ± 1.7a	23.7 ± 1.5b	80.4 ± 7.4a
-Ca	15.8 ± 1.1b	3.5 ± 0.7a	14.2 ± 1.7b	1.4 ± 0.1b	1.9 ± 0.4b	1.5 ± 0.2b	15.6 ± 1.9a	22.8 ± 1.7b	36.9 ± 2.5c
-Mg	15.6 ± 1.2b	3.6 ± 0.5a	19.6 ± 2.1a	5.2 ± 0.4a	1.0 ± 0.2c	2.1 ± 0.5b	14.2 ± 1.1a	16.3 ± 1.3b	73.7 ± 5.8a
-S	10.4 ± 0.9d	3.1 ± 0.8a	16.5 ± 1.8a	4.0 ± 0.6a	1.5 ± 0.6b	0.5 ± 0.1c	13.9 ± 1.6a	14.3 ± 1.1b	25.8 ± 3.2c
-Micronutrients	14.9 ± 1.4b	3.1 ± 0.9a	19.2 ± 1.9a	4.5 ± 0.8a	2.6 ± 0.4b	2.9 ± 0.7a	10.1 ± 1.1b	2.6 ± 0.6c	7.4 ± 0.8d

Values correspond to average ± standard deviation (n = 5). Means followed by different letters within a column indicate significant differences between means according to the Scott-Knott test (5% significance level).

The concentration of chlorophyll *a* and *b* and carotenoids was significantly lower in the treatments -N and -P, and in the Control. The chlorophyll *a*: chlorophyll *b* ratio was significantly higher in the -N and -Mg treatments and in the Control (Figure 3).

DISCUSSION

In the present study, the growth of paricá seedlings was mainly affected by the omission of N, P, K, and micronutrients. The treatments lacking these elements, as well as the Control, which lacked any fertilization, compromised shoot growth in more than 40%. Nitrogen is a constituent of chlorophyll, amino acids, nucleic acids, and protein molecules, including enzymes directly involved in carbon fixation, and participates in the metabolism of carbohydrates and the active transport of other nutrients through membranes. Phosphorus is mainly involved in the production and transport of ATP and is a structural component of nucleotides and phospholipids. Potassium acts primarily as an osmoregulator in stomatal turgor (Jiaying *et al.* 2022; Taiz and Zeiger, 2013). Furthermore, the lack of these elements also negatively impaired root growth. Micronutrient omission reduced root development by more than 40% compared to the Complete treatment, indicating that the unfertilized substrate used in this study, as most Amazonian soils, is nutrient deficient and therefore requires nutrient management to produce high-quality seedlings to support reforestation activities.

The Complete - Lime treatment, in which the soil pH was not corrected and Ca and Mg were not added, caused reduction in SDM and RDM, when compared to the Complete treatment, indicating that the absence of lime is a limiting factor for paricá growth. Such reductions were not observed in the -Ca treatment. On the other hand, in the -Mg treatments, shoot growth was compromised. Soil pH (below 5

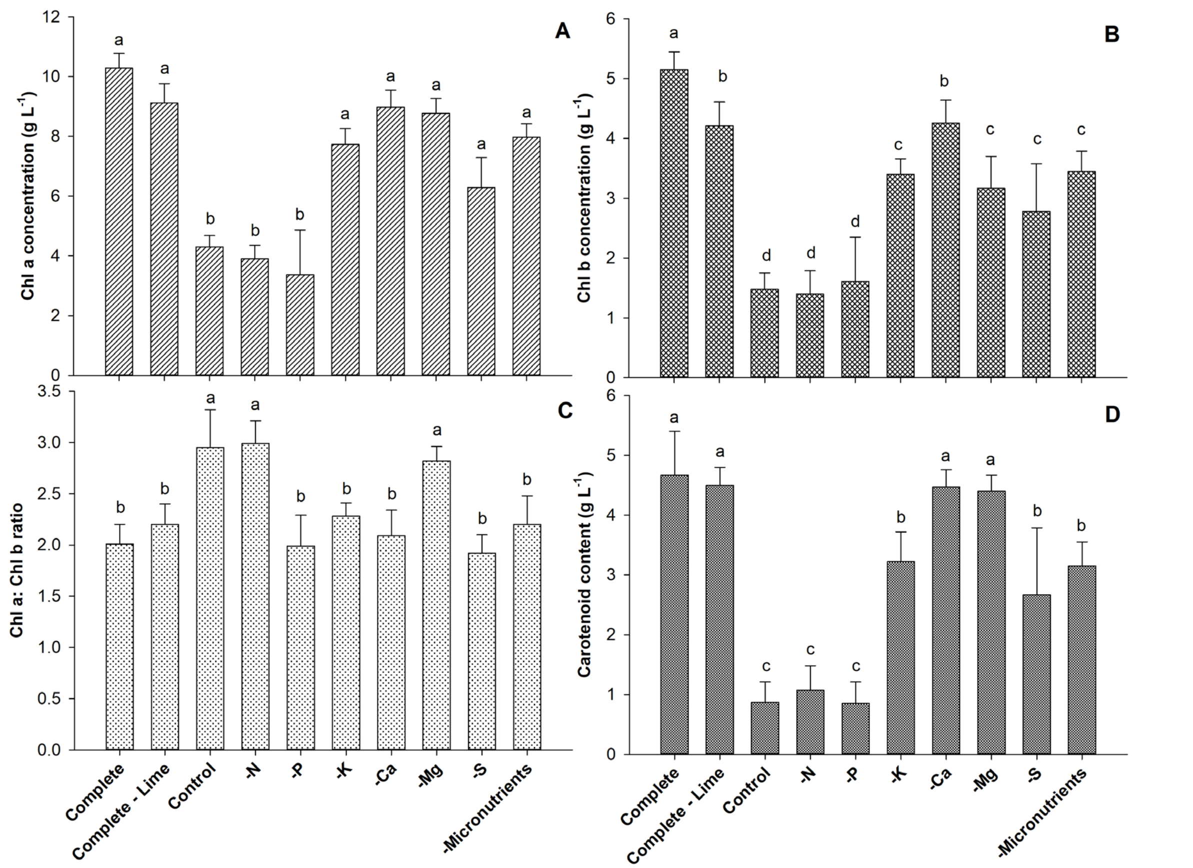

Figure 3. Physiological parameters of paricá (*Schizolobium parahyba* var. *amazonicum*) seedlings subjected to different missing element treatments. A – chlorophyll *a* content; B – chlorophyll *b* content; C – chlorophyll *a*: chlorophyll *b* ratio; D – carotenoid content. Columns represent the mean and bars the standard deviation of five replicates. Different letters above the bars indicate significant differences between means according to the Scott-Knott test (5% significance level).

and above 7) is considered a potential limiting factor for plant growth due to its effect on the availability of nutrients, usually showing strong positive correlation with plant growth variables (Ghosh *et al*. 2016). The lack of lime may have contributed to the low soil pH, immobilizing the applied nutrients in this treatment and rendering them unavailable for the plant. On the other hand, low pH makes cationic micronutrients such as Cu and Mn more available for absorption by the plant and accumulation in the shoots and roots. It is widely known that cationic micronutrient availability in tropical soils increases with decreasing pH (Van Eynde *et al*. 2022). Under very acidic conditions, there is considerable solubilization of Al from the soil, which becomes a potential acidity component and, consequently, as a phytotoxic element, one of the factors responsible for the unfavorable effects of acidity on plants (Yerima *et al*. 2020). Therefore, in acidic soils with the presence of Al such as the substrate used in this study, liming is essential for paricá growth. In addition to reducing or eliminating the toxic effects of Al in the soil, lime increases the absorption of P and other nutrients by plants.

Reforestation success depends on seedling quality, which determines seedling establishment in the field (Sena *et al*. 2010). Our highest DQI values were obtained in the Complete treatment and the treatments lacking lime or Ca, suggesting that this species grows efficiently in soil with low Ca availability and that it is possible to successfully establish these plants in the field under these conditions.

Reduction in SLA are associated with leaves that remain connected to the mother plant for a longer time, a conservation strategy of plants growing in resource-restricted environments (Wright *et al*. 2004). Reduced SLA was observed in the treatments lacking nutrients, especially N, P, and in the Control. The difficulty of seedlings in acquiring N and P may have increased the leaf construction cost, leading to reduced SLA. Changes in leaf construction costs can occur to increase nutrient use efficiency and optimization to maximize photosynthesis, as has been observed in various species (Yao *et al*. 2016). Consistent with our results for other variables, the high SLA values observed in the treatment lacking Ca indicate that the reduced availability of this nutrient did not limit paricá growth and that the species has a high competitive ability in these conditions regarding carbon fixation and biomass accumulation.

Plant chlorophyll synthesis is dependent on mineral nutrition (Kalaji *et al*. 2018). Of all nutrients, nitrogen has the largest influence on plant development and leaf surface in particular. In addition, the photosynthetic potential and its effect is enhanced by phosphorus and, to a lesser extent, by potassium (Bojovic and Stojanovic 2005). Our results reflect this effect as chlorophyll *a* and *b* and carotenoid content was lower in the treatments lacking nitrogen and phosphorus. Besides -N, -P, and -K, carotenoid contents were also reduced in the -S treatment, suggesting that the carotenoid synthesis pathway is particularly susceptible to sulfur deficiency (Ausma *et al*. 2021).

CONCLUSIONS

Considering the response of the assessed biometric and physiological variables, the highest nutritional requirements of paricá seedlings were for N, P, K, micronutrients, Mg, and S. To improve the development of seedlings, major and micronutrients must be added to the substrate. Lime is essential to increase soil pH and to promote nutrient availability. However, seedlings appeared to have low Ca requirement, showing a capacity to grow under deficiency of this nutrient while still producing high-quality seedlings in the Amazon region.

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