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Seedling quality of *Agonandra brasiliensis* in response to different Osmocote® doses and recipient volumes

Qualidade de mudas de *Agonandra brasiliensis* em resposta a diferentes doses de Osmocote® e volumes do recipiente

Calidad de las plántulas de *Agonandra brasiliensis* en respuesta a diferentes dosis de Osmocote® y volúmenes de contenedores

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Abstract
The objective of this work was to evaluate seedlings quality of the tree species *Agonandra brasiliensis* under different doses of the controlled release fertilizer (CRF) Osmocote® and recipient volumes. The experiment was set up in a factorial design for two recipient volumes (1.8 L and 2.2 L) and five CRF doses (0.0; 0.5; 1.0; 2.0; and 3.0 g L^{-1} of substrate). Four repetitions of one plant each were used. After transplanting seedlings, stem height, stem collar diameter, and the robustness index (RI) were measured in a monthly basis during eight months. The highest seedlings growth was observed with the CRF Osmocote® dose of 2.0 g L^{-1} and recipients of 2.2 L. The treatment with CRF dose of 2.0 g L^{-1} in 240 days presented higher initial accumulated growth in height of *A. brasiliensis* seedlings (mean = 31.38 cm). Seedlings under the dose of 2.0 g L^{-1} presented 85.90% increase of stem height in relation to the control (substrate without CRF). CRF Osmocote® had positive effect on growth of *A. brasiliensis* seedlings. Growth was influenced by the different CRF doses and recipient volumes, both for the variables stem height and stem collar diameter and for the RI. The dose 2.0 g L^{-1} allowed greater accumulated growth in height and diameter in 240 days.
Keywords: Native species; Seedling production; Forest nursery; Controlled release fertilizer; Polyethylene.

Resumo
O objetivo deste trabalho foi avaliar a qualidade de mudas da espécie arbórea *Agonandra brasiliensis* sob diferentes doses do fertilizante de liberação controlada (CRF) Osmocote® e volumes de recipientes. O experimento foi configurado em um planejamento fatorial para dois volumes de recipientes (1,8 L e 2,2 L) e cinco doses de CRF (0,0; 0,5; 1,0; 2,0; e 3,0 g L-1 de substrato). Quatro repetições de uma planta cada foram usadas. Após o transplante das mudas, a altura do caule, o diâmetro do colo do caule e o índice de robustez (IR) foram medidos mensalmente durante oito meses. O maior crescimento das mudas foi observado com a dose de CRF Osmocote® de 2,0 g L-1 e os recipientes de 2,2 L. O tratamento com doses de CRF de 2,0 g L-1 em 240 dias apresentou maior crescimento inicial acumulado em altura de mudas de A. brasiliensis (média = 31,38 cm). As mudas na dose de 2,0 g L-1 apresentaram

85,90% de aumento na altura do caule em relação à testemunha (substrato sem CRF). O CRF Osmocote® teve efeito positivo no crescimento de mudas de A. brasiliensis. O crescimento foi influenciado pelas diferentes doses de CRF e volumes do recipiente, tanto para as variáveis altura do caule e diâmetro do colo do caule quanto para o IR. A dose de 2,0 g L-1 permitiu um maior crescimento acumulado em altura e diâmetro em 240 dias.
Palavras-chave: Espécies nativas; Produção de mudas; Viveiro de árvores; Fertilizante de liberação controlada; Polietileno.

Resumen
El objetivo de este trabajo fue evaluar la calidad de plántulas de la especie arbórea *Agonandra brasiliensis* bajo diferentes dosis del fertilizante de liberación controlada (CRF) Osmocote® y volúmenes contenedores. El experimento se configuró en un diseño factorial para dos volúmenes de contenedores (1,8 L y 2,2 L) y cinco dosis de CRF (0,0; 0,5; 1,0; 2,0; y 3,0 g L^{-1} de sustrato). Se utilizaron cuatro repeticiones de una planta cada una. Después de trasplantar las plántulas, se midieron la altura del tallo, el diámetro del cuello del tallo y el índice de robustez (IR) mensualmente durante ocho meses. El mayor crecimiento de plántulas se observó con la dosis de CRF Osmocote® de 2,0 g L^{-1} y los contenedores de 2,2 L. El tratamiento con dosis de CRF de 2,0 g L^{-1} en 240 días presentó mayor crecimiento inicial acumulado en altura de las plántulas de *A. brasiliensis* (media = 31,38 cm). Las plántulas bajo la dosis de 2,0 g L^{-1} presentaron 85,90% de aumento en la altura del tallo en relación al testigo (sustrato sin CRF). CRF Osmocote® tuvo un efecto positivo en el crecimiento de plántulas de *A. brasiliensis*. El crecimiento estuvo influenciado por las diferentes dosis de CRF y volúmenes de contenedores, tanto para las variables altura del tallo y diámetro del cuello del tallo como para el RI. La dosis de 2,0 g L^{-1} permitió un mayor crecimiento acumulado en altura y diámetro en 240 días.
Palabras clave: Especies nativas; Producción de plántulas; Invernadero forestal; Fertilizante de liberación controlada; Polietileno.

1. Introduction

An increasing demand on natural forests for multiuse production requires high quality tree seedlings (Aguilar et al., 2020), which is essential for profitable forest production (Dionisio et al., 2019a). Besides natural forests, reforestation and restoration projects depend mainly on high quality seedlings produced in forest nurseries (Reyes et al, 2014) and, with maximum survivorship rates and rapid initial growth in the field (Marques et al., 2018). Seedlings quality standards vary in each species, among species and sites. These standards evaluation assumes specific parameters and definition criteria. Morphological parameters are the most commonly used to determine seedlings' quality indexes, having more intuitive understanding by nurserymen (Auca et al, 2018). Among morphological parameters to define seedlings' quality indexes, stem height and stem collar diameter are widely used (Dionisio et al., 2019b).

During seedlings production in the nursery, several factors influence in their quality, growth, and production cost, such as: substrate (moisture and porosity), dormancy, temperature, shading and recipient volume, irrigation, seed quality, fertilizer dose, and management of seedlings in the nursery (Rorato et al., 2016; Marques et al., 2018; Bich et al, 2019). The application of the controlled release fertilizer (CRF) Osmocote® improves the quality and initial growth of tree seedlings, while making the nutrients available on a continuous basis, avoiding leaching losses, volatilization, and the salinity decrease of the substrate (Stüpp et al., 2015). However, due to its high acquisition cost, it is essential to establish adequate CRF concentrations for each species to reduce operational costs (Rossa et al., 2013; Rorato et al., 2016).

Besides fertilizers, recipient volume influences seedlings development, since it promotes the proper root system formation and protects roots from mechanical damage and dehydration. Recipient volume also influences on the space occupied inside nursery, labor required to be handled, and transport, which determines the final production cost of seedling production (Stüpp et al., 2015). Seedlings production for both timber and ecosystem restoration purposes are limited to the lack of technical information on the seedlings' needs and correct chemical fertilizers and their precise doses (Rossa et al., 2015), as well as the recommendable recipient volumes to be employed (Dias et al., 2018). Thus, it is essential to carry out research and promote techniques to enable the production of native commercial species at low cost and adapted to the current planting systems. These studies can be an important basis to implement commercial planting under optimized resources (Melo et al., 2018).

Amongst the commercial tree species to face the quality seedlings bottleneck in tropical forests there is *Agonandra brasiliensis* Miers ex Benth. & Hook. f. (Opiliaceae). The species has a geographical distribution over the biomes Amazon, Pantanal, and Atlantic Forest in Brazil where it is popularly known as pau-marfim and quina-de-veado (Moraes et al., 2018). The species is used for urban afforestation, houses construction and carpentry, and its bark, leaves, and seeds' oil have local medicinal usages (Souza et al., 2020). However, *A. brasiliensis* lacks information about protocols for seedling production (Moraes et al., 2018; Souza et al., 2020).

Better nutritional power and smaller recipients can reduce costs in the seedlings production phase, transport, and distribution in the field, providing greater yields (Pinho et al., 2018; Lima Filho et al., 2019). Having *A. brasiliensis* as a model, we bring the following research question: how different CRF doses and recipient volumes can influence the quality of *A. brasiliensis* seedlings Therefore, the objective of this study was to analyze quality of *A. brasiliensis* seedlings submitted to different CRF doses and recipient volumes.

2. Methodology

Seedling production and experimental design

The study was based on a quantitative and qualitative research (Pereira et al., 2018). Data were gathered from an experiment conducted in the forest nursery of Embrapa Roraima (2°45'22" N, 60°43'55" W, altitude = 80 m), located at km 8 of the BR-174 highway, municipality of Boa Vista, state of Roraima, Brazil, from September 2018 to June 2019. According to the Köppen classification, the region's climate is Am (tropical monsoon), with annual average temperature of 25.4 °C (averages of 27.2 °C in the warmest and 23.3 °C in the coldest month), average annual rainfall of 1808 mm, with 365 mm and 26 mm in the peak of the rainy (June) and dry season (February), respectively (Alvares et al, 2013).

Seeds for the production of *A. brasiliensis* seedlings were collected from matrixes in an area of Dense Submontane Ombrophylous Forest (1°38'29" N, 60°58'11" W) in the municipality of Caracaraí, Roraima, in March 2018. After collection, seeds were manually processed and sown over a bed containing washed medium size sand as substrate for the seedling stages of germination, growth, and initial development. Substrate moisture was maintained under manual irrigation four times a day. Seedlings started germination approximately 30 days after sowing. As soon as the seedlings reached a uniform height of 12 cm, they were transplanted into polyethylene bags, filled with washed medium size sand as substrate. The controlled release fertilizer (CRF) Forth Cote (100% Osmocote®) in the formulation 18-05-09 (NPK) and with a release period of 5 months was added in the bag, according to each treatment. Subsequently, the plants were stored in a forest nursery covered by a 50% shading mesh (Sombrite®) and maintained under daily sprinkler irrigation.

The experimental design was fully randomized in a 2 x 5 factorial: two levels for the recipient volume factor, with 1.8 L and 2.2 L black plastic bags (12 x 30 cm and 12 x 35 cm, respectively) and five levels of CRF factor (0.0 – control; 0.5; 1.0; 2.0; and 3.0 g L^{-1} of substrate). Four repetitions were used, each one composed by a plant.

Assessment of seedling quality

Morphological parameters, relations, and quality indexes were considered to evaluate the seedlings quality of *A. brasiliensis*: stem height (cm); stem collar diameter (mm); increment in height (IncH; cm); increment in diameter (IncD; mm); stem dry matter (SDM; g $plant^{-1}$); root dry matter (RDM; g $plant^{-1}$); and total dry matter (TDM = SDM + RDM; g $plant^{-1}$). The calculated quality indexes were: relation of SDM and RDM (SDM/RDM) and the robustness index (RI = stem height/stem collar diameter). Values of SDM/RDM and RI equal to 1 indicate the best seedling's quality value. The Dickson quality index

(DQI) was also included, where the higher it is, better is the seedling's quality (Dickson et al., 1960). DQI was calculated as a function of TDM, stem height, stem collar diameter, SDM, and RDM, using the formula:

$$DQI = \frac{TDM\ (g)}{\frac{\text{stem height (cm)}}{\text{stem collar diameter (mm)}} + \frac{SDM\ (g)}{RDM\ (g)}}$$

Data on stem height and stem collar diameter were collected when seedlings were transplanted to the recipients (day 0), and were re-evaluated again every 30 days during eight months, or 240 days after transplant (DAT), when the experiment ended. A ruler graded in millimeters was used to measure stem height, and a digital caliper (precision = 0.01 mm) was used to measure stem collar diameter. IncH and IncD were calculated through the differences between final (240 DAT) and initial (0 DAT) values.

To determine SDM and RDM at the end of the experiment (240 DAT), all 40 plants in the experiment were cut in two halves at the stem collar diameter. The two pieces were placed separately on kraft paper, dried in a forced ventilation oven at 65 °C until reaching a constant mass (about 72 hours) and then weighed in an analytical balance in the Seed Analysis Laboratory of Embrapa Roraima.

Data analysis

To verify the assumptions of the analysis of variance (ANOVA), the data were first checked for normality with the Shapiro-Wilk test ($p > 0.05$) and homoscedasticity with the Bartlett test ($p > 0.05$). Once fulfilled such assumptions, the data were submitted to ANOVA). In cases of significant interactions by the F test ($p \leq 0.05$), qualitative means were compared by the Tukey test, and quantitative means by polynomial regression, at a 5% probability level. In the polynomial regression, the selected model for each variable was based on the parameters significance and R2 values. Quadratic equations adjusted by regression analysis and the maximum technical efficiency dose (MTED) were calculated from their partial derivatives (Stüpp et al., 2015). All statistical analyses were performed using R software version 3.6.1 (R Core Team, 2019).

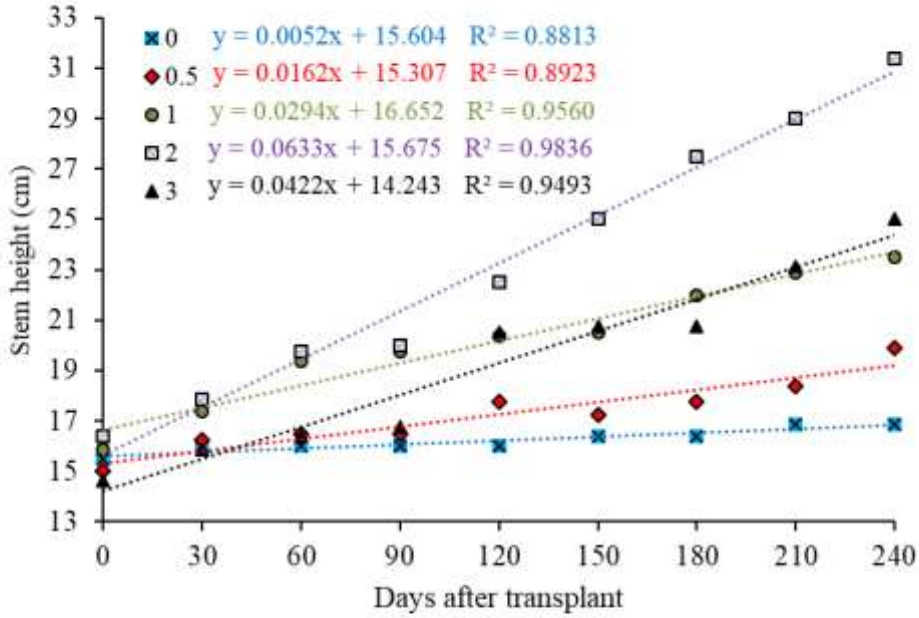
3. Results

Seedling growth in 240 days

In 240 days after transplant (DAT), the *A. brasiliensis* seedlings survivorship was 100% in all treatments. ANOVA for the variable "stem height" showed significant interaction between the factors "controlled release fertilizer (CRF)" and "recipient volumes" ($F_{4;359} = 3.22$, $p = 0.019$) and between DAT and CRF doses ($F_{32;359} = 1.91$, $p = 0.003$). Stem collar diameter presented significant effects for the same interactions, with $F_{4;359} = 15.92$, $p = 0.001$ and $F_{32;359} = 1.76$, $p = 0.010$, respectively. RI showed significant influence for recipients ($F_{1;359} = 6.17$, $p = 0.016$), CRF doses ($F_{4;359} = 5.17$, $p = 0.001$), and DAT ($F_{8;359} = 3.09$, $p = 0.002$).

The CRF dose of 2.0 g L^{-1} at 240 DAT presented higher initial accumulated growth in height of *A. brasiliensis* seedlings, reaching 31.38±10.23 cm and coefficient of determination (R^2) of the growing linear regression model of 98.36% of the stem height variation in time after transplant (Figure 1). The doses 3.0; 1.0; 0.5; and 0.0 g L^{-1} presented the lowest growth means of stem height. The dose 2.0 g L^{-1} provided an 85.90% increase in stem height when compared to the control.

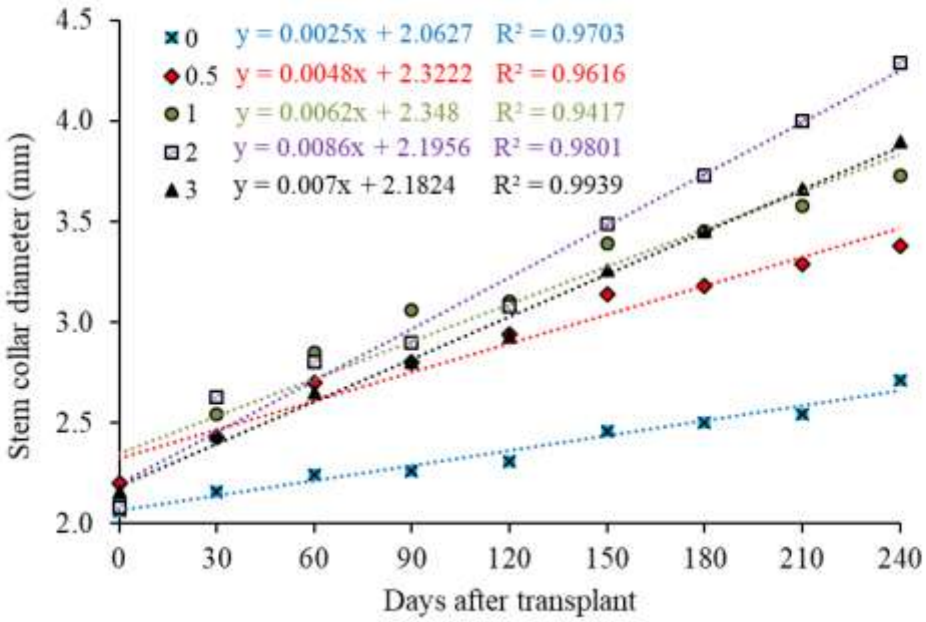
Figure 1. Stem height growth of *Agonandra brasiliensis* seedlings as a function of time after transplant in nursery conditions.



Source: Authors.

Stem collar diameter at 240 DAT presented higher mean (4.29±0.58 mm, $F_{8;270} = 23.32$, $p = 0.001$) in the 2.0 g L^{-1} CRF dose, 58.30% higher than the control (2.71±0.55 mm, $F_{8;270} = 1.96$, $p = 0.051$) (Figure 2).

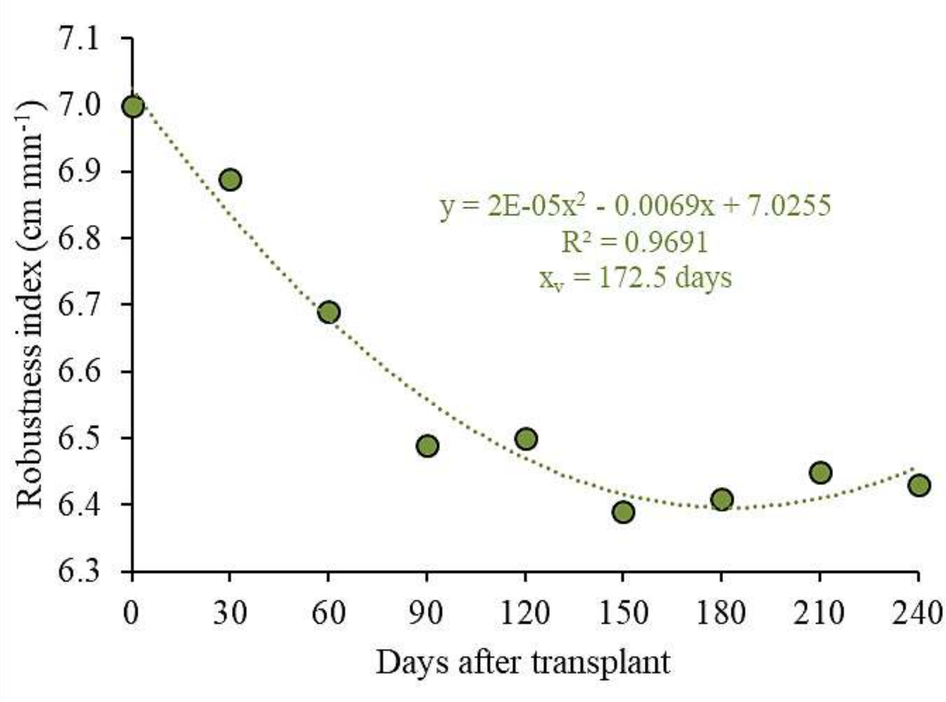
Figure 2. Stem collar diameter growth of *Agonandra brasiliensis* seedlings as a function of the time after transplant in nursery conditions.



Source: Authors.

Unlike stem height and stem collar diameter, robustness index (RI) presented a quadratic behavior, with R^2 explaining 96.91% of time variation after transplant (Figure 3), with a minimum DAT value of 172.5 (6.43±0.80 cm mm^{-1}, $F_{8;359} = 2.39$, $p = 0.017$).

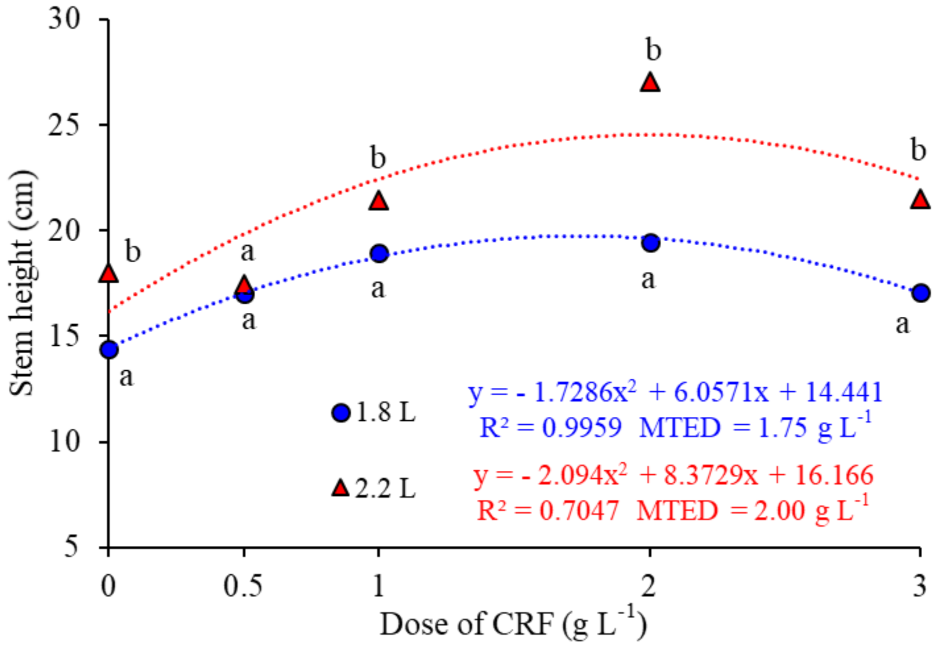
Figure 3. *Agonandra brasiliensis* seedlings robustness index curve as a function of time after transplant in nursery conditions.



Source: Authors.

Seedlings produced in 2.2 L plastic bags showed better performance in stem height, and those produced in 2.0 g L^{-1} CRF dose showed higher mean growth (27.06±8.80 cm, $F_{4;270}$ = 25.82, p = 0.001), 50.31% higher than the control stem height (without Osmocote®). This was statistically different from the 2.0 g L^{-1} dose (19.47±4.38 cm, $F_{4;270}$ = 7.02, p = 0.001), where seedlings in 1.8 L recipients presented higher stem height (Figure 4). The maximum technical efficiency dose (MTED) calculated for stem height was estimated at 2.0 g L^{-1} in 2.2 L bags. In the case of the 0.5 g L^{-1} dose, the means observed for stem height in the 1.8 L and 2.2 L recipients had no significant difference (p = 0.696). The MTED calculated for the stem height curve with the 1.8 L recipient, was estimated in 1.75 g L^{-1}.

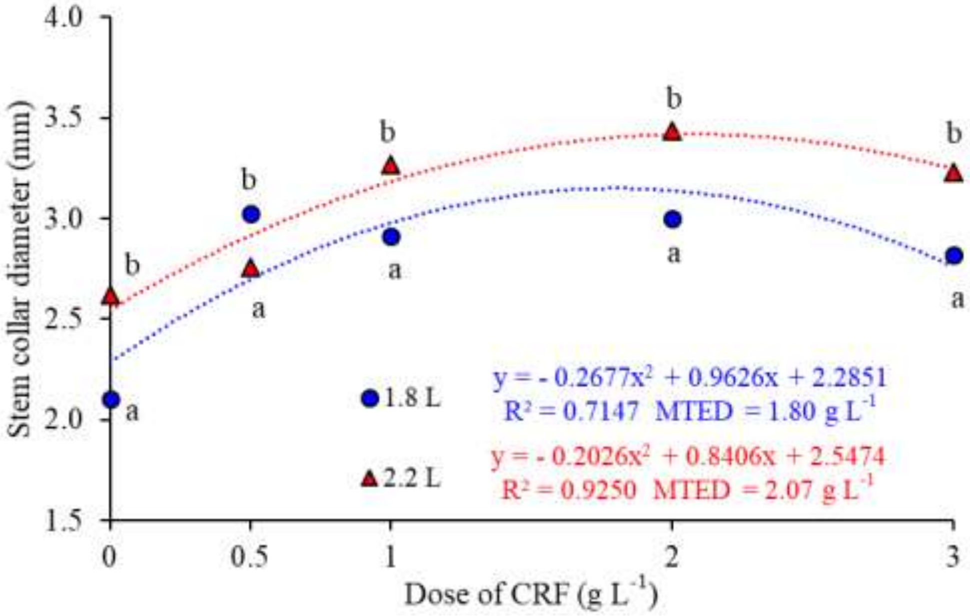
Figure 4. Stem height of *Agonandra brasiliensis* seedlings produced in different recipient volumes (1.8 L and 2.2 L) as a function of the controlled release fertilizer (CRF). Equal letters show no statistical differences by the Tukey test at 5% probability level.



Source: Authors.

Regarding stem collar diameter, seedlings produced in 2.2 L recipients had higher mean growth (3.44±0.80 mm, $F_{4;270} = 25.95$, $p = 0.001$) and those with 2.0 g L^{-1} CRT dose were 31.18% higher than the control, differing significantly from the mean (3.0±0.66 mm, $F_{4;270} = 30.58$, $p = 0.001$) observed in plants produced with the same dose, but in 1.8 L recipients (Figure 5). The calculated MTED for stem collar diameter of seedlings produced in 2.2 L recipients was estimated in 2.07 g L^{-1} and the stem collar diameter means between 1.8 L and 2.2 L recipients differed in all five CRF doses. The calculated MTED for stem collar diameter of seedlings produced in 1.8 L recipients was estimated in 1.80 g L^{-1}.

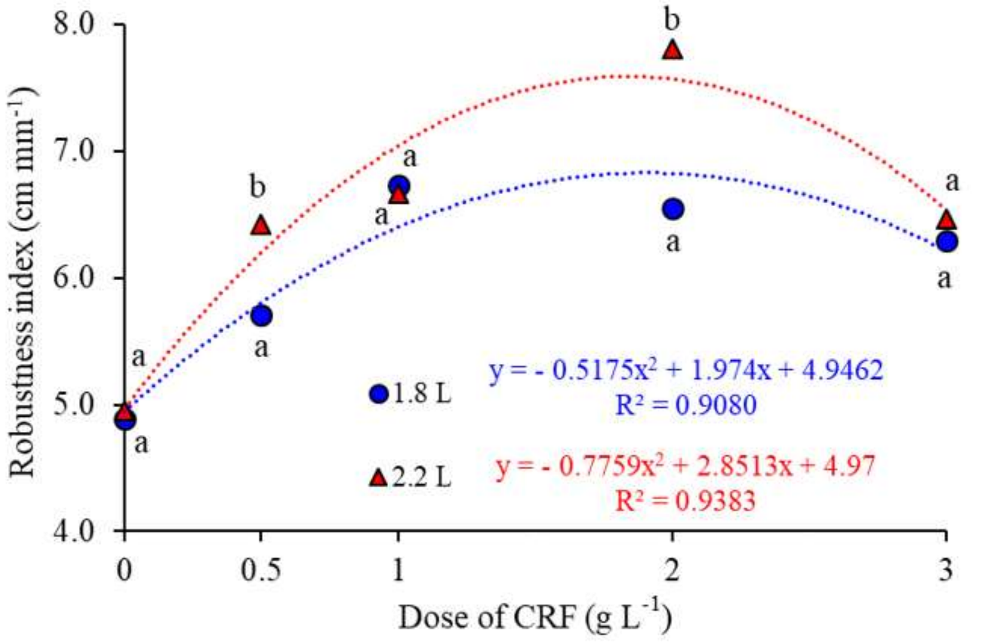
Figure 5. Stem collar diameter of *Agonandra brasiliensis* seedlings produced in recipient volumes of 1.8 L and 2.2 L as a function of controlled release fertilizer (CRF) doses. Equal letters show no statistical differences from each other by Tukey test at a 5% probability level. Maximum technical efficiency dose (MTED).



Source: Authors.

In relation to the RI, the 0 g L^{-1} dose (control) provided the best balance between growth in stem height and diameter, with 4.89±1.15 cm^{-1} and 4.96±0.80 cm^{-1} in 1.8 L and 2.2 L recipients, respectively (Figure 6). The doses of 0.0; 1.0; and 3.0 g L^{-1} showed no significant difference by the Tukey test at 5% probability.

Figure 6. Robustness index of *Agonandra brasiliensis* seedlings produced in 1.8 L and 2.2 L recipient volumes as a function of controlled release fertilizer (CRF) doses. Equal letters show no statistical differences from each other by Tukey test at a 5% probability level.



Source: Authors.

Interactions and effects of factor levels on seedling quality

CRF doses and recipient volume for the root dry matter (RDM) presented interaction ($F_{4;39} = 3.35$, $p = 0.022$) as well as increment in height (IncH) ($F_{4;39} = 13.70$, $p = 0.001$) and SDM/RDM relation ($F_{4;39} = 4.15$, $p = 0.008$) (Table 1). Seedlings produced in 2.2 L recipients and fertilized with 2.0 g L^{-1} CRF doses had the highest RDM (7.50±1.27 g $plant^{-1}$, $F_{4;39} = 10.45$, $p = 0.001$), differing from doses 0.0; 0.5; and 1.0 g L^{-1} in the same recipient volume and the respective mean dose of 2.0 g L^{-1} in the 1.8 L recipient (3.37±1.16 g $plant^{-1}$, $F_{4;39} = 2.50$, $p = 0.063$) (Table 1). The RDM means of 0.0; 0.5; and 1.0 g L^{-1} doses did not differ significantly in recipient volumes ($p = 0.068$, $p = 0.842$, and $p = 0.491$, respectively). For IncH, the 2.0 g L^{-1} dose associated with the 2.2 L recipient presented higher mean (22.50±5.00 cm, $F_{4;39} = 44.88$, $p = 0.001$), differing from the other treatments, while the 0.5 g L^{-1} dose in the 1.8 L recipient was similar to the higher doses. On the other hand, the SDM/RDM relation did not differ significantly in the doses of 1.0 ($F_{1;39} = 0.07$, $p = 0.788$); 2.0 ($F_{1;39} = 0.03$, $p = 0.855$), and 3 g L^{-1} ($F_{1;39} = 2.20$, $p = 0.149$) in both recipients, differing only in the doses of 0.0 ($F_{1;39} = 11.22$, $p = 0.002$) and 0.5 g L^{-1} ($F_{1;39} = 6.99$, $p = 0.013$). Furthermore, the SDM/RDM relation was not influenced by the association of different CRF doses in the 2.2 L recipients ($F_{4;39} = 0.97$, $p = 0.441$).

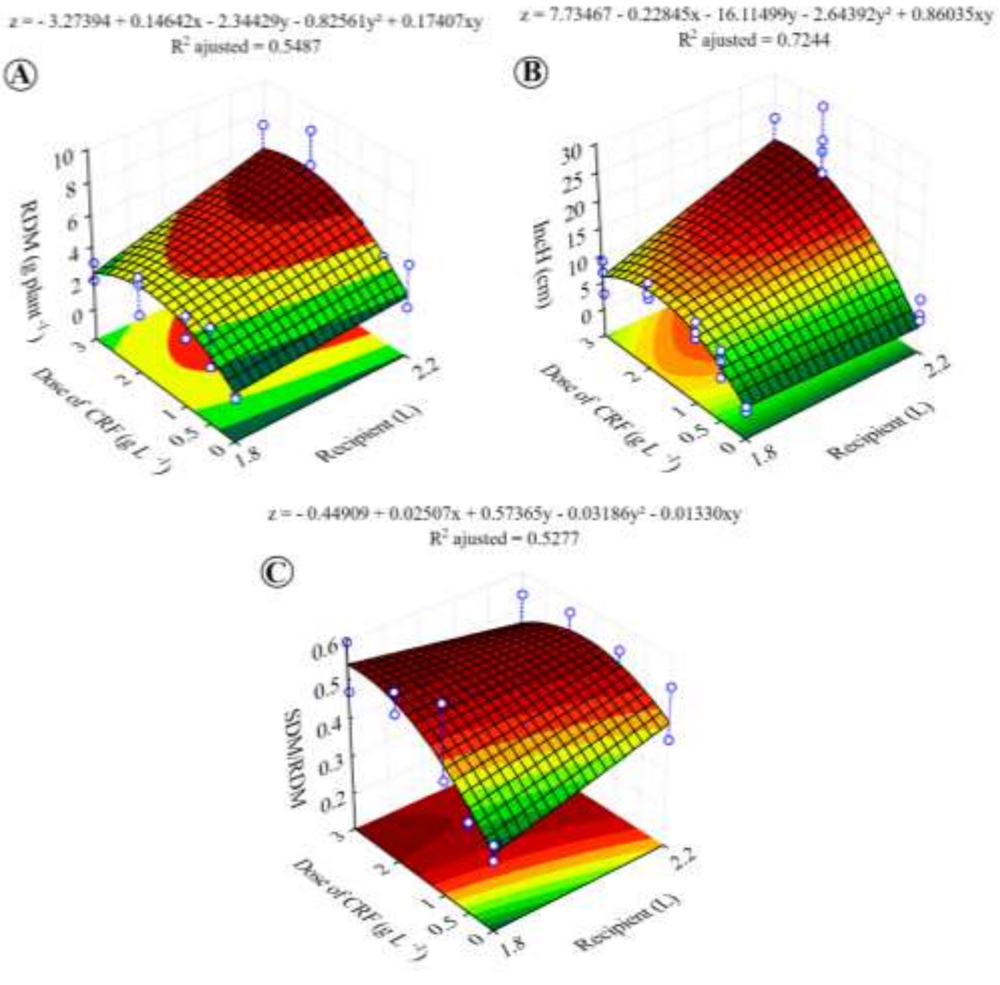
Table 1. Mean (±SD) of root dry matter (RDM), increment in height (IncH) and shoot dry matter/ root dry matter relation (SDM/RDM) of *Agonandra brasiliensis* seedlings in interaction with different controlled release fertilizer (CRF) doses and recipient volumes. CV: coefficient of variation.

CRF dose ($g L^{-1}$)	RDM ($g plant^{-1}$)		IncH (cm)		SDM/RDM	
	Recipient (L)		Recipient (L)		Recipient (L)	
	1.8	2.2	1.8	2.2	1.8	2.2
0	0.86±0.10 Ab	2.53±1.59 aB	0.50±0.58 aB	2.25±1.89 aB	0.31±0.02 aA	0.45±0.08 aB
0.5	2.85±1.42 Ab	3.03±0.43 baB	5.75±2.06 baB	4.00±1.41 aB	0.34±0,00 aA	0.45±0.00 aB
1	3.04±0.80 aB	3.65±1.04 baB	8.00±1.41 bB	7.25±2.06 aB	0.50±0.11 bB	0.49±0.06 aB
2	3.37±1.16 Aa	7.50±1.27 cB	9.00±1.41 bA	22.50±5.00 cB	0.52±0.03 bB	0.53±0.04 aB
3	2.42±0.65 aA	5.15±2.37 cbB	6.50±2.52 bA	16.00±4.00 Bb	0.53±0.07 bB	0.47±0.08 aB
CV (%)	36.14		31.37		13.55	

Means followed by the same letter, lower case in the column and upper case in the row, do not differ statistically from each other by Tukey test at the 5% probability level.
Source: Authors.

The adjustment of the surface response model of the resulting interaction between CRF dose and recipient volume for the RDM parameter showed slight linear increase compared to the higher recipient volume capacity and the quadratic behavior as a function of CRF dose (Figure 8A). For IncH, the model described a linear increase as a function of the recipient and a greater increase in the CRF dose of 2.0 g L^{-1} in 1.8 L and 2.2 L recipients, with R^2 explaining 72.44% of IncH variation in CRF dose (X_1) and recipient volume (X_2) variation (Figure 7B).

Figure 7. Adjusted response surface and respective multiple regression model of root dry matter (RDM) (A), increment in height (IncH) (B) and the shoot dry matter and root dry matter relation (SDM/RDM) (C) of *Agonandra brasiliensis* seedlings as function of different controlled release fertilizer (CRF) doses and recipient volumes.



Source: Authors.

No significant interaction was observed in the factors CRF dose and recipient volume in relation to the variables stem height ($F_{4;39}$ = 1.91, p = 0.134), stem collar diameter ($F_{4;39}$ = 1.34, p = 0.280), stem dry mass (SDM) ($F_{4;39}$ = 1.78, p = 0.158), total dry matter (TDM) ($F_{4;39}$ = 2.65, p = 0.052), increment in diameter (IncD) ($F_{4;39}$ = 0.98, p = 0.43), RI ($F_{4;39}$ = 1.82, p = 0.151), and Dickson quality index (DQI) ($F_{4;39}$ = 0.61, p = 0.658). Seedlings fertilized in the 2.0 g L^{-1} dose had the highest mean for the variables stem height (31.38±10.23 cm, $F_{4;39}$ = 5.72, p = 0.002), stem collar diameter (4.29±0.58 mm, $F_{4;39}$ = 8.64, p = 0.001), SDM (3.0±1.25 g $plant^{-1}$, $F_{4;39}$ = 13.52, p = 0.001), TDM (8.68±3.36 g $plant^{-1}$, $F_{4;39}$ = 12.95, p = 0.001), and IncD (2.21±0.45 mm, $F_{4;39}$ = 9.68, p = 0.001) (Table 2). Concerning the recipient volume, seedlings produced in 2.2 L recipients reached higher means in the variables stem height, stem collar diameter, SDM, TDM, and IncD, except the IncD in the 1.8 L recipients ($F_{4;39}$ = 9.22, p = 0.005).

Table 2. Mean (±SD) of stem height, stem collar diameter, stem dry matter (SDM), total dry matter (TDM), and increment in diameter (IncD) of *Agonandra brasiliensis* seedlings produced under different controlled release fertilizer (CRF) doses and recipient volumes. CV: coefficient of variation.

Factor		Stem height (cm)	Stem collar diam. (mm)	SDM (g plant^{-1})	TDM (g plant^{-1})	IncD (mm)
CRF doses (g L^{-1})	0	16.88±4.29 a	2.71±0.55 a	0.66±0.54 a	2.35±1.90 a	0.65±0.43 a
	0.5	19.88±2.47 a	3.38±0.40 ba	1.17±0.40 ba	4.10±1.35 ba	1.18±0.52 ba
	1.0	23.50±3.74 ba	3.73 0.65 cb	1.64±0.51 ba	4.98±1.39 ba	1.69±0.46 cb
	2.0	31.38±10.23 b	4.29±0.58 c	3.00±1.25 c	8.68±3.36 c	2.21±0.45 c
	3.0	25.00±11.86 ba	3.90±0.84 cb	2.16±1.17 cb	5.69±3.40 b	1.73±0.77 cb
Recipient (L)	1.8	20.20±4.36 a	3.38±0.72 a	1.29±0.70 a	3.79±1.82 a	1.41±0.78 a
	2.2	26.45±10.77 b	3.82±0.83 b	2.16±1.35 b	6.53±3.60 b	1.57±0.72 a
CV (%)		27.90	15.91	40.3	35.48	36.36

Means followed by the same letter in the columns do not differ statistically from each other by Tukey test at the 5% probability level.
Source: Authors.

The RI of *A. brasiliensis* seedlings were not influenced by the different CRF doses ($F_{4;39}$ = 1.42, p = 0.251), but only in the recipient volume ($F_{1;39}$ = 4.33, p = 0.046), where 1.8 L recipients obtained the lowest index (6.09±1.18 cm mm^{-1}). Seedlings produced under 2.0 g L^{-1} doses showed higher DQI (0.92±0.24) than the control ($F_{4;39}$ = 5.13, p = 0.003), with no influence of the recipient volume ($F_{1;39}$ = 0.23, p = 0.637) (Table 3).

Table 3. Mean (±SD) of the robustness index (RI) and Dickson quality index (DQI) of *Agonandra brasiliensis* seedlings produced under different controlled release fertilizer (CRF) doses and recipient volumes.

Factor		RI (cm mm^{-1})	DQI
Dose of CRF (g L^{-1})	0.0	6.22±0.95 a	0.33±0.25 a
	0.5	5.98±1.19 a	0.58±0.29 ba
	1.0	6.39±1.05 a	0.64±0.28 ba
	2.0	7.36±1.70 a	0.92±0.24 b
	3.0	6.52±1.68 a	0.72±0.23 ba
Recipient (L)	1.8	6.09±1.18 a	0.62±0.30 a
	2.2	6.90±1.44 b	0.66±0.33 a
CV (%)		19.07	42.02

Means followed by the same letter in the columns do not differ statistically from each other by Tukey test at the 5% probability level.
CV: coefficient of variation.
Source: Authors.

4. Discussion

Seedling growth during 240 days

The accumulated initial growth of *A. brasiliensis* seedlings 240 days after transplant (DAT) (Figure 1) corroborates studies on growth of *Araucaria angustifolia* and *Ocotea odorifera* seedlings (Rossa et al., 2011) and *Schizolobium parahyba* seedlings (Cabreira et al., 2019). In these studies, the use of controlled release fertilizer (CRF) at doses of 6.0 g L^{-1} and 8.3 g L^{-1}, respectively accelerated seedlings growth. The faster growth of seedlings submitted to higher fertilizer doses can be related to elevate height sensitivity in relation to nitrogen fertilization (Cabreira et al., 2017). Larger nitrogen doses, however, may lead seedlings to excessive grow, which may cause starvation (Rossa et al., 2013). In the production of *Cedrela fissilis* seedlings, Pias et al. (2015) observed a linear increase in diameter with consequent longer necessary time of the seedlings in the forest nursery. Plants with larger diameters have better survival conditions due to better capacity to growth new roots (Elli et al., 2013). Positive results in the use of CRF for stem collar diameter were also evidenced in studies with *Anadenanthera peregrina* and *Schinus terebinthifolia* (Rossa et al., 2015), *Mimosa scabrella* (Stüpp et al., 2015), *Peltophorum dubium* (Dutra et al., 2016), and *Albizia lebbeck* (Aguilar et al., 2020).

Robustness index (RI) is one of the most important morphological parameters to estimate seedling growth in the field, although the Dickson quality index (DQI) aggregates the main allometric parameters (RI and SDM/RDM), indicating more accurately seedlings quality planted in the field. In morphological evaluations of *Toona ciliata*, seedlings submitted to different Osmocote® doses, Somavilla et al. (2014) observed better fit for the quadratic model in 150 days after fertilization. So, the RI showed higher values when stem height was higher in relation to stem collar diameter. The different recipient volumes in relation to the CRF doses caused growth variation in *A. brasiliensis* seedlings, presenting quadratic behavior for the variables stem height, stem collar diameter, and RI over the 240 DAT (Figures 4, 5 and 6). Thus, the effect of the CRF added to the substrate was positive only during a certain period.

Similar results about the Osmocote® effects on height were obtained by Stüpp et al. (2015), evaluating growth of *Mimosa scabrella* seedlings in different recipient volumes (110 cm^3 and 180 cm^3) and fertilizer doses (0.0; 3.0; 6; and 9.0 g L^{-1}) in 96 days after sowing. *M. scabrella* cultivated in 180 cm^3 tubes had highest growth at 6.0 g L^{-1} (23.22 cm), with MTED estimated in 6.25 g L^{-1}; for 110 cm^3 tube. The highest growth occurred at doses of 3.0 and 9.0 g L^{-1} (21.60 cm) and MTED was estimated in 7.70 g L^{-1}. In the production of *Spondias tuberosa*, Cruz et al. 2016 also found greater heights in higher recipient volumes.

A similar answer regarding the CRF effects on the variable stem collar diameter obtained by Rorato et al. (2016) in a study about different recipient volumes (110 cm^3 and 180 cm^3) and CRF concentrations (0.0; 3.0; 6.0; 9.0; and 12.0 g L^{-1}) on the production of *Eugenia involucrata* seedlings. After 180 days, higher means in diameter when the *E. involucrata* seedlings were produced in 180 cm^3 recipients with CRF doses of 12.0 and 9.0 g L^{-1}, respectively. MTED was estimated in 25.90 g L^{-1} in 110 cm^3 tubes and 8.80 g L^{-1} in 180 cm^3 recipients.

Interactions and effects of factor levels on seedling quality

RDM, IncH, and the SDM/RDM relation presented larger means in the 2.0 g L^{-1} dose associated with 2.2 L recipients. Moreover, CRF doses of 2.0 g L^{-1} in 2.2 L recipients resulted in seedlings with larger stem height, stem collar diameter, SDM, TDM, and IncD as well as higher RI and DQI. RDM always corresponds to low values, although seedlings have large volumes of fine roots and absorbent hair, so that, physiologically, root volume is crucial for survival and initial growth after planting. The plant’s capacity to absorb nutrients and water depends directly on the amount of its root biomass, so the larger the root system, the greater are success chances after planting. IncH can increase in proportion to the recipient volume, as it was observed in production of *Schinus terebinthifolia* seedlings under different Osmocote® doses (Cabreira et al., 2017). The authors pointed out that high increase in height in large recipient volumes can trigger seedlings starvation.

Regarding the SDM/RDM relation, the 0.5 g L^{-1} dose associated with 1.8 L recipients provided lower values, which is possibly related to the smaller foliar area, (Figure 7C). The response surface methodology (Figures 7A, 7B, and 7C) involves three aspects: design, model, and optimization technique. Design and model depend on the type of behavior expected in the response. The optimization aspect is formed by some mathematical techniques that given an adequate model in order to obtain information about the optimal points of a given interaction between factors.

Doses above 2.0 g L^{-1}, instead of providing greater gains for stem height, stem collar diameter, SDM, TDM, and IncD in seedlings of *A. brasiliensis,* as could be expected by many nurserymen, it does not differ statistically from doses requiring a smaller amount of inputs (Tables 2). This fact shows, therefore, a strategic way of minimizing operational costs of seedling production without leaving aside quality standards. Lower means for most of the morphological parameters of seedlings quality were also found by Melo et al. (2018), when using 30 cm^3 and 55 cm^3 recipients compared to 110, 180, and 280 cm^3, in the production of *Mimosa caesalpiniifolia*.

Height is an important parameter, especially when seedlings are planted in areas colonized by spontaneous plants, under strong competition for light (Aguilar et al., 2020). The variation in stem height can be related Osmocote® that provides a regular supply of nutrients, which favors development. Pias et al. (2015), testing different recipient volumes, also found larger stem collar diameter dimensions of seedlings produced in larger recipients and with Osmocote®, explaining the higher IncD for doses up to a certain maximum value, from which it tends to decline.

Stem collar diameter indicates seedling's robustness and it is directly related to survival and initial performance after field planting. Once observing post-transplant of *A. brasiliensis* seedlings, growth was influenced by the different CRF doses, recipient volume, and time after transplant, both for the variables stem height, stem collar diameter, and RI. Therefore, the dose of 2.0 g L^{-1} allowed greater growth in height and diameter at 240 DAT. Concerning robustness, a similar result of this study (Table 3) was obtained by Berghetti et al. (2016), with *Cordia trichotoma* seedlings, a significant difference in RI was found only for recipient size (110 cm^3 and 180 cm^3) 210 days after sowing. CRF was able to supply the species nutritional demands through the evaluated period, which was showed as the absence of statistical difference between 1.8 L and 2.2 L recipients for DQI (Table 3). *Ceiba speciosa* in 93 days also did not present differences in growth between small (110 cm^3) and large (180 cm^3) recipients (Lima Filho et al., 2019). The fact that different CRF doses and recipient volumes presented positive effects on the quality of *A. brasiliensis* seedlings corroborates the hypotheses raised in this work.

5. Conclusion

The controlled release fertilizer (CRF) Osmocote® had positive influence on growth of *Agonandra brasiliensis* seedlings. Volumes of 1.8 L and 2.2 L recipients did not influence the Dickson quality index of *A. brasiliensis* seedlings. The highest growth of *A. brasiliensis* seedlings was obtained with the use of the CRF Osmocote® equal to 2.0 g L^{-1} and 2.2 L recipients.

Since there were no differences between the 1.8 L and 2.2 L recipient sizes in the Dickson quality index of *A. brasiliensis* seedlings, future studies could test the use of the CRF Osmocote® at the dose 2.0 g L^{-1} in smaller recipients. Recipients smaller than 1.0 L demand much less substrate, which results in reduced cost to produce seelings of *A. brasiliensis* or other species with no quality losses.

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