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Silvicultural Potential of *Handroanthus heptaphyllus* Under Doses of Controlled Release Fertilizer and Container Volume, in Nursery and in the Field

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Abstract

The present study aimed to characterize the growth of *Handroanthus heptaphyllus* seedlings in a nursery, planted under different container volumes and doses of controlled release fertilizer (CRF), and to verify whether the responses obtained in the nursery are confirmed in the field. For the production of seedlings in the nursery, three volumes of container (180 and 280 cm^3 polypropylene tubes and 500 cm^3 polyethylene bags) and four CRF doses (0, 4, 8, and 12 g L^{-1} of substrate) were used. At 180 d after emergence, height (H), stem diameter (SD), H:SD ratio, shoot dry weight, root dry weight, total dry weight, Dickson Quality Index, leaf area, root length, and fluorescence of chlorophyll *a* were evaluated. The same treatments were evaluated again in the field 540 d after planting, and the survival, increase in H and SD, as well as shoot dry weight, leaf area, chlorophyll fluorescence, and chlorophyll index (*a*, *b* and total) were measured. In the nursery, seedlings of *H. heptaphyllus* responded positively to the volume of the container, as well as the base fertilization using CRF. However, when planted in the field, the plants that received the best nutritional conditions in the nursery showed good performance and was favored in the field. Thus, in the production of quality seedlings, the use of containers of the type polypropylene tubes with 180 cm^3, and basic fertilization with 12 g L^{-1} of CRF conditions that enable growth of *H. heptaphyllus* in the field are recommended.

Keywords: forest seedlings, containers, mineral nutrition, field

1. Introduction

Handroanthus heptaphyllus (Mart.) Mattos (ipê-roxo) is a species belonging to the family Bignoniaceae, occurring in South America, Africa, and Asia (Tropicos, 2017). The species is classified as deciduous, heliophilous, and is commonly found in secondary vegetation (Lorenzi, 2002; Carvalho, 2003).

The species has potential for timber, medicinal, landscape and ecological uses. *Handroanthus heptaphyllus* wood is of high quality, with a naturally high durability and resistance to insect attack and decay (Backes & Irgang, 2002; Campos Filho & Sartorelli, 2015). The bark contains phenolic compounds that help in the treatment of diabetes (Grochanke et al., 2016). It is widely used in urban afforestation and is also suitable for the restoration of riparian forests in places with no periodic flooding (Carvalho, 2003; Coradin et al., 2011).

The great potential of this species, combined with the increased demand for native forest species, makes it essential to define strategies and protocols for the production of quality seedlings (Dutra et al., 2016), which are essential for the initial success of forest plantations (Gasparin et al., 2014). Among the factors that most influence the quality of the seedlings this experiment focusses on container volume and base fertilization.

The volume of the container should allow for the development of the root system without imposing restrictions during the period of permanence of the seedling in the nursery (Carvalho Filho et al., 2003). The use of containers with volumes smaller than what is recommended causes deformations of the radicular system, like the folding of the roots (Freitas et al., 2005), while containers with volumes larger than what is recommended lead to unnecessary expenses regarding substrate (Viana et al., 2008) and fertilizers. Thus, to determine the ideal volume of the container, it is necessary to consider the speed of growth and morphology of the root system of the species to be produced, as well as the financial resources.

Basic fertilization is essential to maximize seedling growth (Klooster et al., 2012). However, both excess and lack of nutrients can be harmful to plants (Gonçalves et al., 2005). The quantity and characteristics of the fertilizers to be used in the production of forest seedlings depend on the form of reaction and efficiency in the release of these, as well as on the nutritional requirement of the species (Gonçalves et al., 2004). In this sense, we highlight the use of controlled release fertilizers (CRF), which increase the efficiency of fertilization because, according to Elli et al. (2013), they provide nutrients on a regular and continuous basis to the seedlings, and reducing leach losses (Shaviv, 2001).

The objective of this study is to characterize the growth of *H. heptaphyllus* seedlings in the nursery—produced in different container volumes and doses of controlled release fertilizer—and verify whether the responses obtained in the nursery are confirmed in the field.

2. **Material and Methods**

2.1 Seedlings Grown in Nursery

The experiment was conducted at the Forest Nursery (29°43′ S and 53°43′ W) at the Federal University of Santa Maria (UFSM), Rio Grande do Sul (RS), Brazil, from March 2014 to September 2014. According to the classification of Köppen, the climate of the region is subtropical, type Cfa, with an average annual precipitation of 1720 mm and average annual temperature of 19.1 °C, with 32 °C and 9 °C as the averages of the hottest and coldest months, respectively (Heldwein et al., 2009).

The experimental design was completely randomized with three replicates in a factorial scheme (3 × 4), considering three container volumes [polypropylene containers (cylindrical and conical) of 180 and 280 cm^3, and polyethylene bags (with lateral perforations) of 500 cm^3] and doses of CRF (0, 4, 8, and 12 g L^{-1} of substrate). Each experimental unit was composed of 20 seedlings.

A 2:1 mixture of commercial substrate (composed of Sphagnum peat and expanded vermiculite) and carbonized rice husk were used to fill the containers. The CRF used in the base fertilization had a release time of 5-6 mo. and the following chemical composition: macronutrients 15% nitrogen (N); 9% superphosphate (P_2O_5); 12% potassium chloride (K_2O); 1% magnesium (Mg) (Mgeni and Price, 1993), and the micronutrients 2.3% sulfur (S); 0.05% copper (Cu); 0.06% manganese (Mn) (Zór et al., 2017); 0.45% iron (Fe), and 0.2% molybdenum (Mo).

The seeds used in the study were collected in the city of Ijuí, RS, Brazil. At sowing, two seeds were used per container, and after 60 d it was thinned to leave only the most vigorous and central seedling. The seedlings remained in a greenhouse, where they received irrigation from a micro sprinkler (5 mm day^{-1}).

At the end of the experiment (120 d after thinning) the seedlings were evaluated, and the following attributes were recorded: height (H), stem diameter (SD), H:SD ratio, leaf area (LA), root length (RL), shoot dry weight (SDW) (Omari et al., 2016), root dry weight (RDW), and chlorophyll *a* fluorescence.

H (cm) was measured from the substrate level to the apical bud using a graduated ruler. SD was evaluated at the substrate level, using a digital caliper (accuracy of 0.01 mm). From these data, the H:SD was obtained. In the quantification of LA and RL, two plants were measured per treatment. The aerial parts and the roots were separated from each other, the roots were washed in water using sieves, and then both were distributed on A4 white paper containing a scale. Photographs were obtained with a SONY digital camera (model DSC-T100) and processed using the ImageJ® program.

SDW and RDW were determined using the same samples used to evaluate LA and RL. The aerial parts and the roots were dried in an air circulation oven at 65 °C until constant weight. They were then weighed using a precision digital scale (0.001 g). The total dry mass (TDW) was obtained from the sum of SDW and RDW. From these data, the Dickson quality index (DQI) was calculated according to Dickson et al., (1960).

The fluorescence of chlorophyll *a* analysis was performed using JUNIOR-PAM modulated pulse fluorometer (Walz, Germany) from 07:00 to 23:00, and a molt from each replicate was randomly selected. For evaluations, a fully expanded leaf of the second branch was pre-adapted to the dark for 30 min. The reading was then taken, obtaining values for the initial fluorescence (F0), maximum fluorescence (Fm), maximum quantum yield (Fv/Fm), and electron transport rate (ETR).

2.2 Planting Seedlings in the Field

The experiment was conducted from October 2014 to April 2016, in an area adjacent to the Forest Nursery of the UFSM (29°43′12″ S and 53°43′14″ W), in a randomized block design, formed by the 12 treatments previously tested. Each plot was composed of four plants, totaling 144 plants.

For planting, circular pits 30 cm in diameter and 35 cm deep were opened with a soil boring machine coupled to a tractor, spaced 1 m^2 apart. The soil chemical characteristics of the area were analyzed by the Soil Analysis Laboratory (UFSM) (Table 1) and guided pH correction with dolomitic limestone (PRNT 74%) 30 d prior to planting.

Table 1. Chemical attributes of the soil where *H. heptaphyllus* seedlings were planted

pH	P*	K	Ca	Mg	Al	MO	Clay	V
H_2O	--------- mg dm^{-3} ---------		---------------- cmolc dm^{-3} ----------------			--------------------- % --------------------		
4.4	4.5	36.0	2.0	0.6	1.8	2.1	31.0	13.3

Note. In which: P: phosphorus * extracted by the method of Mehlich I; K: potassium; Ca: calcium; Mg: magnesium; Al: aluminum; MO: organic matter; V: base saturation.

Seedlings were irrigated once per week during the first month, adding 2 L of water per seedling. Fertilization was provided at 30, 210, and 390 d after planting by applying 100 g of NPK (05-20-20) in the first two fertilizations and 50 g of N in the last fertilization.

H and SD were measured at planting and at the end of the experiment (0 and 540 d after planting), through which the increase in height (IH) and stem diameter (ISD) were obtained.

At 540 d after planting, the survival and determination of LA and SDW were evaluated. We additionally evaluated the physiological attributes: chlorophyll index (*a*, *b*, and total) in two plants per replicate, using a chlorophyll LOG (Falker Automação Agrícola, Brazil) chlorophyllometer and fluorescence of chlorophyll *a* in a seedling per replicate.

2.3 Statistical Analysis

In both experiments, we evaluated the assumptions of normality of the residuals and homogeneity of variance. The data were analyzed by a two-way analysis of variance (ANOVA) and subsequent comparison of the means by a Tukey test or regression analysis at 5% probability of error. The analyses were conducted in the statistical package SISVAR (Ferreira, 2014).

3. Results

3.1 Seedlings Grown in Nursery

For H and TDW, we observed a significant effect for the CRF dose (Figure 1) and container volume. The dose of maximum technical efficiency (MTE) estimated for H (8.16 cm) was 10 g L^{-1} of CRF. TDW presented linear growth with increasing CRF doses, with the highest average observed in doses of 12 g L^{-1} (0.89 g), representing an increase of 111.9% relative to the control (0 g L^{-1}).

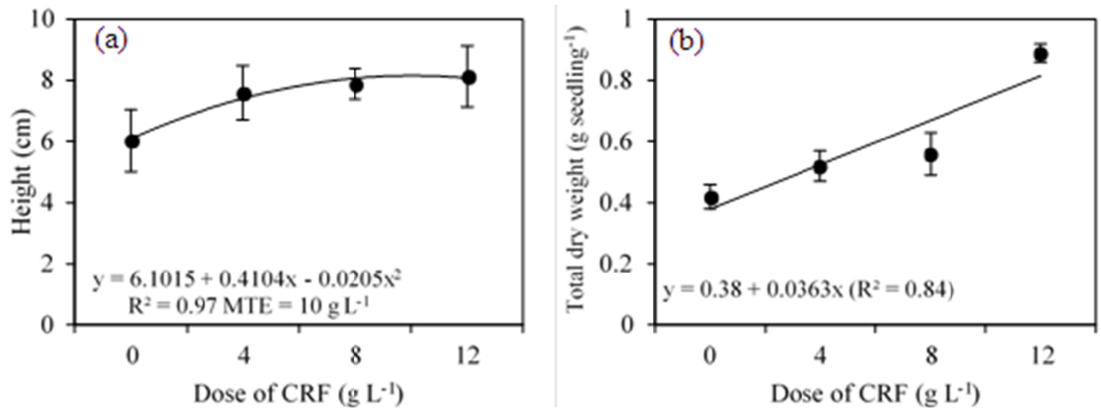

Figure 1. Height (a) and total dry weight (b) of *Handroanthus heptaphyllus* seedlings, at 120 d after thinning, as a function of controlled release fertilizer (CRF) dose, in nursery

Concerning the effect of container volume, seedlings produced in polyethylene bags of 500 cm^3 presented the highest averages for H (8.17 cm) and TDW (0.78 g) (Table 2).

Table 2. Height and total dry weight of *Handroanthus heptaphyllus* seedlings, at 120 d after thinning, as a function of container volume, in nursery

	Height (cm)		Total dry weight (g $plant^{-1}$)	
Tubes 180 cm^3	6.91	b*	0.48	b*
Tubes 280 cm^3	7.16	b	0.54	ab
Polyethylene bags 500 cm^3	8.17	a	0.78	a

Note. * Means followed by the same letter in the column do not differ by Tukey test at 5% of error probability.

CRF doses demonstrated significant effects on the RDW, DQI, and H:SD attributes (Figure 2). The highest RDW (0.38 g) and DQI (0.38) were achieved at a dose of 12 g L^{-1}, while H:SD showed an MTE of 8.4 g L^{-1} of CRF (3.73) (Figure 2).

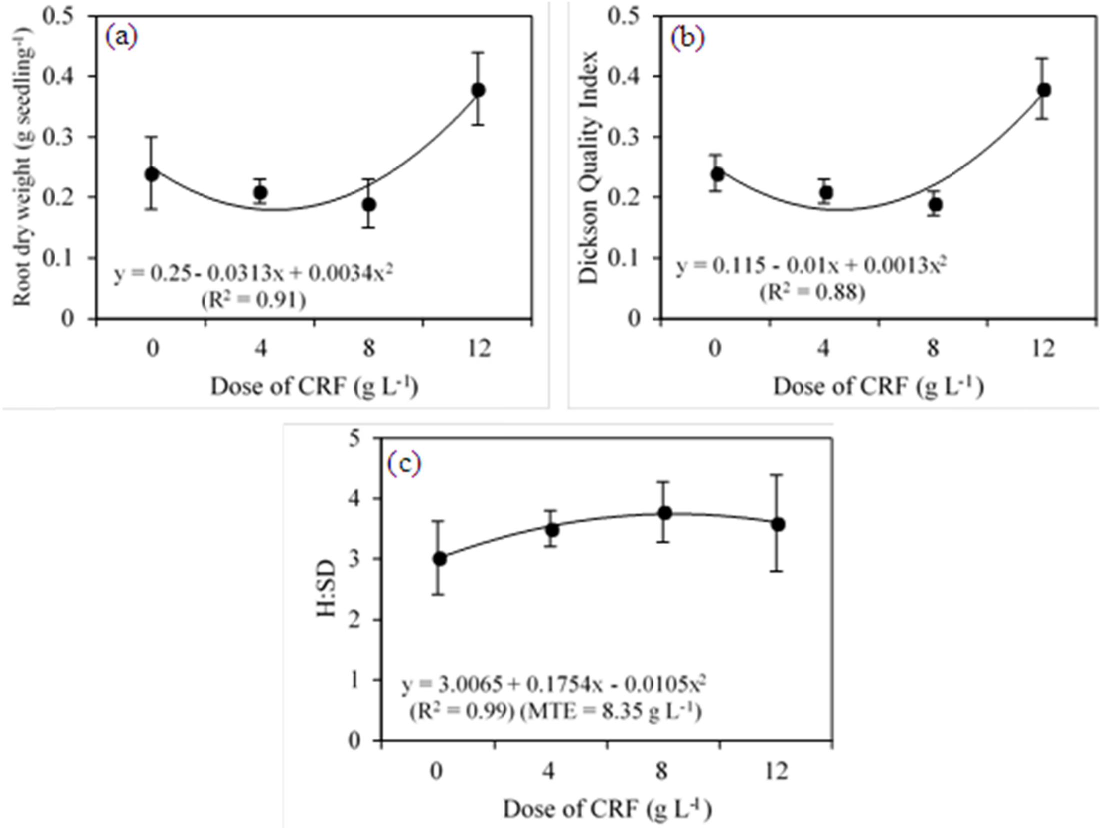

Figure 2. Root dry weight (a), Dickson quality index (b), and H:SD ratio (c) of *Handroanthus heptaphyllus* seedlings at 120 d after thinning, as a function of controlled release fertilizer (CRF) dose, in nursery

SDW, LA, and RL demonstrated significant interactions between the study factors. The SDW presented quadratic behavior for the 180 cm^3 tube and the 500 cm^3 bag, and linear behavior for the 280 cm^3 tube relative to the CRF dosage (Figure 3). The MTE estimated for the 180 cm^3 tube was 7.2 g L^{-1} (0.39 g). The highest values for the 280 cm^3 tube (0.39 g) and 500 cm^3 bag (0.87 g) were obtained at the maximum CRF dose (12 g L^{-1}).

LA exhibited a quadratic tendency as a function of the containers and doses of CRF (Figure 3b). In this case, the MTE found for the 180 cm^3 and 280 cm^3 tubes were 7.9 g L^{-1} and 10.3 g L^{-1}, respectively; a dose of 12 g L^{-1} in the 500 cm^3 bag provided the highest mean (113.94 cm^2).

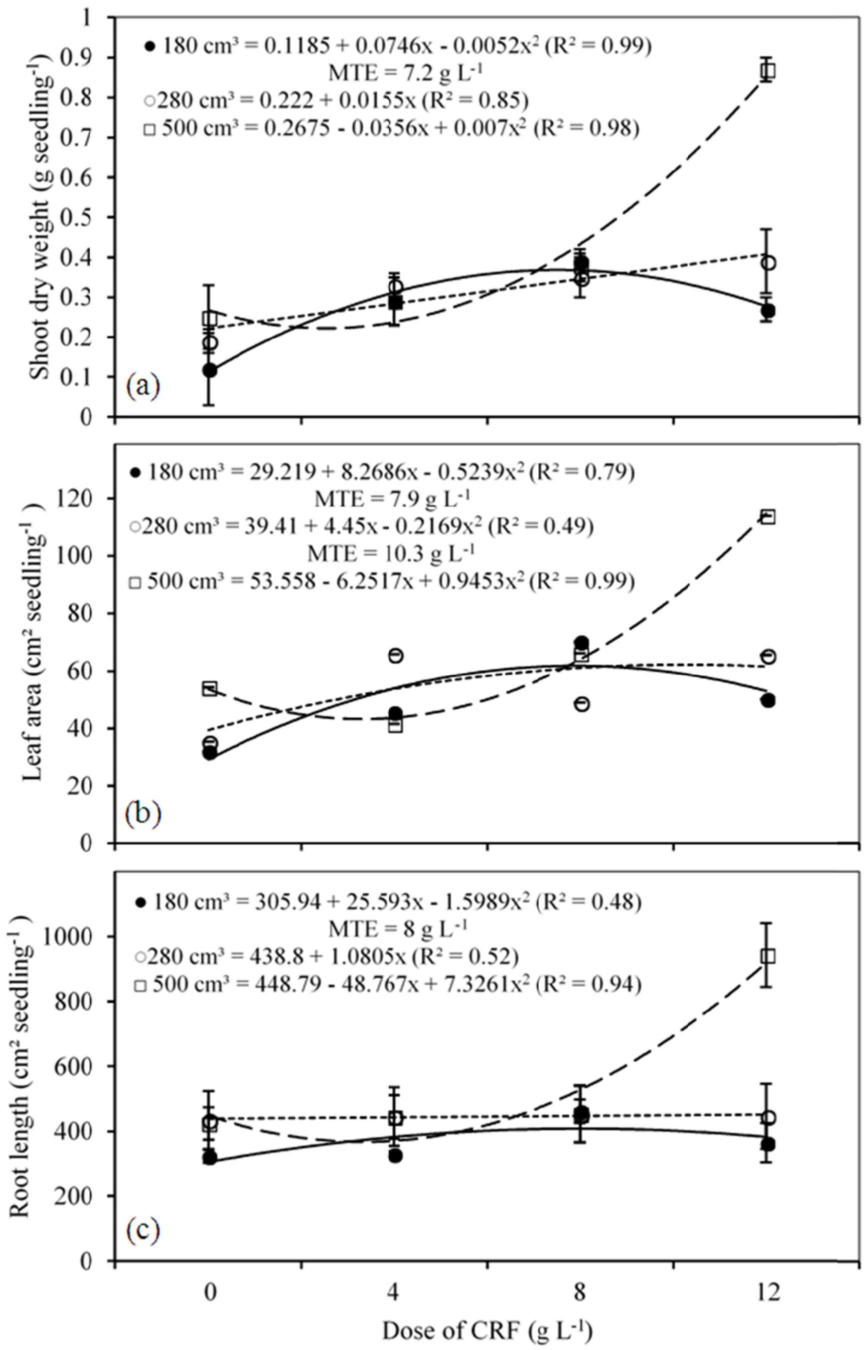

Figure 3. Shoot dry weight (a), leaf area (b), and root length (c) of *Handroanthus heptaphyllus* seedlings at 120 d after thinning, as a function of controlled release fertilizer (CRF) dose, in nursery

The RL presented a trend similar to that observed for DDW. In the tubes of 180 cm^3 and 280 cm^3 MTE was observed at 8 g L^{-1}; while for the bag of 500 cm^3, the dose of 12 g L^{-1} provided the highest RL (943.09 cm), representing an increase of 122.3% relative to the control.

The maximum quantum yield differed in relation to the CRF doses, exhibiting a positive linear trend. The highest mean (0.57) was observed at a CRF dose of 12 g L^{-1} (Figure 4).

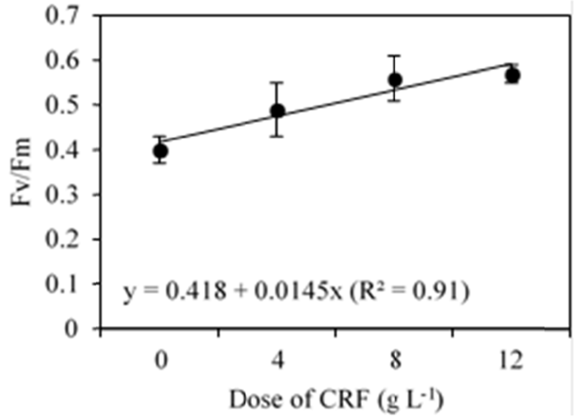

Figure 4. Maximum quantum yield (F_v/F_m) of *Handroanthus heptaphyllus* seedlings, evaluated at 120 d after thinning, as a function of controlled release fertilizer (CRF) dose, in nursery

3.2 Planting Seedlings in the Field

The survival of the seedlings in the field was approximately 60% at 540 d after planting. CRF dosage significantly affected IH, ISD, SDW, LA, Fv/Fm, and the chlorophyll *a* index; however interaction between CRF doses and container volumes was not witnessed.

IH and SDW showed a quadratic behavior with increasing CRF doses, while ISD and LA presented linear trends. However, in all variables, the highest averages (99.53 cm, 22.08 mm, 169.83 g and 6618.35 cm², respectively) were observed for a CRF dosage of 12 g L^{-1} (Figure 5).

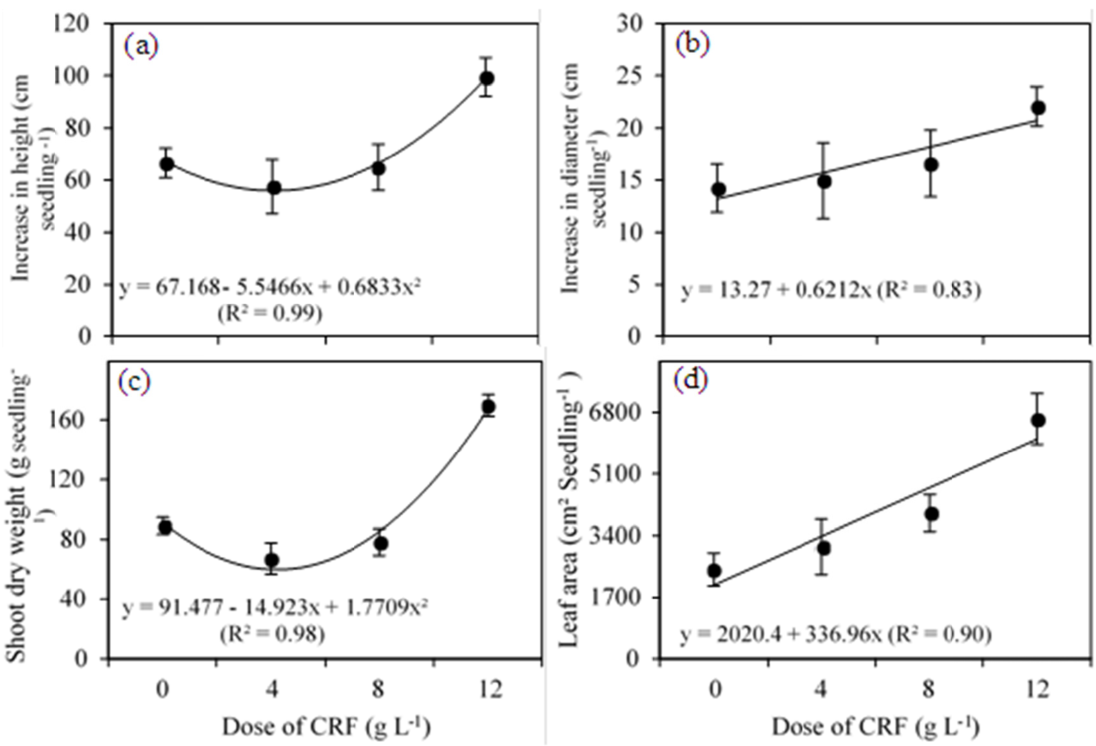

Figure 5. Increase in height (a), increase in stem diameter (b), shoot dry weight (c), and leaf area (d) of *Handroanthus heptaphyllus* seedlings at 540 d after planting, depending on the controlled release fertilizer (CRF) dose, in field

The F_v/F_m presented a positive linear trend with CRF doses, with the highest mean (0.54) verified in the dose of 12 g L^{-1} of CRF (Figure 6). For the chlorophyll *a* index, there was a quadratic trend as a function of CRF dose (Figure 6), with an estimated MTE for the 8.7 g L^{-1} dose of CRF.

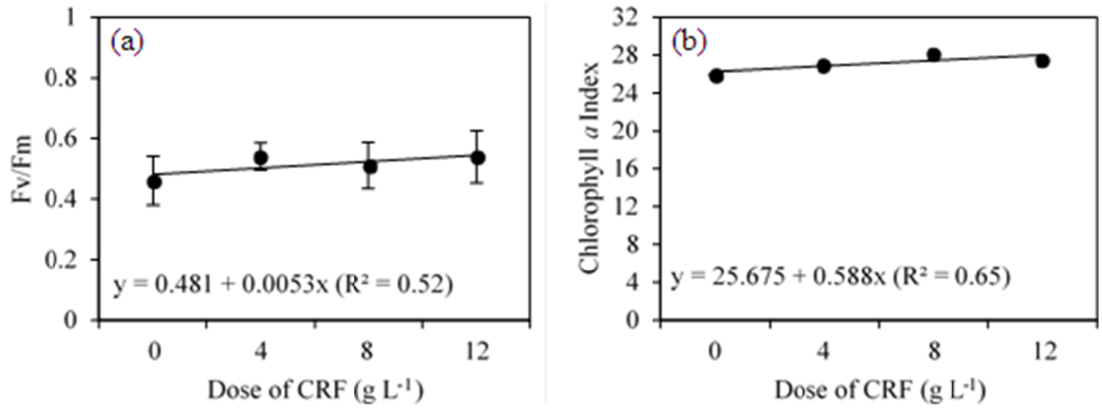

Figure 6. Maximum quantum yield (F_v/F_m) (a) and the chlorophyll content (b) of *Handroanthus heptaphyllus* seedlings at 540 d after planting, depending on the controlled release fertilizer (CRF) dose, in field

4. Discussion

4.1 Seedlings Grown in Nursery

CRF doses above the maximum estimated dose did not influence growth in H or H:SD of *H. heptaphyllus* seedlings. A similar result was observed by Gasparin et al. (2015) for the species *Parapiptadenia rigida*, where growth reduced at higher doses. According White (2012), such behavior is due to the toxicity or induced deficiency of some nutrients by the excess of others. Thus, we show that after meeting the nutritional demand of the plant, a higher fertilization will not result in a growth response, especially for H and H:SD. This phenomenon is characterized, according to Larcher (2000), as "luxury consumption" and can cause toxicity in plants.

On the other hand, the TDW and DQI variables presented the best results at the maximum dose used. TDW is a direct reflection of the net photosynthesis, an important factor for the initial growth of the plants in the field, since these plants initially depend on the photosynthates stored by the seedlings (Kozlowski et al., 1991). In this sense, Batista et al. (2014) considered that higher the value of this variable, the better the quality of the seedling.

When produced at a dose of 12 g L^{-1} CRF, *H. heptaphyllus* seedlings obtained a DQI of 0.18. Birchler et al. (2008) indicated that at values higher than 0.20 seedlings presented quality, a high rate of survival, and growth after planting. The DQI is an important indicator of seedling quality (Gomes & Paiva, 2011), as it considers the robustness and balance of biomass distribution (Fonseca et al., 2002).

High values for SDW, LA, and RL attributes were observed in *H. heptaphyllus* seedlings grown in 500 cm^3 polyethylene bags with the addition of 12 g L^{-1} CRF. This is primarily due to the higher volume of substrate, which allows for better development of the root system, in turn expanding the area of water and nutrient absorption and directly favoring the growth of the plant (Freitas et al., 2013).

The volume of the container also influenced H and TDW, and there was a restriction in the development of these variables in the 180 and 280 cm^3 tubes in the nursery. In a study using seedlings of *Hymenaea courbaril*, *Tabebuia chrysotricha*, and *Parapiptadenia rigida*, Ferraz and Engel (2011) verified that the seedlings produced in 300 cm^3 containers provided higher H and SD, as well as greater development of aerial parts and root systems, compared to those grown in 50 and 110 cm^3 containers. Additionally, Abreu et al. (2014) noted that seedlings tended to have a balanced growth between shoots and roots; however, when a limitation is imposed on the root system, shoot growth is also impaired.

In physiological terms, *H. heptaphyllus* seedlings presented higher values for the F_v/F_m variable when produced at a dose of 12 g L^{-1} CRF. Several studies have demonstrated a positive correlation between F_v/F_m and the concentration of nutrients in leaves (Loustau et al., 1999; Laing et al., 2000; Morales et al., 2000). Jacobs et al. (2005) also observed that seedlings of forest species demonstrated a significant increase in F_v/F_m with the use of CRF. Seedlings produced under adequate nutritional conditions tended to show an increase in the operational efficiency of PSII (Maxwell & Johnson, 2000), resulting in an increased net photosynthetic rate (Jacobs et al., 2005).

Based on our results, we recommend a dose of 12 g L^{-1} CRF for the production of quality *H. heptaphyllus* seedlings, corroborating with the findings of Rorato et al. (2016) for *Eugenia involucrata* seedlings. This dose represents twice of that recommended by the CRF manufacturer, and is higher than indicated for other native species, such as *Anadenanthera colubrina* (Brondani et al., 2008), *Parapiptadenia rigida* (Gasparin et al., 2015) and *Cabralea canjerana* (Aimi et al., 2016).

We show that the different native forest species vary in their nutritional requirements. This underscores the importance of supplying the appropriate nutrients to a species in the nursery, allowing the production of quality seedlings, which improves its post-planting performance, ultimately reducing operational costs resulting from the replacement of dead seedlings.

4.2 Planting Seedlings in the Field

Although high, the dose efficiency of 12 g L^{-1} CRF was confirmed in the field, unlike the container volume that did not influence seedling growth after field planting. Thus, it is evident that seedlings produced with the highest CRF dose recorded better morphophysiological characteristics, which was reflected in the quality and response of the seedlings after planting. On the other hand, as Freitas et al. (2005) suggested, restrictions in the nursery can reduce growth after planting, thus increasing replacement, maintenance, and control costs.

The positive establishment in the field of seedlings produced in the nursery with 12 g L^{-1} CRF is associated with the highest observed root system. The root system might have favored better establishment, increasing soil surface area contact, resulting in a higher nutrient uptake for plant growth.

At the end of the field experiment, there was no significant difference between the container volumes. This result differs from that observed in the nursery, in which the 500 cm^3 bag provided the highest growth. Close et al. (2009) evaluated seedlings of *Eucalyptus globulus* 4 y after planting and verified that container volume does not affect long-term growth. This reinforces the findings described by José et al. (2005), who reported that differences in growth, provided by the distinct volumes of the containers used during the production phase, tend to disappear as individuals become established in the field over time.

The positive response to the use of CRF in the production of *H. heptaphyllus* seedlings can be evidenced by the analysis of the maximum quantum yield (F_v/F_m) and relative index of chlorophyll *a.* The results of the present study demonstrate *H. heptaphyllus* as a species responsive to fertilization, and are consistent with those observed in species of the Bignoniaceae family (Kitajima & Hogan, 2003).

Seedlings produced with 12 g L^{-1} CRF demonstrated the best performance both in the nursery and after planting in the field, while the container volume influenced only nursery performance. In coclusion, 180 cm^3 tube is the most suitable size, due to the substrate economy provided. It is important to evaluate the results obtained in nurseries along with field planting and indicate silvicultural inputs and techniques that will actually influence the growth of seedlings.

5. Conclusions

Handroanthus heptaphyllus responds positively to base fertilization. We therefore recommend the use of 180 cm^3 polypropylene tubes and 12 g L^{-1} of controlled release fertilizer in the production of these seedlings in the nursery. The post-planting performance of *H. heptaphyllus* is influenced by the way seedlings are produced, in that the best results were achieved by plants that received better nutritional conditions in the nursery.

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