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Do doses of controlled-release fertilizer and container volume influence the quality of *Hymenaea courbaril* seedlings?

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Abstract: The objective was to determine the effects of doses of controlled-release fertilizer and container volume on the initial growth and quality of *Hymenaea courbaril* seedlings. The experimental design was completely randomized in a 2 x 4 factorial scheme, corresponding to two container volumes (1.8 and 2.2 L) and four doses of controlled-release fertilizer (0, 1.5, 3.0 and 4.5 g L^{-1} substrate) with eight replicates, each consisting of five seedlings (one in each container). The variables evaluated were: shoot height (H), stem diameter (SD), shoot dry mass (SDM, g $plant^{-1}$), root dry mass (RDM, g $plant^{-1}$), total dry mass (TDM, g $plant^{-1}$), Dickson quality index (DQI), root volume (RV), nitrogen balance index (NBI) and chlorophylls. Controlled-release fertilizer at doses of 1.5 and 3.0 g L^{-1} provide *Hymenaea courbaril* seedlings with quality and sturdiness in both container sizes. Controlled-release fertilizer at the dose of 4.5 g L^{-1} is not indicated to obtain high quality standard in seedlings of *Hymenaea courbaril*, regardless of container volume.

Index Terms: mineral fertilization; chlorophylls; jatobá; nitrogen.

Doses de fertilizante de liberação controlada e volume de recipiente influenciam a qualidade de mudas de *Hymenaea courbaril*?

Resumo: O objetivo foi determinar os efeitos de doses de fertilizante de liberação controlada e o volume do recipiente no crescimento inicial e na qualidade de mudas de *Hymenaea courbaril*. O delineamento experimental foi inteiramente casualizado, em esquema fatorial 2 x 4, correspondendo a dois volumes de recipientes (1,8 e 2,2 L) e quatro doses de adubo de liberação controlada (0; 1,5; 3,0 e 4,5 g L^{-1} de substrato), com oito repetições, cada uma composta por cinco mudas (uma em cada recipiente). As variáveis avaliadas foram: altura da parte aérea (H), diâmetro do caule (DC), massa seca da parte aérea (MSPA, g $planta^{-1}$), massa seca da raiz (MSR, g $planta^{-1}$), massa seca total (MST, g $planta^{-1}$), índice de qualidade de Dickson (IQD), volume radicular (VR), índice de balanço de nitrogênio (IBN) e clorofilas. O

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fertilizante de liberação controlada, nas doses de 1,5 e 3,0 g L^{-1}, proporciona qualidade e robustez às mudas de *Hymenaea Courbaril,* em ambos os tamanhos de recipiente. O fertilizante de liberação controlada, na dose de 4,5 g L^{-1}, não é indicado para obtenção de alto padrão de qualidade em mudas de *Hymenaea courbaril*, independentemente do volume do recipiente.

Termos para indexação: adubação mineral; clorofilas; jatobá; nitrogênio.

Introduction

Hymenaea courbaril L., popularly known in Portuguese as 'jatobá', 'jutaí', 'jataí', among others, occurring from southern Mexico to South America, belongs to the Fabaceae family. *Hymenaea courbaril* L. 'stinkingtoe' is present in the Cerrado (lato sensu- The Cerrado's vegetation features trees and bushes over grassland and it holds a combination of various vegetal formations and ecosystems), Riparian or Gallery forest, Terra Firme forest (non-flooded forest floor in Amazon), Ombrophilous forest and sandbank vegetation (Sandbank vegetation is an ecosystem which has ecological functions and is undergoing anthropogenic occupations that result in the disturbance and its suppression of these environments (IBÁ, 2022), with natural preference for dry, low-fertility soils, with good drainage terrains. It has tolerance to water deficit and, depending on the region, is adapted to average annual temperatures from 18 ºC to 27 ºC (SOUZA et al., 2023; SMIDERLE et al., 2021a). It can reach 20 m in height and 50 cm in diameter in adulthood, with flowering at the end of the dry season and beginning of the rainy season and fruiting for a period of 3 to 4 months, with alternate maturation (SMIDERLE; SOUZA, 2022).

Hymenaea courbaril L. 'stinkingtoe' is considered endangered due to overexploitation (SMIDERLE et al., 2022a), with only one tree per hectare according to the Institute for Forest Research and Studies (IPEF). In this scenario, the production of seedlings of native forest species, for the enrichment and recovery of degraded areas, is ultimately compromised, given the lack of information about their needs regarding fertilizers, especially the dose of maximum technical efficiency (SOUZA et al., 2020a, SMIDERLE et al., 2021b; 2022b), and the type and volume of the container to be used (BRITO et al., 2018).

Among fertilizers, there are those with controlled release, which have been widely used in nurseries of native forest seedlings (SMIDERLE et al., 2020; 2021b; 2022a). Controlled-release fertilizers make it possible to provide and maintain constant levels of macro and micronutrients in different formulations (MENEGATTI et al., 2022), during periods that may range from 3 to 18 months (MENEGATTI et al., 2021). These characteristics are favorable for seedling production, since nutrients are made available during the production process, meeting the demands of plants and avoiding leaching of nutrients in the case of excessive irrigation of the substrate (MENEGATTI et al., 2020).

However, this type of fertilizer generates higher costs of seedlings, so doses and formulations need to be adjusted for each species to be produced, reducing losses and maximizing investments in seedling production (MENEGATTI et al., 2019).

In addition to fertilizers, the volume of the container can influence several aspects, since it promotes the proper formation of the root system, protects the roots from mechanical damage and dehydration, besides directly influencing the space occupied in the nursery and the cost of production, as it determines the labor required and the demand for substrate and inputs (SMIDERLE; SOUZA, 2021).

Associating nutritional power with the use of smaller containers can be important to reduce production, transportation and distribution in the field, promoting higher efficiency in yield and in the planting operation (PINHO et al., 2018; LIMA FILHO et al., 2019).

Objective was to determine the best doses of controlled-release fertilizer and container volume for the initial growth and quality of *Hymenaea courbaril* seedlings.

Material and Methods

The study was conducted at the Seed Analysis Laboratory (LAS) and in the seedling nursery of Embrapa Roraima's forestry sector from January to May 2022. The climate of the municipality of Boa Vista, RR, Brazil, is type Am (tropical monsoon climate), with average temperatures of 27.2 °C in the hottest month and 23.3 °C in the coldest month, with an annual average of 25.4 °C. The average annual rainfall is 1808 mm, with mean values of 365 mm and 26 mm for the months of highest (June) and lowest (February) precipitation, respectively.

The forest species used in the present study was *Hymenaea courbaril* L. The fruits were collected manually from trees present in an area of Submontane Dense Ombrophilous Forest with an emerging canopy, located at the geographic coordinates 1°38'29" North and 60°58'11" West, in the municipality of Boa Vista (RR), in November 2021.

After collection, the fruits were selected by removing decayed fruits, which allowed obtaining a uniform lot. The fruits were broken with a wooden stick manual extraction, selecting those that were visibly healthy and well-formed. These were sown in a bed, which contained washed medium sand as substrate. Moisture in the sand substrate was maintained by manual irrigation, with four daily waterings.

Approximately ten days after sowing, the seedlings began to emerge and, as soon as they homogeneously reached an approximate height of 12.0 cm, they were transplanted to polyethylene bags (15 x 35 cm) containing washed medium sand as substrate (The main constituent of medium sand was silicon 0.4 µg dm^{-3}), in which the doses of controlled-release fertilizer, 18-05-09 NPK formulation, according to each treatment, were incorporated in surface. Then, the plants were arranged in a screened nursery with 50% shading and maintained under sprinkler irrigation three times a day for periods of five minutes. The average temperature within the nursery in the experimental period was 25 ± 5 °C and the relative humidity was 60% to 70%.

The experimental design was completely randomized in a 2x4 factorial scheme, corresponding to two container volumes (1.8 and 2.2 L) and four doses of Forth Cote® (0, 1.5, 3.0 and 4.5 g L^{-1} substrate) with four replicates, each consisting of five seedlings (one in each container).

At 120 days after transplantation (DAT), *Hymenaea courbaril* seedlings were evaluated for shoot height (H), obtained with a graduated ruler, and stem diameter (SD), measured with a digital caliper. Nitrogen balance index (NBI), was also determined using a chlorophyll meter (Dualex Model), is an important indicator for scientific diagnostic and quantitative research on crop growth status. The quick and accurate assessment of NBI is necessary for farmers to make timely N management decisions, was also determined using a chlorophyll meter (Dualex Model). Between 9 and 11 a.m., measurements were performed on two fully expanded leaves, located in the apical third of each plant. Chlorophyll *a*, chlorophyll *b* and total chlorophyll contents were determined using a portable chlorophyll meter (Falker model) in two fully expanded leaves from the middle region of the crown of each plant of the experimental unit, with measurements in two leaf positions (opposite sides). The average of the four readings was calculated for both sampled leaves, using the meter itself.

Shoot dry mass (SDM, g $plant^{-1}$) and root dry mass (RDM, g $plant^{-1}$) were determined after the material was dried 65 °C, for 72 hours. Total dry mass (TDM, g $plant^{-1}$) was obtained by the sum of SDM + RDM. Dickson quality index (DQI) was determined as a function of shoot length (H), stem diameter (SD), shoot dry mass (SDM) and root dry mass (RDM), using the formula described by Dickson et al. (1960).

All variables were subjected to comparison of means by Tukey test, at 5% probability level. Data analysis was performed in the statistical program Sisvar (FERREIRA, 2014).

Results and Discussion

At the end of the experiment (120 days after transplanting), the survival rate of *Hymenaea courbaril* seedlings was 100% for all treatments. According to the analysis of variance, there was significant interaction between the factors container volume and doses of controlled-release fertilizer (CRF) for the variables: height (cm), root dry mass (RDM), root volume (RV) and total dry mass (TDM). The shoot height (H) of plants grown in the container with 2.2 L of substrate under the CRF dose of 1.5 g L^{-1} was equal to 95.2 cm, corresponding to an increase of 9.7% when compared to the H value of plants grown in 1.8 L containers at the CRF dose of 1.5 g L^{-1} (Table 1).

Table 1. Mean values of height (cm), stem diameter (mm), shoot dry mass (g $plant^{-1}$), root dry mass (g $plant^{-1}$), total dry mass (g $plant^{-1}$), Dickson Quality Index and root volume of *Hymenaea courbaril* plants as a function of doses of controlled-release fertilizer and volume of the container used in the formation of seedlings evaluated at 120 days after transplanting.

Dose (g L^{-1})	Height (cm)		Stem diameter (mm)		Shoot dry mass (g $plant^{-1}$)		Root dry mass (g $plant^{-1}$)	
	1.8 L	2.2 L	1.8 L	2.2 L	1.8 L	2.2 L	1.8 L	2.2 L
0	48.4 bA	50.4 cA	5.5 bA	5.6 bA	5.0bA	4.5cA	4.4bA	5.4bA
1.5	85.9aB	95.2aA	7.5aA	7.5aA	14.1aA	14.6aA	8.5aB	10.0aA
3.0	86.4aA	90.4aA	6.8aA	6.9aA	12.7aA	13.0aA	6.1aB	7.9abA
4.5	81.7aA	72.2bB	6.0bA	5.9bA	9.8abA	10.1bA	4.5bB	6.1bA
CV%	10.40	8.90	9.64	10.99	10.22	11.62	11.05	12.11

Dose (g L^{-1})	Root volume (cm^3)		Total dry mass (g $plant^{-1}$)		Dickson Quality Index	
	1.8 L	2.2 L	1.8 L	2.2 L	1.8 L	2.2 L
0	27.3bA	28.4bA	9.4bA	9.9cA	0.97bA	0.99bA
1.5	40.6aB	52.0aA	22.6aB	24.6aA	1.70aA	1.78aA
3.0	35.7abB	47.7aA	18.8aB	20.9aA	1.29aA	1.42aA
4.5	31.6bA	36.7abA	14.3abB	16.1bA	0.92bA	0.98bA
CV%	8.90	9.64	9.52	10.33	8.60	9.11

[1] Lowercase letters (a, b) compare the means for the variables between the doses of controlled-release fertilizer, and uppercase letters (A, B) compare the means for the variables between volume of the container, by Tukey test at 5% probability level.

According to Souza et al. (2020a), shoot height combined with stem diameter constitutes one of the most important morphological parameters for estimating the growth of forest seedlings after definitive planting in the field.

In addition, a mean value of 7.5 mm at the CRF dose of 1.5 g L^{-1} in both containers was found for stem diameter (SD) (Table 1). Certainly, such increment was due to the adequate dose of the controlled-release fertilizer, with a combination between the continuous supply of nitrogen (N) to the plant and the local edaphic or climatic factors of the region, such as solar radiation and temperature, thus leading to higher photosynthetic efficiency and production of new tissues in the plant organs.

According to Damasceno et al. (2019), shoot dry mass weight indicates the rusticity of a seedling, and the highest values in *Hymenaea courbaril* seedlings were obtained at CRF doses of 1.5 and 3.0 g L^{-1} for both container volumes (Table 1), which represented more lignified and rustic seedlings, with greater possibility of establishment and survival in the field.

However, positive response was also observed in variables related to other plant organs, such as root dry mass (RDM) with the CRF dose of 1.5 g L^{-1} in the 2.2 L container volume, which showed a 15.0% gain when

compared with the 1.8 L container volume at the CRF dose of 1.5 g L^{-1} (Table 1). This result is probably related proportionally to the volume of the container and the availability of a larger space for root growth, thus ensuring greater expansion of the root system and utilization of nutrients.

The results obtained for RDM reinforce the hypothesis of greater influence of the container volume on the roots, besides indicating that RDM determines the results obtained for root volume, since the CRF dose 1.5 g L^{-1} in the 2.2 L container led to better results (Table 1). The results obtained suggest that during the first DAT plants tend to invest a greater amount of energy in the production of roots, in order to increase the area of nutrient absorption. Subsequently, the plant tends to alter the partition of assimilates, that is, the preferential sinks of consumption and storage of mineral nutrients and photoassimilates become those present in the shoots, such as stems and expanding leaves, culminating along the growth stages of the plant in greater accumulation of SDM and TDM (MENEGATTI et al., 2022), as observed in *Hymenaea courbaril* seedlings at 120 DAT.

The CRF dose of 1.5 g L^{-1} in 2.2 L container at 120 DAT led to TDM accumulation of 24.6 g $plant^{-1}$ (Table 1). In addition, biomass accumulation in the shoot was 60%, followed by 40% in the root system in the 2.2 L container with CRF dose of 1.5 g L^{-1}, while in the 1.8 L container at CRF dose of 1.5 g L^{-1} the biomass accumulation was equal to 62% for shoots and to 38% for roots, which allowed the best quality index of *Hymenaea courbaril* seedlings at 120 DAT.

In general, *Hymenaea courbaril* seedlings grown at CRF doses 0.0 and 4.5 g L^{-1} in both containers showed Dickson Quality Index (DQI) below 1.0 (Table 2), which is lower than the value considered ideal by Smiderle and Souza (2022) for *Hymenaea courbaril* seedlings suitable for planting in the field. According to Smiderle and Souza (2022), this index is a good indicator of initial survival of seedlings in the field, as it considers important characteristics for evaluating the quality of the seedlings to be transplanted, such as sturdiness and balance of biomass distribution.

Table 2. Mean values of chlorophyll *a* (CHL a, µg/mL), chlorophyll *b* (CHL b, µg/mL), total chlorophyll (CHL Total µg/mL) and N balance index (NBI), determined in leaves of *Hymenaea courbaril* as a function of the doses of controlled-release fertilizer and volume of the container used in the formation of the seedlings evaluated at 120 days after transplanting

Dose (g L^{-1})	CHL a (µg/mL)		CHL b (µg/mL)		CHL Total (µg/mL)		NBI	
	1.8 L	2.2 L	1.8 L	2.2 L	1.8 L	2.2 L	1.8 L	2.2 L
0	26.21 bA	27.06 bA	7.11 bA	6.26 bA	33.32 bA	33.32 bA	16.82 bA	16.07 bA
1.5	30.11 aB	38.22 aA	9.15 aA	10.16 aA	39.26 aB	48.38 aA	25.13 aB	32.20 aA
3.0	30.72 aB	38.37 aA	8.66 aB	10.69 aA	39.38 aB	46.41 aA	26.30 aB	31.97 aA
4.5	30.35 aB	38.51 aA	8.63 aB	10.12 aA	38.98 aB	45.47 aA	25.35 aA	28.78 aA
CV%	9.12	9.62	10.32	10.90	9.02	9.11	10.25	10.27

[1] Lowercase letters (a, b) compare the means for the variables between the doses of controlled-release fertilizer, and uppercase letters (A, B) compare the means for the variables between volume of the container, by Tukey test at 5% probability level.

According to Souza et al. (2020b), these results are of great interest to producers of forest seedlings, since there is an increase in the quality of the seedlings produced, which is an advantage at the time of planting, since seedlings with better quality tend to have faster establishment and their growth is favored also in the field, besides contributing to minimizing production costs.

Thus, the incorporation of CRF, regardless of the doses tested, in the 2.2 L container had a positive effect on *Hymenaea courbaril* seedlings, which can be verified in the chlorophyll *a*, chlorophyll *b* and total chlorophyll contents and in N balance index (NBI), all with higher values compared to the control (Table 2). Thus, the demand for the synthesis of photoassimilates, amino acids and proteins

was met, promoting higher concentrations of chlorophylls, a determinant physiological parameter for plant growth, as shown in Table 1, for the morphological characteristics of *Hymenaea courbaril* seedlings.

Higher results for chlorophyll *a* and total chlorophyll were recorded in plants fertilized with CRF at doses of 1.5, 3.0 and 4.5 g L^{-1} (Table 2) in the 2.2 L container. For chlorophyll *b* and NBI, plants under CRF doses of 1.5 and 3.0 g L^{-1} in the 1.8 L container differed from plants grown in the 2.2 L container. *Hymenaea courbaril* is a C_3 plant and, according to Smiderle et al. (2022b), *Hymenaea courbaril* seedlings with chlorophyll *a* from 35 to 39 µg/ml, chlorophyll *b* from 8.5 to 10.8 µg/ml and NBI from 25 to 33 are considered suitable for planting in the field.

It is known that, for performing photosynthesis, higher plants depend on the absorption of light and significant presence of chlorophylls *a* and *b* and carotenoids in the leaves to direct the metabolism of carbohydrates in chloroplast and cytosol through the chemical forms ATP and NADPH (LEAL et al., 2020).

In order to improve the sector of forest seedlings native to the Northern region of Brazil, the use of appropriate container volume and CRF dose, aiming at rapid growth and high quality of seedlings, is essential to avoid wasting resources, especially in production systems using plastic bags and protected environment.

Conclusions

Controlled-release fertilizer at doses of 1.5 and 3.0 g L^{-1} provide *Hymenaea courbaril* seedlings with quality and sturdiness in both container sizes.

The container volume of 2.2 L at CRF doses of 1.5 and 3.0 g L^{-1} promotes higher root volume in *Hymenaea courbaril* seedlings at 120 days than all other treatments.

Controlled-release fertilizer at the dose of 4.5 g L^{-1} is not indicated to obtain high quality standard in seedlings of *Hymenaea courbaril*, regardless of container volume.

The highest nitrogen balance index in leaves of *Hymenaea courbaril* occurs in 2.2 L containers with the doses of 1.5 and 3.0 g L^{-1} controlled-release fertilizer.

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