

Nutrient omission and nutritional status of young *Theobroma grandiflorum* plants

Jessivaldo Rodrigues Galvão^{1*}, Ismael de Jesus Matos Viégas¹, Bruno Kleidson da Silva Maia², Anderson de Santana Botelho³, Cristine Bastos do Amarante⁴, Matheus Gustavo dos Santos Canuto¹, Luiz Eduardo Freitas Da Silva Júnior¹, Thaysa Helena Alves Farias¹

¹Universidade Federal Rural da Amazônia, Belém – PA, Brasil

²Universidade Estadual Paulista, Jaboticabal – SP, Brasil

³Universidade do Estado do Amapá, Macapá – AP, Brasil

⁴Museu Paraense Emilio Goeldi, Belém – PA, Brasil

*Corresponding author, e-mail: jessigalvao50@gmail.com

Abstract

The cupuaçu tree (*Theobroma grandiflorum* (Willd. ex Spreng.) Schum.), belonging to the Malvaceae family, is one of the most important and popular fruit species in the Amazon. With the growth of commercial production and the increasing demand for seedlings, research aimed at optimizing its cultivation has become essential. Therefore, this study aimed to evaluate the development of young cupuaçu plants subjected to nutrient omission. The experiment was conducted under greenhouse conditions at Embrapa Eastern Amazon. The soil used was a Yellow Latosol of medium texture, collected from a depth of 0–20 cm. The experimental design was completely randomized with 10 treatments: complete (macro- and micronutrients); omission of N, P, K, Ca, Mg, S, B, and Zn; and a control treatment, with five replications. The evaluated variables included plant height, stem diameter, number of leaves, leaf area, dry matter production (leaves, stems, branches, and roots), macro- and micronutrient contents, and leaf analysis. To compare means, the Scott-Knott test at a 5% probability level was applied, following significance by the F test. Overall, nutrient omission limited plant development; however, the most detrimental to plant growth were N, P, K, Mg, and S. These same nutrients (with the exception of Mg) were also those that most affected total dry matter. It was concluded that young cupuaçu plants cultivated in medium-textured Yellow Latosol soils have high demands for macronutrients and the micronutrients B and Zn to achieve optimal development.

Keywords: Cupuaçu trees, Nutrition, fruits of the Amazon

Introduction

The cupuaçu tree (*Theobroma grandiflorum* (Willd. ex Spreng.) Schum.), belonging to the Malvaceae family and Sterculioideae subfamily, is one of the most important and popular fruit crops in the Amazon region. The species occurs naturally in upland forests and high floodplains, with a strong presence in the states of Pará and Amazonas—especially in the basins of the Tapajós, Xingu, Guamá, and Tocantins rivers—as well as records in northeastern Maranhão (Santos et al., 2023).

Commercial cultivation of cupuaçu began in the 1970s, based on native populations. In recent years, the cultivated area in the Amazon region has continued to expand significantly, exceeding 30,000 hectares, of which approximately 14,000 hectares are in Pará. The state of Amazonas also has a growing production chain, involving thousands of producers (Almeida et al., 2022).

Among Amazonian fruit crops, cupuaçu stands

out for its socioeconomic relevance and potential to strengthen regional fruit production. Its pulp, with a distinctive flavor and aroma, is widely used in the preparation of juices, ice creams, creams, jams, jellies, and sweets, enjoying broad acceptance in the regional market (Rodrigues et al., 2021).

With the advancement of commercial production and the consequent increase in seedling demand, research aimed at optimizing production processes has become essential, focusing on cost reduction and the production of seedlings with suitable morphological and physiological quality for planting systems. Balanced nutrition, combined with the rational use of inputs, is considered a cornerstone for increasing productivity and ensuring sustainable cultivation (Silva et al., 2022).

The formulation of an efficient fertilization program depends on prior knowledge of the effects that nutrient deficiencies can have on plant development.

A widely employed technique for this purpose is the nutrient omission trial, also known as the missing-element technique. This methodology allows the identification of nutrients essential for plant growth through the observation of physiological and morphological symptoms resulting from the absence of specific elements (Santos et al., 2023).

Given the diversity of soils and ecological conditions in the Amazon region, researchers have intensified studies aimed at characterizing the nutritional requirements of major regional crops. These studies seek to fill gaps in knowledge regarding Amazonian soil fertility, contributing to the adoption of more effective and sustainable management practices, particularly in cupuaçu cultivation (Viégas et al., 2020).

Therefore, with the aim of deepening the understanding of the role of nutrients in the development of this crop, this study aimed to evaluate the growth of young cupuaçu plants, characterize the symptoms of macronutrient (N, P, K, Ca, Mg, and S) and micronutrient (B and Zn) deficiencies, and determine the leaf nutrient contents of plants subjected to nutrient omission.

Materials and Methods

The experiment was conducted in a greenhouse at Embrapa Eastern Amazon, located in the municipality of Belém, state of Pará, at the geographic coordinates 01° 27' 21" S latitude and 48° 30' 16" W longitude. The region has an equatorial climate of type Af, according to the Köppen classification, with an average annual temperature of 26 °C, high relative humidity around 90%, and high rainfall. The annual average precipitation is approximately 2,754.4 mm, with a wetter season from December to May and a drier season from June to November (Pereira et al., 2017).

The soil used as a substrate was a medium-textured Yellow Latosol, collected from the 0–20 cm layer in an area located in Belém, state of Pará. This soil has adequate drainage, good depth, and intermediate levels of natural fertility (Santos et al., 2018). Before the experiment was established, the soil was sieved through a 4 mm mesh and subjected to physical and chemical characterization following the methodological procedures established by Embrapa (Teixeira et al., 2017). The analysis revealed the following parameters:

The experiment was conducted in a completely

randomized design (CRD), consisting of 10 treatments with five replications each. The treatments included: complete fertilization (with macro- and micronutrients), omission of nitrogen (-N), phosphorus (-P), potassium (-K), calcium (-Ca), magnesium (-Mg), sulfur (-S), boron (-B), zinc (-Zn), and a full control treatment.

The seeds used in the experiment belonged to progeny 63 of cupuaçu (*Theobroma grandiflorum*), developed by Embrapa Eastern Amazon. Initially, the seeds were sown in containers filled with a substrate composed of terra preta (dark earth) and decomposed sawdust. After germination and development to the stage known as "toothpick stage," the seedlings were transplanted into 5 kg capacity polyethylene bags, measuring 35 cm in height and 18 cm in diameter, with a thickness of 0.20 mm.

Forty-five days after transplanting, mineral fertilization was carried out in the pots according to the established treatments, using the missing element technique described by Silva et al. (2008). The nutrient rates and sources were applied according to the crop's requirements and the specific nutrient omissions defined for each treatment (**Table 2**).

Fertilizations containing nitrogen and potassium were split into three applications (at 45, 90, and 150 days after planting, respectively).

Plant collection was carried out 300 days after seedling planting, separating the plants into leaves, petioles, stems, and roots. The separated parts were placed in paper bags and dried in a forced-air oven at 70°C until a constant weight was achieved. After drying, the plant material was weighed and ground using a Willey-type mill in preparation for nutrient content analysis. To calculate the relative growth, the following formula was used:

$$CR(\%) = \frac{(M.S.O.N)}{(M.S.T.C)} \times 100$$

Where

CR = Relative Growth

M.S.O.N = Total dry weight obtained under each nutrient omission

M.S.T.C = Total dry weight obtained in the complete fertilization treatment

The determination of macro- and micronutrient contents was performed on the leaves, petioles + stems, and roots of the plants, following the

Table 1. Soil analysis results

Prof. cm	OM gkg ⁻¹	P -----mg dm ³ ----	K	Na	Al	Ca	Ca+Mg	pH H ₂ O	Coarse sand	Fine sand	Silt	Total clay
0-20	13,84	5	10	4	1,5	0,2	0,3	4,3	345	410	126	120

Organic matter (OM, g kg⁻¹); phosphorus (P), potassium (K), sodium (Na), aluminum (Al), calcium (Ca), and sum of calcium plus magnesium (Ca + Mg) in cmolc dm⁻³; pH in water (H₂O); particle size fractions: coarse sand, fine sand, and silt (g kg⁻¹), and total clay (g kg⁻¹).

Table 2. Applied doses in the treatments and their respective sources.

Nutrient	Dose	Source
N	100 mg kg ⁻¹ of the soil	Urea
P	50 mg kg ⁻¹ of the soil	Monosodium phosphate
K	90 mg kg ⁻¹ of the soil	Potassium chloride
Ca	30 mg kg ⁻¹ of the soil	Calcium chloride
Mg	30 mg kg ⁻¹ of the soil	Magnesium chloride
S	7,5 mg kg ⁻¹ of the soil	Sodium sulfate
B	1,2 mg kg ⁻¹ of the soil	Boric acid
Cu	1,0 mg kg ⁻¹ of the soil	Copper sulfate
Mn	4,0 mg kg ⁻¹ of the soil	Manganese sulfate
Zn	5,0 mg kg ⁻¹ of the soil	Zinc sulfate

Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), copper (Cu), manganese (Mn), and zinc (Zn)

methodology proposed by Malavolta et al. (1997). Throughout the experimental period, visual symptoms of nutrient deficiency were monitored, described, and photographically recorded.

The variables analyzed in the experiment included: plant height (PH), stem diameter at the collar (SD), leaf dry mass (LDM), stem + branch dry mass (SBDM), root dry mass (RDM), and total dry mass (TDM), in addition to the foliar contents of macronutrients and the micronutrients boron (B) and zinc (Zn).

The data obtained were subjected to analysis of variance (ANOVA), and treatment means were compared using the Scott-Knott test at a 5% probability level.

Results and discussion

The omission of nutrients limited the development of cupuaçu plants compared to the complete treatment (Table 3).

Table 3. Plant height (PH), stem diameter (SD), number of leaves, and leaf area in young cupuaçu plants as affected by nutrient omission treatments

Treatment	PH (cm)*	SD (mm)*	N ^o of leaves*	leaf area (cm ²)*
Compleat	75.2 a	11.8 a	20.0 a	6533.55 a
Omission N	64.2 b	9.2 c	12.0 d	2192.00 c
Omission P	46.4 d	9.0 c	10.5 d	1192.90 c
Omission K	41.6 e	8.2 d	15.0 c	2863.00 b
Omission Ca	54.6 c	9.6 c	19.5 a	3127.82 b
Omission Mg	43.2 e	9.0 c	11.0 d	2258.40 c
Omission S	63.8 b	8.4 d	9.0 e	2037.82 c
Omission B	45.6 d	10.6 b	17,5 b	2741.87 b
Omission o Zn	53.0 c	10.2 b	14.0 c	3077.50 b
Average	54.18	9.56	14.28	2891.65
C.V (%)	4.18	7.86	10.82	15.73

Means followed by the same lowercase letter in the column do not differ statistically from each other according to the Scott-Knott test at 5% probability.

The individual omission of nutrients significantly influenced the growth of young cupuaçu plants, as shown in Table 1. Regarding plant height (PH), the treatments with K and Mg omission showed the lowest

mean values, 41.6 cm and 43.2 cm, respectively, representing reductions of 44.6% and 42.5% compared to the complete treatment (75.2 cm). Plant height is a relevant parameter for evaluating seedling quality in nurseries, as it directly reflects the plant's post-transplant development potential.

P deficiency reduces photosynthesis and increases the plant's respiration rate, limiting the production and transport of carbohydrates (Zorb et al., 2014; Cavalcante et al., 2018). Similarly, Mg is essential for energy transfer in the photosystems and for chlorophyll synthesis, directly affecting plant growth (Taiz & Zeiger, 2013).

Regarding stem diameter (SD), K and S omission treatments most negatively impacted development, resulting in reductions of 30.5% and 28.8%, respectively, compared to the complete treatment. Stem diameter is an indicator of seedling robustness, directly related to the assimilation rate of photoassimilates (Almeida et al., 2005). P plays a role in maintaining electroneutrality and cellular metabolism, reinforcing the effects of its absence (Taiz & Zeiger, 2013). S deficiency, in turn, tends to more intensely affect the aerial part of the plant, due to its role in forming amino acids such as cysteine and methionine, and its involvement in vital processes like photosynthesis and protein synthesis (Marschner, 2012; Epstein & Bloom, 2006).

The variable number of leaves was also affected by nutrient omission, especially s, which caused a 50% reduction compared to the complete treatment. The absence of S compromises chlorophyll formation and leaf development, resulting in stiffer, deformed, and fewer leaves (Barroso et al., 2005).

As TLA, the omission of P, S, N, and Mg caused the greatest reductions. The omission of P resulted in a leaf area 81.7% smaller than the complete treatment, followed by N (66%) and Mg (65%) omissions. P is a fundamental nutrient for ATP and nucleic acid formation, playing a crucial role in cell division and growth (Malavolta, 2012; Alves et al., 2018). Studies indicate that P deficiency can reduce both the number and size of leaves, as also observed by Alves et al. (2018) in cupuaçu seedlings.

N, in turn, is the most required nutrient by crops, being essential for the synthesis of proteins and nucleic acids. Its absence negatively affects the net CO₂ assimilation rate, limiting plant growth (Evans, 1989; Cruz et al., 2007; Marschner, 2012). Mg deficiency impairs photosynthesis and the distribution of photoassimilates, directly affecting leaf area development.

Ca omission had a moderate impact on plant

growth, with less pronounced reductions. However, all measured variables showed declines under this treatment. Freitas (2018) reported leaf deformities and limited shoot and root growth in cupuaçu seedlings under calcium deficiency, supporting the findings of this study.

B absence mainly affected plant height and total leaf area due to its role in meristematic tissues and cell division processes (Bastos & Carvalho, 2004; Mascarenhas et al., 2014). Zn omission caused reductions in all analyzed variables, although to a lesser extent. A 47.1% reduction in leaf area was especially noted, along with elongation and narrowing of new leaves, indicating typical deficiency symptoms. Dry mass production in young cupuaçu plants was significantly influenced by nutrient omissions, as shown in **Table 4**.

LDM was one of the most affected variables, with

Table 4. Leaf dry mass (LDM), root dry mass (RDM), stem dry mass (SDM), and total dry mass (TDM) of young cupuaçu plants (progeny 63) as affected by the treatments

Treatment	LDM (g)*		RDM(g)*		SDM (g)*		TDM (g)*	
Completo	17.8	a	15.8	a	21.0	a	54.8	a
Omissão N	7.8	c	9.6	b	11.0	d	28,4	e
Omissão P	8.4	c	8.6	b	9.0	e	25.8	e
Omissão K	9.6	b	8.6	b	8.8	e	26.8	e
Omissão Ca	8.0	c	13.4	a	12.8	d	34.2	c
Omissão Mg	10.2	b	10.6	b	9.2	e	30.0	d
Omissão S	9.6	b	7.8	b	8.0	e	26.0	e
Omissão B	16.2	a	14.2	a	16.8	b	47.4	b
Omissão o Zn	16.0	a	14.0	a	14.8	c	44.6	b
Average	11.51		11.40		12.38		35.33	
C.V (%)	12.81		14.47		12.18		7.46	

* Means followed by the same lowercase letter in the column do not differ significantly at the 5% significance level, according to the Scott-Knott test.

significant reductions observed under the omission of P, Ca, and N. The absence of P resulted in the lowest leaf accumulation (8.4 g), representing a decrease of over 50% compared to the complete treatment (17.8 g). This result highlights the essential role of phosphorus in cell division and energy metabolism through the formation of ATP and nucleic acids (Malavolta, 2012).

The omission of Ca also compromised LDM (8.0 g), likely due to its structural function in cell walls and its role in the growth of meristematic tissues. The absence of N reduced leaf dry mass to 7.8 g, lower than all other omissions except P, emphasizing the importance of this nutrient in protein synthesis and vegetative growth (Freitas, 2018). Similar results were observed by Araújo et al. (2016) in açaí seedlings and by Viégas et al. (2018) in mangosteen seedlings, where the omission of N, P, and Ca severely limited development.

For root dry mass (RDM), the lowest values were recorded in treatments with omission of S (7.8 g), P (8.4 g), P (8.6 g), and N (9.6 g). S deficiency is known

to primarily affect the aerial part, but in this study, it also resulted in reduced root development. P, on the other hand, regulates osmotic balance and the transport of photoassimilates, which may explain its role in root formation. Although magnesium omission did not result in the lowest absolute values, it still had a negative impact, with an RDM of 10.8 g.

Stem dry mass followed a similar trend to the other variables. The lowest values were observed under P (9.0 g), S (7.8 g), K (8.6 g), and N (11.0 g) omission treatments, again highlighting the adverse effects of macronutrient deficiencies on structural plant growth. The role of K in maintaining cell turgor and sugar transport reinforces its importance in supporting tissue formation.

The analysis of TDM provides an integrated view of the effects of nutrient omissions. The omission of P resulted in the lowest TDM (25.0 g), followed by N (28.4 g), S (30.2 g), K (32.6 g), and Ca (34.2 g). These results confirm that macronutrients are crucial for biomass accumulation in young cupuaçu plants. Barreto (2017) had already noted that the omission of N, Ca, and Mg are among the main factors responsible for reduced growth in tropical fruit species.

In contrast, the omission of micronutrients such as B and Zn also impacted plant development, but to a lesser extent. Zn omission reduced TDM to 44.6 g, while B omission reduced it to 47.4 g. Although both values were lower than the complete treatment (54.8 g), they were still higher than the values observed for macronutrient omissions. This indicates that, despite their importance, these micronutrients have a relatively smaller impact compared to macronutrients, although they can still compromise full plant growth, especially in the long term.

Table 5 presents the foliar contents of macro- and micronutrients in young cupuaçu plants under both adequate and deficient nutritional conditions. It is evident that the omission of essential nutrients significantly reduced foliar nutrient contents, directly affecting plant development.

Table 5. Foliar nutrient contents in young cupuaçu plants (*Theobroma grandiflorum*) as affected by nutrient omission.

Macronutrients	Completo treatment (g kg ⁻¹)	Omissão (g kg ⁻¹)
N – Nitrogen	21,4	15,17
P – Phosphorus	0,96	0,66
K – Potassium	6,00	2,75
Ca – Calcium	3,25	2,25
Mg – Magnesium	2,56	0,79
S - Sulfur	2,18	1,53
Micronutrients	Completo treatment (g kg ⁻¹)	Omissão (g kg ⁻¹)
B - Boron	48,7	38,68
Zn - Zinc	58	42,85

The N content in the leaves of plants under omission was 15.17 g kg^{-1} , representing a 28.5% reduction compared to the complete treatment (21.24 g kg^{-1}). Similar results were observed by Salvador et al. (1994), who reported N content of 22.4 g kg^{-1} in non-deficient leaves and 10.1 g kg^{-1} in deficient plants, which represents a reduction of approximately 54%. In strawberry cultivation, Barreto et al. (2017) found N content of 2.01 g kg^{-1} with complete fertilization, and 1.08 g kg^{-1} in the absence of N, a decrease of 46.27%. These data, although from different species, demonstrate the relevance of nitrogen in plant metabolism. N deficiency leads to a reduction in chlorophyll synthesis, resulting in chlorosis, especially in older leaves, due to its high mobility within the plant (Malavolta et al., 1997).

P omission resulted in a 31% reduction in leaf content, from 0.96 g kg^{-1} in the complete treatment to 0.66 g kg^{-1} under omission. Lima (2002) observed similar reductions in P levels in cupuaçu leaves subjected to nutrient omission. Symptoms such as dark green coloration and slight wrinkling of older leaves were observed, typical of phosphorus deficiency, which is directly related to ATP production and cell division (Malavolta, 2012).

In the case of K, the leaf content dropped from 6.00 g kg^{-1} (complete treatment) to 2.75 g kg^{-1} (with omission), a 54% reduction. Salvador et al. (1994) also found similar values in the lower leaves of cupuaçu plants with K deficiency, with levels around 2.2 g kg^{-1} . These results are similar to those obtained by Barreto et al. (2017), who found 2.7 g kg^{-1} and 10.9 g kg^{-1} in treatments with and without deficiency, respectively. K is involved in important physiological functions, such as maintaining cell turgor, stomatal opening, and sugar translocation, being essential for plant growth (Taiz & Zeiger, 2013).

Ca omission resulted in a leaf content of 2.25 g kg^{-1} , while nourished plants had 3.25 g kg^{-1} , representing a 30% reduction. Freitas (2018) observed that Ca deficiency in cupuaçu seedlings caused leaf deformations and wrinkling, interfering with the plant's physical structure. Ca is responsible for the integrity of cell walls, and its absence compromises the development of forming tissues (White & Broadley, 2003).

Mg deficiency had the greatest impact among the analyzed macronutrients. The leaf content dropped from 2.28 g kg^{-1} to 0.71 g kg^{-1} , a 69% reduction. Cakmak and Yazici (2010) highlight that Mg is directly involved in chlorophyll formation and photoassimilate mobilization, in addition to being an enzymatic cofactor in several metabolic reactions. The plants exhibited severe interveinal chlorosis and necrosis, classic symptoms of Mg

deficiency.

S omission reduced leaf content from 1.16 g kg^{-1} to 0.82 g kg^{-1} (a 29% reduction). Although the visual symptoms were not prominent, a loss of coloration and mild chlorosis were observed in younger leaves, as expected due to S's low mobility in the phloem. According to Malavolta (1980), S is essential for the formation of sulfur-containing amino acids, and its deficiency can reduce overall plant growth by disrupting protein synthesis and nitrogen metabolism.

Among the micronutrients, B omission reduced leaf content from 48.7 g kg^{-1} to 36.68 g kg^{-1} , a decrease of approximately 20%. Freitas (2018) also observed a similar reduction, with values of 48.28 g kg^{-1} (without deficiency) and 36.68 g kg^{-1} (with deficiency). B deficiency affects cell division and the integrity of meristematic tissues, leading to deformed leaves and apical dieback (Marschner, 2012; Wimmer & Eichert, 2013).

Zn deficiency resulted in a leaf content of 42.85 g kg^{-1} , compared to 58.00 g kg^{-1} in the complete treatment, a 26% reduction. Visually, leaves were narrow and elongated, with marginal chlorosis and localized necrosis. Zn plays a role in enzymatic activation and auxin synthesis, making it vital for the growth of young tissues (Vitti & Serrano, 2007). Freitas (2018) also observed reductions in foliar Zn content from 65 g kg^{-1} to 49.5 g kg^{-1} , corroborating the data presented in this study.

Conclusion

The omission treatments that most affected the development of cupuaçu seedlings, in order, were $P < S < K < N$.

The individual omission of macro- and micronutrients N, P, Ca, Mg, S, Zn, and B reduced the foliar contents of these elements, limited biometric variables, and exhibited visually observable deficiency symptoms.

References

- ADS. Agência de Desenvolvimento Sustentável do Amazonas. 2023. Cupuaçu está na safra e é facilmente encontrado nas feiras da ADS. Manaus, Brasil. <https://www.ads.am.gov.br/cupuacu-esta-na-safra-e-e-facilmente-encontrado-nas-feiras-da-ads> <Acesso em 30 Mar. 2025>
- Almeida, L.S., Maia, N., Ortega, A.R., Angelo, A.C. 2005. Crescimento de mudas de Jacarandá puberula Cham. em viveiro, submetidas a diferentes níveis de luminosidade. *Ciência Florestal* 15: 323-329.
- Alves, T.L., Almeida, G.M., Viégas, I.D.J.M., Oliveira, R.L.L., Alves, R.M., Moreira, W.K.O., Silva, B.C. 2018. Avaliação biométrica da omissão de nutrientes no desenvolvimento de plantas jovens de cupuaçuzeiro (*Theobroma grandiflorum*) progênie 61. In: II Simpósio de Propagação

- de Plantas e Produção de Mudás. Água de Lindóia, Brasil.
- Araújo, F.R.R., Viégas, I.J.M., Cunha, R.L.M., Vasconcelos, W.L.F. 2016. Nutrient omission effect on growth and nutritional status of assai palm seedlings. *Pesquisa Agropecuária Tropical* 46: 374-382.
- Barreto, C.F., Silva, P.S., Navroski, R., Benati, J.A., Nava, G., Antunes, L.E.C. 2017. Deficiência de nutrientes com efeitos no desenvolvimento de morangueiros. *Scientia Agraria* 18: 63-71.
- Barroso, D.G., Figueiredo, F.A.M.M.A., Pereira, R.C., Mendonça, A.V.R., Silva, L.C. 2005. Diagnósticos de deficiências de macronutrientes em mudas de tecas. *Revista Árvore* 29: 671.
- Bastos, A.R.R., Carvalho, J.G. 2004. Absorção radicular e redistribuição do boro pelas plantas e seu papel na parede celular. *Revista Universidade Rural: Série Ciências da Vida* 24: 47-66.
- Byng, J.W., Chase, M.C., Christenhusz, M.J.M., Fay, M.F., Judd, W.S., Mabberley, D.J., Sennikov, A.N., Soltis, D.E., Soltis, P.S., Stevens, P.F. 2016. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. *Botanical Journal of the Linnean Society* 181: 1-20.
- Cakmak, I., Yazici, A.M. 2010. Magnesium: a forgotten element in crop production. *Better Crops with Plant Food* 94: 23-25.
- Cavalcante, P.B. 1976. *Frutas comestíveis da Amazônia III*. Museu Paraense Emílio Goeldi, Belém, Brasil.
- Costa, F.L.A. 2020. *Adubação potássica e fosfatada na sucessão cártamo e soja*. <http://repositorio.bc.ufg.br/tede/handle/tede/10418>
- Cruz, C.R.P., Carvalho, J.E.B., Souza Filho, L.F.S., Queiroz, D.C. 2007. Níveis de nitrogênio e a taxa fotossintética do mamoeiro "golden". *Ciência Rural* 37: 64-71.
- Epstein, E., Bloom, A. 2006. *Nutrição mineral de plantas: princípios e perspectivas*. Planta, Londrina, Brasil. 401 p.
- Evans, J.R. 1989. Photosynthesis and nitrogen relationship in leaves of C3 plants. *Oecologia* 78: 09-19.
- Finch, D.A., Bailey, W.G., McArthur, L.J.B., Nasitwitwi, M. 2004. Photosynthetically active radiation regimes in a southern African savanna environment. *Agricultural and Forest Meteorology* 122: 229-238.
- Freitas, M.C. 2018. *Avaliação da fertilidade do latossolo amarelo textura média, para o cultivo de plantas jovens de cupuaçuzeiro (Theobroma grandiflorum) progênie 56*. 40 f. (Trabalho de Conclusão de Curso) – Universidade Federal Rural da Amazônia, Capanema, Brasil.
- IDAM. Instituto de Desenvolvimento Agropecuário e Florestal Sustentável do Estado do Amazonas. 2021. Cultivo de cupuaçu na agricultura familiar. Manaus, Brasil. <https://www.idam.am.gov.br/wp-content/uploads/2021/01/Cupuaçu.pdf> <Acesso em 30 Mar. 2025>
- Jones Jr., J.B. 1970. Distribution of 15 elements in corn leaves. *Communications in Soil Science and Plant Analysis* 1: 27-34.
- Leandro, R.C., Yuyama, K. 2008. Rooting of cutia nuttings with indolbutiric acid. *Acta Amazonica* 38: 597-601.
- Lima, M.M. 2002. *Crescimento, composição mineral e sintomas de deficiência de macronutrientes em plantas de cupuaçuzeiro (Theobroma grandiflorum)*. 52 f. (Dissertação de Mestrado) – Universidade Federal Rural da Amazônia, Belém, Brasil.
- Lima, R.F., Silva, A.O., Dias, P.H.B., Viégas, I.J.M., Silva, D.A.S. 2018. O cultivo de *Aster ericoide* cv. renna: primeiro corte a partir do substrato de Latossolo Amarelo textura média na região nordeste paraense. In: III Congresso Internacional das Ciências Agrárias. João Pessoa, Brasil. <https://doi.org/10.31692/2526-7701.IIIICOINTERPDVAGRO.2018.00587>
- Locatelli, M., Souza, V.F., Quisen, R.C. 1996. Estudo do comportamento produtivo do cupuaçuzeiro em sistemas agroflorestais. In: I Workshop sobre as Culturas do Cupuaçu e Pupunha na Amazônia. Manaus, Brasil. p. 158-159.
- Lopes, A.S. 1998. *Manual internacional de fertilidade do solo*. Potafós, Piracicaba, Brasil. 177 p.
- Lopes, J.R.M., Luz, E.D.M.N., Bezerra, J.L. 1999. Situação atual do cupuaçuzeiro no Sul da Bahia. *Agrotropica* 11: 183-188.
- Malavolta, E., Vitti, G.C., Oliveira, S. 1997. *Avaliação do estado nutricional das plantas*. Potafós, Piracicaba, Brasil. 319 p.
- Marschner, P. 2012. *Marchner's mineral nutrition of higher plants*. Academic Press, New York, USA. 651 p.
- Mascarenhas, H. A.A., Esteves, J.A.F., Wutke, E.B., Gallo, P.B. 2014. Micronutrients in soybeans in the State of São Paulo. *Nucleus* 11: 131-149.
- Mesa, A.R., Hernandez, M., Reyes, F. 1998. Determinacion de los niveles críticos de N, P e K, rendimiento de materia seca y composicion quimica em *Andropogon gayanus* cv. CIAT-621. *Pastos y Forrages* 11: 235-241.
- Mesquita, E.F., Chaves, L.H.G., Freitas, B.V., Silva, G.A., Sousa, M.V.R., Andrade, R. 2012. Produção de mudas de mamoeiro em função de substratos contendo esterco bovino e volumes de recipientes. *Revista Brasileira de Ciências Agrárias* 7: 58-65.
- Nechet, D. 1993. Análise da precipitação em Belém-PA, de 1986 a 1991. *Boletim de Geografia Teorética* 23: 150-156.
- Nunes, J.A.R., Ramalho, M.A.P., Abreu, A.F.B. 2005. Graphical method in studies of adaptability and stability of cultivars. *Annual Report of the Bean Improvement Cooperative* 48: 182-183.
- Pereira, L.G., Rodrigues, C.F.A., Monteiro, A.R. 2017.

- Composição florística e estrutura da floresta secundária em um perímetro urbano, Belém-PA. In: 21º Seminário de Iniciação Científica da Embrapa Amazônia Oriental. <https://www.embrapa.br/busca-de-publicacoes/-/publicacao/1076226/composicao-floristica-e-estrutura-da-floresta-secundaria-em-um-perimetro-urbano-belempa>
- Rajj, B.V. 1991. *Fertilidade do solo e adubação*. Associação Brasileira para Pesquisa de Potassa e do Fosfato/Agronômica Ceres, São Paulo, Brasil. 343 p.
- Roy, E.D., Willig, E., Richards, P.D., Martinelli, L.A., Vazquez, F.F., Pegoroni, L., Spera, A.S., Porder, S. 2017. Soil phosphorus sorption capacity after three decades of intensive fertilization in Mato Grosso, Brazil. *Agriculture, Ecosystems and Environment* 249: 14.
- Salvador, J.O., Muraoka, T., Rossetto, R., Ribeiro, G.A. 1994. Sintomas de deficiências nutricionais em cupuaçuzeiro (*Theobroma grandiflorum*) cultivado em solução nutritiva. *Scientia Agricola* 51: 407-414.
- Santos, H.G., Jacomine, P.K.T., Anjos, L.H.C., Oliveira, V.A., Lumbreiras, J.F., Coelho, M.R., Almeida, J.A., Araujo Filho, J.C., Oliveira, J.B., Cunha, T.J.F. 2018. *Sistema brasileiro de classificação de solos*. Embrapa, Brasília, Brasil. 356 p.
- Silva, E.B., Gonçalves, N.P., Pinho, P.J. 2008. Limitações nutricionais para crescimento de mudas de umbuzeiro em Latossolo Vermelho distrófico no Norte de Minas. *Acta Scientiarum. Agronomy* 27: 55-59.
- Silva, S.P., Viegas, I.J.M., Okumura, R.S., Silva, D.A.S., Galvao, J.R., Silva Junior, M.L., Araujo, F.R.R., Mera, W.Y.W.L., Silva, A.O. 2018. Growth and micronutrients contents of smell pepper (*Capsicum chinense* Jac.) submitted to organic fertilizer. *Journal of Agricultural Science* 10: 425.
- Silva, A.O., Nunes, L.R.T., Pinheiro Junior, F.O., Silva, D.A.S., Silva, A.O., Viegas, I.J.M., Tavares, G.S., Mera, W.Y.W.L., Galvao, J.R. 2020. Produção de massa seca em plantas jovens de açaizeiro (*Euterpe oleracea* Mart.) na nova cultivar BRS Pai d'égua e níveis de concentração de Ca, Mg, S e B em Latossolo Amarelo textura média, em função da calagem. *International Journal of Development Research* 10: 33128-33132.
- Souza, A.G.C., Resende, M.D.V., Silva, S.E.L., Souza, N.R. 2002. The cupuaçuzeiro genetic improvement program at Embrapa Amazônia Ocidental. *Crop Breeding and Applied Biotechnology* 2: 471-478.
- Souza, H.A., Pio, R., Chagas, E.A., Reis, J.M.R., Rodrigues, H.C.A., Ramos, J.D., Mendonça, V. 2007. Doses de nitrogênio e fósforo na formação de mudas de tamarindo. *Bioscience Journal* 23: 59-64.
- Souza, S.R., Fernandes, M.S. 2006. Nitrogênio. In: Fernandes, M.S. (ed.) *Nutrição mineral de plantas*. Sociedade Brasileira de Ciência do Solo, Viçosa, Brasil. p. 215-252.
- Taiz, L., Zeiger, E. 2013. *Fisiologia vegetal*. Artmed, Porto Alegre, Brasil. 918 p.
- Tanaka, A.H.A., Mera, W.Y.W.L., Silva, A.O., Silva, A.O., Silva, D.A.S., Viégas, I.J.M. 2020. Different pre-cleaning times and types of packages in the conservation of chili pepper (*Capsicum chinense* Jacq). *Research, Society and Development* 9: e7799118964.
- Teixeira, P.C., Donagemma, G.K., Fontana, A., Teixeira, W.G. 2017. *Manual de métodos de análise de solo*. Embrapa, Brasília, Brasil. 574 p.
- Troeh, F.R., Thompson, L.M. 2007. *Solos e fertilidade do solo*. Andrei, São Paulo, Brasil.
- Viégas, I.D.J.M., Cordeiro, R.A.M., Almeida, G.M., Silva, D.A.S., Silva, B.C., Okumura, R.S., Freitas, J.M.N. 2018. Growth and visual symptoms of nutrients deficiency in mangosteens (*Garcinia mangostana* L.). *American Journal of Plant Sciences* 9: 1014-1028.
- Viégas, I.J.M., Frazão, D.A.C., Conceição, H.E.O., Rodrigues, E.S.F., Brito, J.S.A., Sousa, G.O., Vasconcelos, R.D. 2005. Sintomas de deficiências de macronutrientes em plantas de *Helicônia psittacorum* (cv. Golden torch). In: Congresso Brasileiro de Olericultura, 45; Congresso Brasileiro de Floricultura e Plantas Ornamentais, 15; Congresso Brasileiro de Cultura de Tecidos de Plantas, 2. Fortaleza, Brasil. CD-ROM.
- Viégas, I.J.M., Galvão, J., Silva, A.O., Conceição, H., Pacheco, M., Viana, T., Ferreira, E., Okumura, R., Silva, D. 2020. Chlorine nutrition of oil palm tree (*Elaeis guineensis* Jacq) in Eastern Amazon. *Journal of Agricultural Studies* 8: 704-720.
- Vitti, G.C., Serrano, C.G.E. 2007. O zinco na agricultura. *DBO Agrotecnologia* 3: 10-11.
- White, P.J., Broadley, M.R. 2003. Calcium in plants. *Annals of Botany* 92: 487-511.
- Wimmer, M.A., Eichert, T. 2013. Review: mechanisms for boron deficiency-mediated changes in plant water relations. *Plant Science* 203-204: 25-32.
- Zorb, C., Senbayram, M., Peiter, E. 2014. Potassium in agriculture status and perspectives. *Journal of Plant Physiology* 171: 656-669.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

All the contents of this journal, except where otherwise noted, is licensed under a Creative Commons Attribution License attribution-type BY.