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Container volume and doses of maximum technical efficiency of controlled-release fertilizer on *Cordia alliodora* seedlings

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Abstract The objective of this study was to determine the correlation between the morphological characteristics of *Cordia alliodora* seedlings produced as a function of container volume and controlled-release fertilizer (CRF) doses under nursery conditions in Northern Amazon. The experimental design was a 2 x 6 factorial scheme, corresponding to two container volumes (1.8 and 2.2 L) and six doses of Forth Cote® (0, 1, 2, 4, 8, and 12 g L^{-1} in medium sand), with five replicates. The evaluations were: height (H), stem diameter (SD), shoot dry mass (SDM), root dry mass (RDM), total dry mass, increment in stem diameter (ΔSD) and increment in height (ΔH) obtained from the data collected every fifteen days, from transplanting, encompassing the period of plant growth until the end of the experiment (three months), in addition to Dickson quality index (DQI). Container volume of 2.2 L is suitable for the formation of good-quality *Cordia alliodora* seedlings at 90 days after transplanting. Controlled-release fertilizer doses from 8.0 g L^{-1} are not indicated to obtain seedlings of this species in the northern region of Brazil, with quality, regardless of the container volume.

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All relevant data are within the paper and its Supporting Information files.

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The authors declare no competing interests.

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1. Introduction

The forest-based sector can be described as an important component of the Brazilian economy, because it contributes significantly to the generation of products, taxes, jobs and income (Smiderle *et al*., 2021 a). The growing expansion of this sector has driven forest investors to opt for the cultivation of native species in the state of Roraima (Smiderle *et al*., 2022). In this scenario, there arises a challenge to meet the demand for seedlings of high-quality standard and adequate nutritional status for the implementation of reforestation for economic purposes.

Among the potential species for the implementation of reforestation in the Northern region of Brazil, *Cordia alliodora* Ruiz & Pavon (Boraginaceae), popularly known as 'freijó' and 'louro-freijó', component

of the local flora of the state of Roraima, stands out (Smiderle and Souza, 2022). The species lacks information in the national and international literature that can provide important methods and techniques for producing seedlings in quantity and quality (Massad *et al*., 2017).

Regarding the growth of *Cordia alliodora*, Smiderle and Souza (2022) reported that under favorable conditions plants in the seedling stage can reach growth in height of approximately two meters in the first year in the field. In turn, height increments occur between the second and tenth year, and maturity is reached between 5 and 10 years (Smiderle and Souza, 2022). Smiderle *et al*. (2021 b), in studies with native forest species of Roraima, determined that their initial growth is slow and they require more time in the nursery to reach desirable minimum size, which in turn induces the use of larger containers, as well as the addition of adequate fertilization.

Controlled-release fertilizers (CRF) have been described as an alternative to conventional fertilizers for fertilization of seedlings in the nursery phase, because they induce rapid initial growth (Wang *et al*., 2016; AO *et al*., 2018; Shi *et al*., 2019) and favor survival and vigor after the field planting phase (Fu *et al*., 2017; Shi *et al*., 2019). Currently, research has shown a positive effect of controlled-release fertilizers on the production of native seedlings in northern Brazil. For instance, Smiderle *et al*. (2020) worked with CRF and container size and concluded that the CRF dose of maximum technical efficiency of 4.71 g L^{-1} in medium sand substrate under container volume of 2.2 L promotes greater increments of shoots, stem diameter and biomass of *Agonandra brasiliensis* Miers ex Benth. & Hook. f. seedlings.

For some species native to northern Brazil, controlled-release fertilizer has shown negative influence, as observed by Smiderle *et al*. (2022) when evaluating *Hymenaea courbaril* L. seedlings in a screened nursery. These authors reported that controlled-release fertilizer doses greater than 6.0 g L^{-1} are not indicated to obtain seedlings suitable for planting in the field and with quality. Likewise, Mota *et al*. (2021) also revealed that CRF doses above 8.0 g L^{-1} induce reduction in the variables related to the root system of pau-marfim plants.

Studies of this nature indicate the need for research related to the appropriate doses of CRF, in NPK 18-05-09 formulation, as well as the appropriate container volume for producing seedlings of native forest species of Roraima, which need to be determined. In view of the above, the objective was to correlate the morphological characteristics of *Cordia alliodora* seedlings produced as a function of container volume and controlled-release fertilizer doses under nursery conditions in Northern Amazon, aiming to obtain quality seedlings.

2. Materials and Methods

The seeds of *Cordia alliodora* used to obtain the seedlings were collected from trees located at Embrapa Roraima (2°45'22" North latitude, 60°43'55" West longitude and altitude of 80 m), located beside the BR-174 highway, km 8, in the municipality of Boa Vista, state of Roraima, Brazil.

After obtaining the seeds, they were manually processed and then sown in a bed containing washed sand of medium particle size as substrate for seedling emergence. The moisture of the sand substrate was maintained through automated irrigation, with four daily waterings. To irrigate the plants, the field capacity for the amount of substrate was determined before the experiment (1.8 and 2.2 litres); this was then taken as the reference for maintaining the supply of water to the plants throughout the experimental period.

Approximately 12 days after sowing, the seedlings began to emerge and, as soon as they homogeneously reached an approximate height of 5.0 cm, they were transplanted to polyethylene bags containing medium sand as substrate (inert material) and controlled-release fertilizer (Forth Cote®), in NPK 18-05-09 formulation, was incorporated into the surface, according to treatment. Then, the plants were arranged in a screened nursery with 50% shading and maintained under sprinkler irrigation three times a day for periods of 5 min.

The experimental design adopted was completely randomized in a 2x6 factorial scheme, corresponding to two container volumes (1.8 and 2.2 L of substrate) and six doses of Forth Cote® (0; 1; 2; 4; 8 and 12 g L^{-1} of fertilizer), with five replicates, each consisting of five seedlings (one in each container).

The morphological attributes evaluated at 90 days after transplantation were: stem diameter (SD, in mm) (5 cm from the plant collar, determined with a digital caliper), shoot height (H) (from the sand level to the seedling apex, measured with a graduated ruler, in cm), and survival rate (%).

Subsequently, the plants were collected and divided into roots and shoots (stem and leaves), and then dried in an oven with forced air circulation, at 70± 5°C, until reaching constant weight. After drying, the dry mass of the different plant parts was individually determined: shoot dry mass (SDM, g plant^{-1}) and root dry mass (RDM, g plant^{-1}), which were summed to obtain the total dry mass (TDM, g plant^{-1}). The results allowed the calculation of the Dickson quality index (DQI), following the formula proposed by Dickson *et al*. (1960).

$$DQI = \frac{TDM\ (g)}{[(H/SD)+ (SDM/RDM)]}$$

The increment in stem diameter (ΔSD) and the increment in height (ΔH) were obtained from the data collected every fifteen days, during the growing period of the plants, from transplanting to the end of the experiment.

Possible differences between treatments were checked by analysis of variance (ANOVA) in factorial scheme. Variables that showed significant differences were subjected to regression analysis in order to assess the growth response of the plants as a function of the increasing doses of CRF for the two container volumes. The dose of maximum technical efficiency (DMTE) was calculated using the equation proposed by Tiesdale *et al*. (1993) ($y=ax^2+bx+c$) and by the mathematical model x = -b/2a. Data analysis was performed with Sisvar statistical software (Ferreira, 2014).

3. Results and Discussion

At the end of the experiment (90 days after transplanting), the survival rate of *Cordia alliodora seedlings* was 100% for all treatments.

All morphological variables evaluated showed quadratic behavior in the fit of the regression equations. Figure 1A shows the height (H) of seedlings cultivated with the CRF dose of maximum technical efficiency of 4.54 g L^{-1}, corresponding to 24.30 cm, representing an increase of 17.7% when compared to H of plants cultivated without the addition of CRF. Smiderle *et al*. (2020), in a study conducted with paumarfim (*Agonandra brasiliensis*) seedlings in substrate, also recorded positive quadratic response for all morphological variables evaluated according to the increase in CRF doses up to dose of maximum

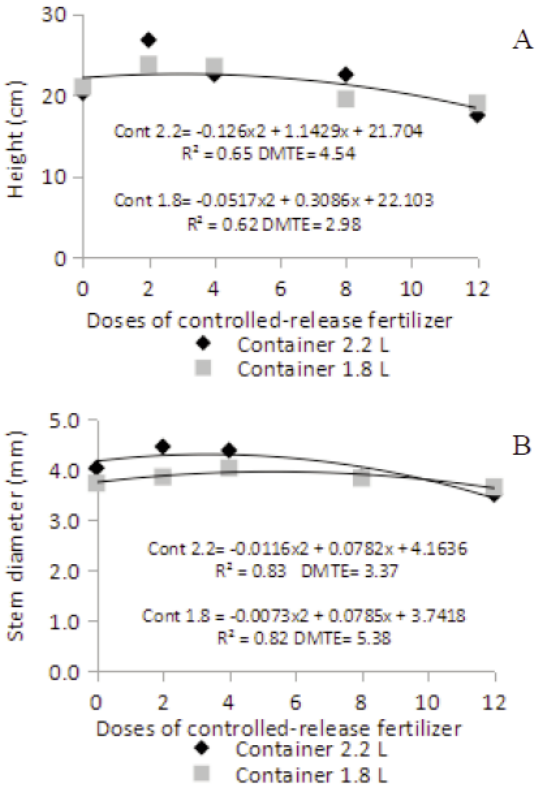

Fig. 1 - Combinations of CRF doses and container volume on the height (A) and stem diameter (B) of *Cordia alliodora* seedlings produced under nursery conditions, Boa Vista, RR.

technical efficiency (DMTE), suggesting that the application of doses higher than DMTE does not guarantee the absorption and mainly utilization of nutrients by the plant. In addition, DMTE for the 1.8 L container was 2.98 g L^{-1} of CRF, resulting in a height of 22.46 cm (Fig. 1B). According to Smiderle *et al*. (2022), shoot height combined with stem diameter is one of the most important morphological parameters to estimate the growth of native forest seedlings in northern Brazil, after definitive planting in the field.

For stem diameter (SD), the maximum estimated value was 4.35 mm at the DMTE of 3.37 g L^{-1} of CRF incorporated into the medium sand substrate in the container with volume of 2.2 L (Fig. 1B). In turn, the 1.8 L container led to the largest stem diameter (3.95 mm) of *Cordia alliodora* seedlings at the DMTE of 5.38 g L^{-1} of CRF (Fig. 1B). Conversely, without addition of CRF (control) the stem diameter was equal to 3.73 mm in the 1.8 L container. Thus, 3.37 g L^{-1} of CRF in the 2.2 L container (Fig. 1B) resulted in stem diameter 0.4 mm (10%) higher than the value found in the

1.8 L container, which even with 2.01 g L^{-1} more was not able to promote the same diameter, with a value 0.62 mm higher than that obtained without application of CRF (3.73 mm), an increase of 16%.

Determining the volume of container and the DMTE of fertilizers allows obtaining the ideal SD for planting the field in a shorter time, so it becomes of paramount importance for the production of *Cordia alliodora* seedlings, both to reduce the period of obtaining commercial seedlings, which is long in the traditional method, and to achieve efficiency in the use and utilization of fertilizer by the plant, thus ensuring maximum increment of plant organs in a short time when performing this management.

The highest increment in height - ΔH (Fig. 2A) occurred at the estimated DMTE of 4.70 g L^{-1} in the 2.2 L container, corresponding to a height of 21.92 cm, which represents an increase of 22.45% compared to the control treatment (substrate without addition of CRF), at 90 DAT (Fig. 1A). Certainly the increment in height was due to the higher dose of the controlled-release fertilizer, as well as the volume of the container, with a combination between the continuous supply of nitrogen (N) to the plant and factors such as solar radiation and temperature, thus resulting in greater photosynthetic efficiency and the production of new tissues in the plant organs. In addition, the DMTE for ΔSD was 4.64 g L^{-1}, corresponding to a value of 3.45 mm (Fig. 2B) in the 2.2 L container, values similar to those reported by Mota *et al*. (2020), who worked with *Agonandra brasiliensis* seedlings under different doses of controlled-release fertilizer and containers of different sizes in substrate and obtained seedlings similar to those of the present study.

Conversely, *Cordia alliodora* plants produced in the 1.8 L container showed lower ΔSD (2.94 mm) with the DMTE of 5.76 g L^{-1} compared to those grown in the 2.2 L container at the DMTE of 4.64 g L^{-1} (Fig. 2B). High N doses in 1.8 L containers affected the physiological quality of plants, causing negative effects on their development, especially those related to seedling diameter (Menegatti *et al*., 2022). Mota *et al*. (2020) commented that the N supply in containers with a volume of less than 1.8 L can easily have a negative effect on native forest species, which is not common with other nutrients.

However, a positive response was found for the 2.2 L container, for instance in shoot dry mass (SDM), which had DMTE of 5.82 g L^{-1} of CRF, with 24.6% gain in the SDM of *Cordia alliodora* when compared with

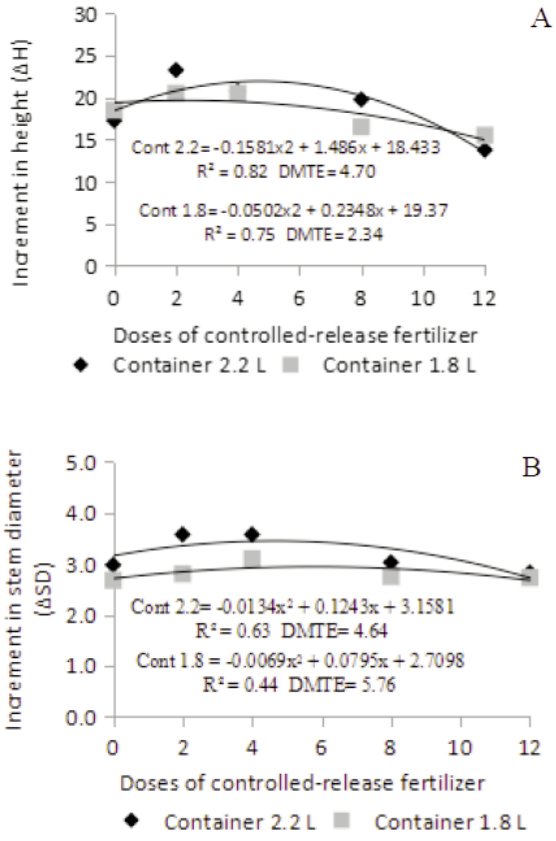

Fig. 2 - Increments in height (ΔH) (A, cm) and stem diameter (ΔSD) (B, mm) of *Cordia alliodora* seedlings as a function of the dose of controlled-release fertilizer, in two volumes of container, produced under nursery conditions, Boa Vista, RR.

the container volume of 1.8 L, with DMTE of 5.80 g L^{-1} of CRF (Fig. 3A). This result is probably related proportionally to the volume of the container, as well as the availability of greater space for root growth, thus ensuring greater expansion of the root system and utilization of nutrients.

According to Damasceno *et al*. (2019), shoot dry mass indicates the rusticity of a seedling, and the highest values, obtained in plants grown in the 2.2 L container, with the DMTE of 5.82 g L^{-1} of CRF (Fig. 3A), represented more lignified and rustic seedlings, with greater guarantee for establishment and survival in the field.

According to figure 3B, the maximum value (3.17 g $plant^{-1}$) of root dry mass was obtained at the DMTE of 5.54 g L^{-1} of CRF in the 2.2 L container, which represents a gain in root dry mass of 13.0%, compared with the 1.8 L container at the DMTE of 3.50 g L^{-1} of CRF. Chu *et al*. (2019) related the decrease in growth characteristics related to the root system to exces-

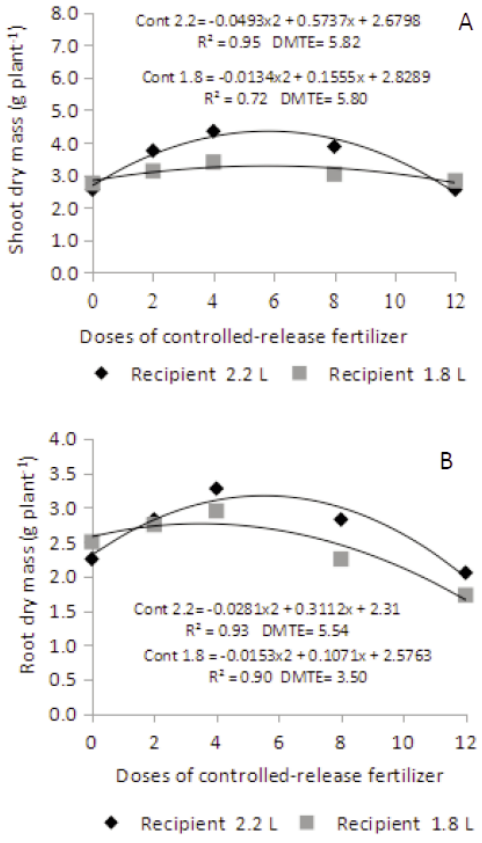

Fig. 3 - Shoot dry mass (A, g plant^{-1}) and root dry mass (B, g plant^{-1}) of *Cordia alliodora* seedlings as a function of the dose of controlled-release fertilizer and the container volume, produced under nursery conditions, Boa Vista, RR.

sive and toxic absorption of nutrients. For Fu *et al*. (2017), higher fertilization rates lead to a reduction in variables related to the root system of plants, due to the reduction in pH, which reduces the availability of some nutrients indispensable to the photosynthetic apparatus, such as phosphorus and magnesium, and favors excessive solubilization of elements, such as aluminum, making the substrate highly saline and toxic, especially to the organ in direct contact, the roots.

Menegatti *et al*. (2020) tested different CRF doses and also found higher production of root dry mass in *Prunus persica* seedlings up to DMTE of 4.82 g L^{-1} of CRF; above the dose of maximum technical efficiency, the other treatments became inferior to the control, that is, there was an inhibitory effect on the initial growth of the seedlings.

Regarding the total dry mass (TDM), a gradual increase was observed as a function of the doses up to DMTE of 5.75 g L^{-1} of CRF, followed by a reduction with the dose of 8 g L^{-1} of CRF, assuming a logistic form (Fig. 4A), regardless of the volume of the container in which *Cordia alliodora* seedlings were grown.

According to the results obtained for TDM, the increase in the CRF doses used caused reduction in its values, indicating a DMTE equal to 5.75 g L^{-1}, since positive responses in the gain of TDM were obtained at the dose of 4.0 to 5.75 g L^{-1} of substrate until 90 days of growth of *Cordia alliodora* seedlings.

The quality of *Cordia alliodora* seedlings was estimated using Dickson quality index, and the highest estimate was obtained for plants grown in the 2.2 L container, with DMTE of 6.24 g L^{-1} of CRF (Fig. 4B) incorporated into the medium sand substrate. Therefore, the seedlings of this treatment were again considered superior, with greater growth balance. According to Smiderle *et al*. (2021 b), this quality index is a good indicator of initial survival of seedlings in the field, because it considers important characteristics for evaluating the quality of the seedlings to be

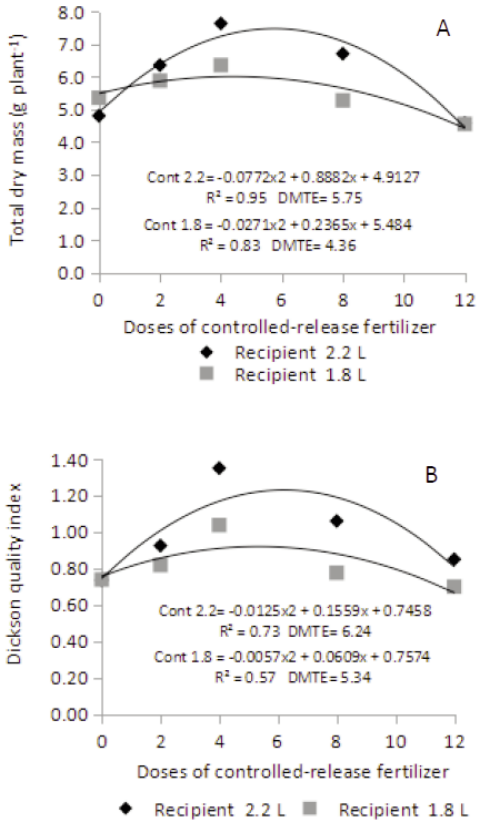

Fig. 4 - Total dry mass (A, g plant^{-1}) and Dickson quality index (B) of *Cordia alliodora* seedlings as a function of doses of controlled-release fertilizer and container volume, produced under nursery conditions, Boa Vista, RR.

transplanted, considering their robustness and balance of biomass distribution.

According to Souza *et al*. (2018), results obtained for native species of Northern Amazon are of great interest to producers of seedlings of forest species in the region, since there is an increase in the quality of 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, in addition to contributing to minimizing the time of establishment.

According to Table 1, there was a positive and strong correlation (0.92) between the variables H and SD of *Cordia alliodora* seedlings, which can be attributed to their cultivation in containers, since the volume and depth of soil to be explored are limited, making the expenditure of energy and nutrients for root growth in length, as occurs in field growth, unnecessary. For Smiderle *et al*. (2021 a), the positive and strong correlation between H and SD demonstrates the balance of growth between the height and stem diameter of seedlings.

There was also a positive and weak correlation between SD and ΔH; the correlation is considered weak when it has a coefficient of variation of $0.1 \leq p < 0.5$ (Santos, 2010). The estimate of correlation between TDM and DQI at 90 days after transplantation was 0.95, a correlation considered positive and strong according to the criterion of Santos (2010), with coefficient of variation of $0.8 \leq p < 1$. Considering the results obtained in this study, it is possible to obtain *Cordia alliodora* seedlings with high quality standard with CRF incorporated into the substrate and the container volumes used.

In general, the correlation between the dose of maximum technical efficiency and container volume found in this study can be described as dependent on the container volume and CRF dose. All this information, if considered jointly, allows suggesting the improvement of the traditional system for the production of *Cordia alliodora* seedlings in suitable containers, through the use of fertilization of plants in nursery phase, considering the nutritional efficiency as a function of the container volume, aiming at better use of the input and reduction in the time for production.

4. Conclusions

Container volume of 2.2 L with controlled-release fertilizer in NPK 18-05-09 formulation is suitable for the formation of good-quality *Cordia alliodora* seedlings at 90 days after transplanting.

Controlled-release fertilizer at the maximum technical efficiency dose of 4.64 g L^{-1} in 2.2 L container is indicated to obtain *Cordia alliodora* seedlings with greater increment in stem diameter.

Container volume of 2.2 L at the maximum technical efficiency dose of 5.75 g L^{-1} of controlled-release fertilizer led to higher biomass in *Cordia alliodora* seedlings at 90 days after transplanting.

Controlled-release fertilizer doses from 8.0 g L^{-1} are not indicated to obtain *Cordia alliodora* seedlings in the northern region of Brazil, with quality, regardless of the container volume.

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Table 1 - Correlation matrix between phytotechnical variables, plant height (H), stem diameter (SD), increments in height (ΔH) and stem diameter (ΔSD), shoot dry mass (SDM), root dry mass (RDM), total dry mass (TDM) and Dickson quality index (DQI) of *Cordia alliodora* seedlings as a function of the doses of controlled-release fertilizer and container volume under nursery conditions, Boa Vista, RR

Variables	SD	ΔH	ΔSD	SDM	RDM	TDM	DQI
H	0.92 *	0.87 *	0.58 *	0.83 *	0.79 *	0.83 *	0.77 *
SD		0.54 *	0.72 *	0.84 *	0.73 *	0.74 *	0.73 *
ΔH			0.68 *	0.80 *	0.74 *	0.72 *	0.54 *
ΔSD				0.79 *	0.81 *	0.87 *	0.56 *
SDM					0.72 *	0.87 *	0.71 *
RDM						0.90 *	0.82 *
TDM							0.95 *

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