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Scientific Article

THE EFFECT OF THE TUBE VOLUME AND ALTERNATIVE SUBSTRATES ON THE PRODUCTION OF NATIVE SEEDLINGS

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ABSTRACT

The production of seedlings of fast-growing native species in unfavorable areas is essential for the ecological restoration, making it crucial to evaluate the responses of these species to different substrate compositions and tube sizes to optimize the seedling production. Thus, the objective was to evaluate the seedling production of *Vernonia polyanthes* Less., *Solanum paniculatum* L., *Baccharis dracunculifolia* DC. and *Solanum lycocarpum* St. Hil. using different substrate compositions and tube volumes. Three substrate formulations were evaluated, consisting of commercial substrate, coconut fiber, carbonized rice husk, and cattle manure in different proportions, combined with two tube volumes (55 and 110 cm³). The experiment followed a randomized block design with treatments arranged in a 3 × 2 factorial scheme (substrates × tube volumes). The seedlings were assessed by measuring height, stem diameter, and dry matter, in addition to calculating the height/diameter ratio, shoot-to-root ratio, and Dickson quality index. Superior results were obtained with the 110 cm³ tube compared to the 55 cm³ tube, the seedlings of *V. polyanthes*, *S. paniculatum*, *B. dracunculifolia*, and *S. lycocarpum* achieved Dickson Quality Index (DQI) averages of 0.97, 2.12, 0.37, and 2.01, respectively. The substrate composition distinctly influenced the development of each species. For *S. paniculatum*, any of the tested substrates proved suitable, whereas for *V. polyanthes* and *B. dracunculifolia*, a substrate containing 15% cattle manure was more favorable. In contrast, *S. lycocarpum* performed best with 30% cattle manure. It is concluded that high-quality seedlings of the four studied species can be produced using 110 cm³ tubes and alternative substrates.

Keywords: Ecological restoration; Dickson quality index; Silviculture

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EFEITO DO VOLUME DE TUBETE E SUBSTRATOS ALTERNATIVOS NA PRODUÇÃO DE MUDAS NATIVAS

RESUMO A produção de mudas de espécies nativas com rápido desenvolvimento em áreas desfavoráveis é essencial para a restauração ecológica, tornando-se crucial avaliar as respostas dessas espécies em diferentes substratos e dimensões de recipientes para aprimorar a produção de mudas. Assim, objetivou-se avaliar a produção de mudas de *Vernonia polyanthes* Less., *Solanum paniculatum* L., *Baccharis dracunculifolia* DC. e *Solanum lycocarpum* St. Hil. sob diferentes composições de substrato e volumes de tubetes. Foram avaliados três substratos, compostos por substrato comercial, fibra de coco, casca de arroz carbonizada e esterco bovino em diferentes proporções, dispostos em dois volumes de tubetes (55 e 110 cm³). O delineamento experimental foi em blocos casualizados, com os tratamentos dispostos em esquema fatorial 3 x 2 (substratos x tubetes). As mudas foram avaliadas por meio da mensuração da altura, do diâmetro do coleto e da matéria seca, além do cálculo da relação altura/diâmetro, relação parte aérea/raiz e índice de qualidade de Dickson. Resultados superiores foram obtidos no tubete de 110 cm³ em comparação ao de 55 cm³, onde as mudas de *V. polyanthes*, *S. paniculatum*, *B. dracunculifolia* e *S. lycocarpum* obtiveram médias do IQD de 0,97, 2,12, 0,37 e 2,01 respectivamente. A composição do substrato influenciou de forma distinta o desenvolvimento das mudas de cada espécie. Para *S. paniculatum*, qualquer um dos substratos avaliados pode ser utilizado, enquanto para *V. polyanthes* e *B. dracunculifolia* 15 % de esterco bovino e para *S. lycocarpum* 30 %. Conclui-se que é possível produzir mudas de qualidade das quatro espécies estudadas utilizando-se tubetes de 110 cm³ e substratos alternativos.

Palavras-Chave: Restauração ecológica; Índice de qualidade de Dickson; Silvicultura

1. INTRODUCTION

The United Nations General Assembly declared the United Nations Decade on Ecosystem Restoration 2021-2030, aiming to encourage political leaders, the private sector, and the civil society to take actions to restore the 170 million hectares of degraded areas worldwide (United Nations - UN, 2019). In this scenario, the demand for native species seedlings, which are essential to meet the global restoration goals, is growing (Rodrigues et al., 2020). The production of high-quality seedlings, with attributes such as height, stem diameter, and well-developed root mass, is essential for successful field establishment, as these factors favor overcoming post-planting stress and initiating more vigorous growth (Grossnickle & MacDonald, 2018).

One of the main challenges faced by newly planted seedlings is the competition from already established herbaceous vegetation, especially aggressive exotic grasses (Rugemalila et al., 2024). The high density of these invasive species can intensify competition for light, water, and nutrients, significantly hindering the establishment and the growth of native species (Michelan et al., 2018), which reinforces the importance of using robust and well-developed seedlings. In addition to biotic factors, environmental conditions and silvicultural practices also directly influence the time required for establishment and the costs involved in forest restoration projects (Lima Filho et al., 2019).

In this context, adopting strategies that promote the production of quality seedlings at an affordable cost becomes essential to enable large-scale restoration initiatives. One such strategy is incorporating organic and/or industrial waste into the production process to reduce costs and reuse materials that would otherwise be discarded. The use of components such as cattle manure, carbonized rice husks, and coconut fiber represents a viable and sustainable alternative, as these materials are widely available and show good results in seedling formation (Carneiro & Vieira, 2020; Cardozo & Neto, 2021; Vieira et al., 2019). However, it is important to consider that different species may react differently to substrate compositions and the types of containers used, such as tubes of different volumes. Larger tubes require higher input costs; on the other hand, smaller tubes can restrict the seedling growth, which can directly impact the growth and the quality of the seedlings produced (Rodrigues et al., 2021).

Therefore, it is essential to identify native species that not only respond positively to these alternative inputs but also exhibit rapid growth in nurseries and perform well in unfavorable areas, potentially offering greater security for the demand required for ecological restoration. Species such as *Vernonia polyanthes* Less. (assa-peixe), *Solanum paniculatum* L. (jurubeba), *Baccharis dracunculifolia* DC. (alecrim do campo), and *Solanum lycocarpum* St. Hil. (lobeira) are found in areas undergoing natural regeneration and in areas affected by human activity, characterizing them as important colonizers of degraded areas. This highlights the importance of obtaining knowledge about the production, growth, and quality of their seedlings. Thus, this study aimed to evaluate the production of *V. polyanthes*, *S. paniculatum*, *B. dracunculifolia* and *S. lycocarpum* seedlings under different substrate compositions and tube volumes.

2. MATERIAL AND METHODS

The study was conducted at the Forest Nursery of the Federal University of Lavras (UFLA), located in the municipality of Lavras, Minas Gerais state, at 21°13'S and 44°58'W, at an altitude of 913 meters. The climate is Cwa, a rainy temperate (mesothermal) climate with a dry winter and a rainy summer (Alvares et al., 2013) (Figure 1).

The seedling production was carried out using the species *V. polyanthes*, *S. paniculatum*, *B. dracunculifolia*, and *S. lycocarpum*. The seeds used in seedling production came from mother trees located in the municipalities of Lavras and Ijaci, Minas

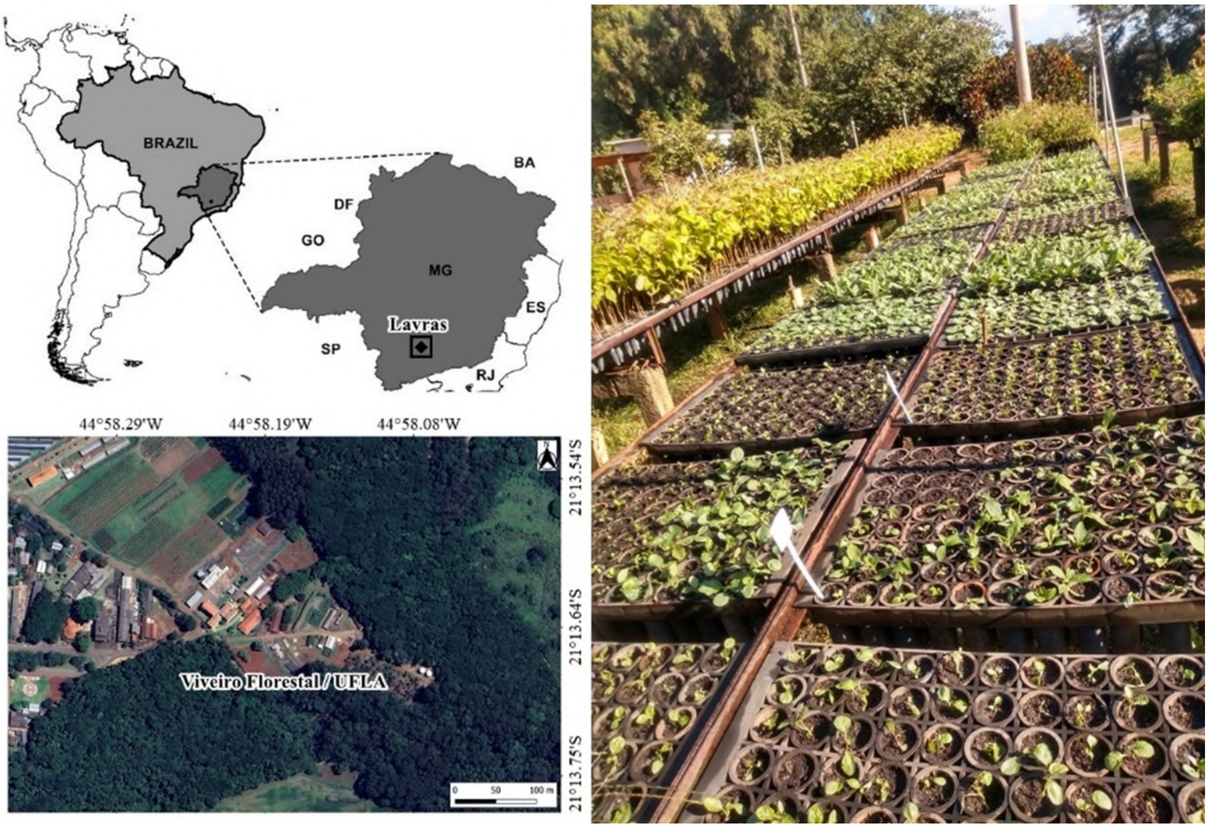

Figure 1. Location map of the Forest Nursery of the Federal University of Lavras, where the experiment was developed and the test beds installed (Source: The author, 2025)

Figura 1. Mapa de localização do Viveiro Florestal da Universidade Federal de Lavras, onde foi desenvolvido o experimento e canteiros com os testes instalados (Fonte: Da autora, 2025)

Gerais state. The *V. polyanthes* and *B. dracunculifolia* seeds were manually removed from the fruits, and 1.00 mm mesh sieves were used to remove impurities. For the species *S. paniculatum* and *S. lycocarpum*, the fruits were rubbed through 1.00 mm and 4.76 mm sieves, respectively, and the seeds were washed in running water until all residue was removed.

The seeds were then sown directly into the tubes, placing two *S. paniculatum* seeds and four *S. lycocarpum* seeds per tube. For *V. polyanthes* and *B. dracunculifolia*, approximately 0.034 g and 0.056 g were used, corresponding to 105 and 60 seeds, respectively, per tube, due to their seed size. The seeds were covered with a thin layer of commercial substrate to prevent them from being blown away by the wind. The tubes were placed in full sun, with automatic irrigation five times a day, using a daily depth of 8 mm. The sowing took place in March 2022, and after 20 days, the thinning was carried out, leaving only one plant per tube.

Two tube volumes (55 cm³ and 110 cm³) and three substrate compositions were evaluated, with the addition of 3 kg m³ of 8-month slow-release Osmocote Plus 15-9-12 fertilizer to each composition (Table 1). The seedling growth was assessed 120 days after sowing using the variables height (H), measured with a millimeter ruler, and stem diameter (SD), measured with a digital caliper with 0.01 mm precision. The height-to-stem diameter ratio (HDR) was calculated from the data obtained.

Table 1. Volumetric proportion (%) of the components used for the formulation of the substrates utilized in seedling production
Tabela 1. Proporção (%) volumétrica dos componentes utilizados para a formulação dos substratos utilizados na produção das mudas

Substrate/composition	CS	CF	CRH	CM
1	50	30	20	0
2	35	30	20	15
3	20	30	20	30

CS: Commercial substrate: 85% composted Pinus bark; 10% vermiculite; 5% carbonized rice husk, enriched with NPK (Maxfertil). CF: Coconut fiber; CRH: Carbonized rice husk; CM: Aged cattle manure. (Source: Author, 2025)
SC: Substrato comercial: 85% de cascas de Pinus compostada; 10% de vermiculita; 5% de cascas carbonizadas de arroz e aditivado com NPK (Maxfertil); FC: Fibra de coco; CA: Casca de arroz carbonizada; EB: Esterco bovino curtido. (Fonte: Da autora, 2025)

The seedling biomass was determined using dry matter, using four seedlings per plot. The shoots and roots of the seedlings were separated, and the parts were placed in kraft paper bags and incubated at 65°C until they reached constant weight. From the collected data, shoot dry matter (SDM), root dry matter (RDM), total dry matter (TDM) and the ratio of SDM to RDM were measured (APRR). The seedling quality was determined using the Dickson Quality Index (DQI) (Dickson et al., 1960) (Equation 1).

$$DQI = \frac{\text{TDM (g)}}{\left(\frac{\text{H (cm)}}{\text{SD (mm)}}\right) + \left(\frac{\text{SDM (g)}}{\text{RDM (g)}}\right)} \quad \text{(Eq. 1)}$$

Where:
TDM (g) = total dry matter;
H (cm) = height;
SD (mm) = stem diameter;
SDM (g) = shoot dry matter; and
RDM(g) = root dry matter.

The experimental design was a randomized complete block design (RBD) with four replicates and 24 plants per plot. The treatments were arranged in a 3 x 2 factorial scheme (substrates x tube volumes) for each species individually. The data were initially subjected to assumption analysis, with the normality of the residuals being verified by the Shapiro-Wilk test ($p > 0.05$) and the homogeneity of variances by the

Bartlett test ($p > 0.05$). Once the assumptions were met, analysis of variance (ANOVA) was performed, and in case of significance ($p \leq 0.05$), the means were compared by the Tukey test at 5% probability, using RStudio software version 4.2.2 (R Core Team, 2022) applying the easyanova package (Arnhold, 2022).

3. RESULTS

Through analysis of variance (ANOVA), a significant interaction was observed between the factors, tube volumes, and substrates for the SD variable ($p = 0.0301$) of the species *V. polyanthes*. For the other variables Height (H) and Height and Diameter Ratio (HDR), a significant difference was observed only between the tube volumes. The seedlings produced in the 110 cm³ tube had higher H when compared to the seedlings produced in the 55 cm³ tube. Lower means were also observed for the SD variable in seedlings produced in the 55 cm³ tube containing substrate 2 when compared to those produced with the 110 cm³ tube. For the HDR variable, the highest means were observed in the 110 cm³ tube, regardless of the substrate used (Table 2).

Table 2. Growth parameters, dry matter, and Dickson Quality Index (DQI) of seedlings evaluated for the specie *Vernonia polyanthes*

Tabela 2. Parâmetros de crescimento, matéria seca e Índice de Qualidade de Dickson (IQD) de mudas avaliados para a espécie *Vernonia polyanthes*

		Tube (cm³)		
	Substrate	**55**	**110**	**Mean**
Height (H) (cm)	1	17,75 Ba*	24,78 Aa	21,26 a
	2	14,04 Ba	22,38 Aa	18,21 a
	3	15,57 Ba	22,52 Aa	19,04 a
	Mean	15,78 B	23,22 A	
Stem diameter (SD) (mm)	1	6,67 Aa	6,06 Aa	6,37 a
	2	6,06 Ba	6,89 Aa	6,47 a
	3	6,43 Aa	6,65 Aa	6,54 a
	Mean	6,38 A	6,53A	
Ratio H/SD (HDR)	1	2,61 Ba	3,87 Aa	3,24 a
	2	2,25 Ba	3,18 Aa	2,72 a
	3	2,39 Ba	3,28 Aa	2,83 a
	Mean	2,41 B	3,44 A	
SDM(g)	1	3,69 Aa	3,91 Aa	3,80 a
	2	2,95 Ba	4,53 Aa	3,74 a
	3	3,12 Aa	4,08 Aa	3,60 a
	Mean	3,25 B	4,17 A	
RDM (g)	1	0,74 Ba	1,28 Ab	1,01 b
	2	0,96 Ba	2,07 Aa	1,52 a
	3	0,88 Ba	1,66 Aab	1,27 ab
	Mean	0,86 B	1,67 A	
TDM (g)	1	4,44 Aa	5,20 Aa	4,82 a
	2	3,91 Ba	6,61 Aa	5,26 a
	3	4,00 Aa	5,75 Aa	4,87 a
	Mean	4,12 B	5,85 A	

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	Tube (cm³)			
	Substrate	55	110	Mean
SDM/RDM (APRR)	1	4,96 Aa	2,91 Aa	3,93 a
	2	5,87 Aa	2,16 Aa	4,01 a
	3	3,61 Aa	2,40 Aa	3,01 a
	Mean	4,81 A	2,49 B	
DQI	1	0,58 Aa	0,71 Ab	0,65 b
	2	0,70 Ba	1,21 Aa	0,95 a
	3	0,66 Ba	0,98 Aab	0,82 ab
	Mean	0,64 B	0,97 A	

*Means followed by the same uppercase letters in the rows (comparison of tube volume) or lowercase letters in the columns (comparison of substrates) for each analyzed variable do not differ according to Tukey test at a 5% probability level. (Source: Author, 2025)
*Médias seguidas pelas mesmas letras maiúsculas nas linhas (comparação de volume do tubete), ou letras minúsculas nas colunas (comparação dos substratos), para cada variável analisada, não diferem pelo teste de Tukey ao nível de 5% de probabilidade de erro. (Fonte: Da autora, 2025)

When analyzing the dry matter and quality index (DQI) of *V. polyanthes* seedlings, there was no significant interaction between the factors, only significant differences between the factors alone. Lower averages were observed in seedlings produced in the 55 cm³ tube using substrate 2 for the variables SDM and TDM, and for the DQI variable, substrates 2 and 3. Seedlings produced in the 110 cm³ tube showed higher averages for RDM and DQI when produced with substrate 2 (Table 2).

S. paniculatum showed significant differences between tube volumes for the variables H, SD, and HDR, with seedlings produced in the 110 cm³ tube having higher H when compared to seedlings produced in the 55 cm³ tube. Lower averages were observed for the variable SD, in seedlings produced in the 55 cm³ tube containing substrate 1 and for the variable HDR with substrates 1 and 3. No significant interaction was observed between the factors of the average dry matter and DQI. However, higher averages were observed in the variables SDM, RDM, TDM and DQI and a lower average for the Aerial Part and Root Ratio (APRR) of the seedlings produced with the 110 cm³ tube (Table 3).

For the *B. dracunculifolia* species, no significant interaction was observed between the factors, nor was there a statistical difference between tube and substrate volumes for the variables H, SD, and HDR.

Table 3. Growth parameters, dry matter, and Dickson Quality Index (DQI) of seedlings evaluated for the specie *Solanum paniculatum*
Tabela 3. Parâmetros de crescimento, matéria seca e Índice de Qualidade de Dickson (IQD) de mudas avaliados para a espécie *Solanum paniculatum*

	Tube (cm³)			
	Substrate	55	110	Mean
Height (H) (cm)	1	12,17 Ba*	21,44 Aa	16,80 a
	2	15,05 Ba	19,77 Aa	17,41 a
	3	14,26 Ba	19,57 Aa	16,91 a
	Mean	13,83 B	20,26 A	

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		Tube (cm³)		
	Substrate	**55**	**110**	**Mean**
Stem diameter (SD) (mm)	1	7,78 Ba	8,79 Aa	8,29 a
	2	8,06 Aa	8,70 Aa	8,38 a
	3	8,60 Aa	8,85 Aa	8,72 a
	Mean	8,15 B	8,78 A	
Ratio H/SD (HDR)	1	1,54 Ba	2,43 Aa	1,99 a
	2	1,86 Aa	2,26 Aa	2,06 a
	3	1,65 Ba	2,22 Aa	1,93 a
	Mean	1,69 B	2,30 A	
SDM (g)	1	4,35 Ba	6,86 Aa	5,61 a
	2	4,77 Ba	6,59 Aa	5,68 a
	3	5,23 Ba	6,17 Aa	5,70 a
	Mean	4,78 B	6,54 A	
RDM (g)	1	1,80 Ba	3,04 Aa	2,42 a
	2	2,07 Ba	3,01 Aa	2,54 a
	3	2,08 Ba	2,89 Aa	2,49 a
	Mean	1,98 B	2,98 A	
TDM (g)	1	6,15 Ba	9,9 Aa	8,03 a
	2	6,85 Ba	9,61 Aa	8,23 a
	3	7,32 Ba	9,07 Aa	8,19 a
	Mean	6,77 B	9,53 A	
SDM/RDM (APRR)	1	2,40 Aa	2,26 Aa	2,33 a
	2	2,30 Aa	2,20 Aa	2,25 a
	3	2,52 Aa	2,15 Ba	2,34 a
	Mean	2,41 A	2,20 B	
DQI	1	1,54 Ba	2,11 Aa	1,82 a
	2	1,65 Ba	2,16 Aa	1,90 a
	3	1,75 Ba	2,09 Aa	1,92 a
	Mean	1,65 B	2,12 A	

*Means followed by the same uppercase letters in the rows (comparison of tube volume) or lowercase letters in the columns (comparison of substrates) for each analyzed variable do not differ according to Tukey test at a 5% probability level. (Source: Author, 2025)
*Médias seguidas pelas mesmas letras maiúsculas nas linhas (comparação de volume do tubete), ou letras minúsculas nas colunas (comparação dos substratos), para cada variável analisada, não diferem pelo teste de Tukey ao nível de 5% de probabilidade de erro. (Fonte: Da autora, 2025)

However, a significant difference was observed between tube volumes for the variables dry mass and DQI, with higher values for seedlings produced in the 110 cm³ tube using substrates 1 and 2 for the variables SDM, TDM, and DQI, while for the variable RDM using only substrate 2 (Table 4)

S. lycocarpum seedlings produced in the 110 cm³ tube with substrates 1 and 3 obtained significantly higher averages for the variables H and HDR when compared to those produced with the 55 cm³ tube. For the variable SD, the 110 cm³ tube combined with substrate 3 produced seedlings with larger diameters. In the analysis of seedling dry

Table 4. Growth parameters, dry matter, and Dickson Quality Index (DQI) of seedlings evaluated for the specie *Baccharis dracunculifolia*

Tabela 4. Parâmetros de crescimento, matéria seca e Índice de Qualidade de Dickson (IQD) de mudas avaliados para a espécie *Baccharis dracunculifolia*

		Tube (cm³)		
	Substrate	**55**	**110**	**Mean**
Height (H) (cm)	1	20,64 Aa*	23,23 Aa	21,94 a
	2	19,81 Aa	21,38 Aa	20,60 a
	3	20,67 Aa	20,71 Aa	20,69 a
	Mean	20,37 A	21,78 A	
Stem diameter (SD) (mm)	1	3,45 Aa	3,81 Aa	3,63 a
	2	3,43 Aa	3,41 Aa	3,42 a
	3	3,5 Aa	3,42 Aa	3,46 a
	Mean	3,46 A	3,55 A	
Ratio H/SD (HDR)	1	5,95 Aa	6,11 Aa	6,03 a
	2	5,78 Aa	6,23 Aa	6,01 a
	3	5,89 Aa	6,05 Aa	5,97 a
	Mean	5,88 A	6,13 A	
SDM (g)	1	2,21 Ba	3,28 Aa	2,74 a
	2	2,04 Ba	2,97 Aa	2,50 a
	3	2,15 Aa	2,88 Aa	2,52 a
	Mean	2,13 B	3,04 A	
RDM (g)	1	0,61 Aa	0,82 Aa	0,71 a
	2	0,52 Ba	0,74 Aa	0,63 a
	3	0,62 Aa	0,71 Aa	0,66 a
	Mean	0,58 B	0,76 A	
TDM (g)		2,82 Ba	4,11 Aa	3,46 a
	2	2,56 Ba	3,72 Aa	3,14 a
	3	2,77 Aa	3,60 Aa	3,19 a
	Mean	2,72 B	3,81 A	
SDM/RDM (APRR)	1	3,65 Aa	4,03 Aa	3,84 a
	2	3,95 Aa	4,00 Aa	3,97 a
	3	3,5 Aa	4,24 Aa	3,87 a
	Mean	3,70 A	4,09 A	
DQI	1	0,29 Ba	0,40 Aa	0,34 a
	2	0,26 Ba	0,36 Aa	0,31 a
	3	0,29 Aa	0,35 Aa	0,32 a
	Mean	0,28 B	0,37 A	

*Means followed by the same uppercase letters in the rows (comparison of tube volume) or lowercase letters in the columns (comparison of substrates) for each analyzed variable do not differ according to Tukey test at a 5% probability level. (Source: Author, 2025)

*Médias seguidas pelas mesmas letras maiúsculas nas linhas (comparação de volume do tubete), ou letras minúsculas nas colunas (comparação dos substratos), para cada variável analisada, não diferem pelo teste de Tukey ao nível de 5% de probabilidade de erro. (Fonte: Da autora, 2025) matter and quality index (DQI), a significant interaction between the tube volumes and substrates was observed only for the APRR variable (p = 0.0263). A significant difference was observed in the means of seedlings produced in the 110 cm³ tube using substrates 1 and 3, where they achieved higher values for the variables SDM and RDM. In the DQI, this difference was found only using substrate 3. Furthermore, substrate 2 in the 110 cm³ tube demonstrated lower values for SDM, RDM, and TDM compared to the other substrates in the same tube volume (Table 5).

Table 5. Growth parameters, dry matter, and Dickson Quality Index (DQI) of seedlings evaluated for the specie *Solanum lycocarpum*
Tabela 5. Parâmetros de crescimento, matéria seca e Índice de Qualidade de Dickson (IQD) de mudas avaliados para a espécie *Solanum lycocarpum*

		Tube (cm³)		
	Substrate	**55**	**110**	**Mean**
Height (H) (cm)	1	8,27 Ba*	11,56 Aa	9,91 a
	2	6,08 Aa	8,22 Ab	7,15 b
	3	6,13 Ba	10,17 Aab	8,15 ab
	Mean	6,83 B	9,98 A	
Stem diameter (SD) (mm)	1	6,31 Aa	6,55 Aa	6,43 a
	2	5,85 Aa	6,25 Aa	6,05 a
	3	5,61 Ba	6,89 Aa	6,25 a
	Mean	5,93 B	6,56 A	
Ratio H/SD (HDR)	1	1,30 Ba	1,76 Aa	1,53 a
	2	1,04 Aa	1,28 Ab	1,16 b
	3	1,06 Ba	1,47 Aab	1,27 ab
	Mean	1,13 B	1,50 A	
SDM (g)	1	1,52 Ba	2,36 Aa	1,94 a
	2	1,39 Aa	1,81 Ab	1,60 a
	3	1,23 Ba	2,39 Aa	1,81 a
	Mean	1,38 B	2,18 A	
RDM (g)	1	1,41 Ba	2,73 Aab	2,07 a
	2	1,49 Aa	2,01 Ab	1,75 a
	3	1,32 Ba	2,95 Aa	2,13 a
	Mean	1,40 B	2,56 A	
TDM (g)	1	2,94 Ba	5,09 Aa	4,02 a
	2	2,88 Ba	3,82 Ab	3,35 a
	3	2,55 Ba	5,34 Aa	3,94 a
	Mean	2,79 B	4,75 A	
SDM/RDM (APRR)	1	1,11 Aa	0,87 Aa	0,99 a
	2	0,94 Aa	0,9 Aa	0,92 a
	3	0,97 Aa	0,82 Aa	0,89 a
	Mean	1,01 A	0,86 A	

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	Tube (cm³)			
	Substrate	55	110	Mean
DQI	1	1,31 Aa	1,94 Aa	1,63 a
	2	1,46 Aa	1,75 Aa	1,60 a
	3	1,30 Ba	2,36 Aa	1,83 a
	Mean	1,36 B	2,01 A	

*Means followed by the same uppercase letters in the rows (comparison of tube volume) or lowercase letters in the columns (comparison of substrates) for each analyzed variable do not differ according to Tukey test at a 5% probability level. (Source: Author, 2025)
*Médias seguidas pelas mesmas letras maiúsculas nas linhas (comparação de volume do tubete), ou letras minúsculas nas colunas (comparação dos substratos), para cada variável analisada, não diferem pelo teste de Tukey ao nível de 5% de probabilidade de erro. (Fonte: Da autora, 2025)

4. DISCUSSION

The size of the seedlings produced in the nursery is an important component for the success of a forest restoration project because it allows access to light in areas with fast-growing grasses (Oliet et al., 2019). In the present study, *V. polyanthes* and *S. paniculatum* seedlings produced in 110 cm³ tubes presented higher H when compared to seedlings produced in 55 cm³ tubes (Tables 2 and 3). Similar results were found by Navroski et al. (2017), where *Eucalyptus dunnii* Maiden seedlings grown in 110 cm³ tubes presented greater development for all analyzed variables when compared to 55 cm³ tubes. In addition, a smaller amount of fertilizer was required to obtain maximum technical efficiency. Similarly, limitations in the tube dimensions caused losses in growth, biomass production, and quality of *Coffea canephora* Pierre ex. Froehner seedlings (Verdin Filho et al., 2021).

The use of smaller containers is an alternative to reduce space and production costs. However, they require greater care, mainly due to reduced water retention in the substrate and nutrient availability (Melo et al., 2018). When these needs are not met, they can restrict the plant growth (Kul et al., 2021). Thus, understanding the relationship between spatial and material costs and the return on seedling quality is essential for optimizing and maintaining this silvicultural activity (Kim et al., 2021).

In the HDR variable, *S. paniculatum* seedlings produced with substrates 1 and 3 in the 110 cm³ tube showed higher averages compared to those produced in the 55 cm³ tube, while for *V. polyanthes*, the seedlings produced with the 110 cm³ tube showed higher averages using any of the substrates tested (Tables 2 and 3). These results suggest that, although seedlings grown in the larger container (110 cm³) showed greater height growth, the root system development did not follow the height, resulting in an increase in HDR. This factor requires attention, as seedlings with a high height-to-diameter ratio tend to be more fragile, with a greater risk of toppling and less resistance to post-planting stress. Birchler et al. (1998) recommend that the index in forest species should be less than 10 for the seedling to present high quality, that is, a high growth rate and survival after planting. So, despite higher averages with the 110 cm³ tube, the averages are within the recommended range.

V. polyanthes seedlings produced with the 55 cm³ tube associated with substrate 2 showed lower averages for the variables SD, SDM, and TDM, and for the variable DQI, for substrates 2 and 3. However, the seedlings produced in the 110 cm³ tube showed better averages for RDM and DQI when produced with substrate 2 (Table 2). This result reinforces the importance of using a larger-volume container, which allows more space for the root system growth and better substrate exploration, favoring biomass accumulation and morphological balance of the seedling (Dionísio et al., 2021). These characteristics are fundamental for the survival and the initial performance after planting, especially in degraded environments or with competition for resources. The substrate selection is a complex task and should be based on factors such as a regional availability, price, and agronomic feasibility for the production of high-quality seedlings (Pascual et al., 2018). Therefore, the interaction between the type of substrate and the volume of the container must be carefully analyzed for each species, seeking to optimize the quality of the seedlings produced and, consequently, increase the chances of success in the implementation of ecological restoration projects.

Substrate 2 has the most balanced proportion among the materials used in this study. However, in the 55 cm³ tube, this substrate did not perform well, possibly due to the limited volume available for root growth. The smaller space may have restricted water and nutrient absorption, compromising the seedling development. In the 110 cm³ tube, the larger volume of substrate allowed for better utilization of the nutrients present, favoring the seedling development. Larger volume tubes not only provide better seedling development but also allow the seedlings to remain in the nursery longer. Schorn et al. (2019), when producing *Araucaria angustifolia* (Bertol.) Kuntze seedlings, found that the appropriate ages for seedling shipment, considering their quality, depend on the volume of tubes and, thus, the amount of substrate available to the seedlings. These results reinforce the importance of considering not only the substrate composition but also the interaction between the substrate type and the container volume to optimize the seedling quality.

Higher averages were found in seedlings produced in 110 cm³ tubes using substrates 1 and 3 for the species *S. lycocarpum* (Table 5). However, these substrates differ in the concentration of CS (comercial substrate) and CM (cattle manure) used. While substrate 1 has no CM in its composition and 50% CS, substrate 3 has the highest CM concentration evaluated in the study (30%) and only 20% CS. Rezende et al. (2023) found higher absolute averages for most morphological growth characteristics of *Handroanthus chrysotrichus* (Mart. ex DC.) Mattos seedlings with a 91% CS proportion. Conversely, Melo et al. (2014) found high mortality rates in *Eremanthus erythropappus* (DC.) MacLeish seedlings produced in substrates with the highest percentages of cattle manure tested (60% and 90%). Therefore, it is noteworthy that the combination of compounds can affect the physical and chemical properties of the substrate, and that organic materials, such as manure, despite improving aeration, porosity, and particle aggregation, can have adverse effects on seedlings. Therefore, selecting the correct substrate composition will result in greater production savings and will increase the plant productivity (Bastos et al., 2023).

Besides that, substrates must meet the chemical, physical, and microbiological needs of each species. Given the costs of commercial substrates, the formulation of alternative and sustainable substrates is essential (Fiorin et al., 2022; Aires et al., 2020). A viable alternative for forest seedling production is the use of organic waste, a rich source of mineralized organic matter and essential nutrients for plant development (Pelloso et al., 2020). Agroindustrial byproducts provide good substrate attributes, such as carbonized rice husk, which provides a good amount of silicon and has a conditioning effect on the substrate (Li et al., 2023; Costa et al., 2023); coconut fiber, which has high porosity and water retention capacity (Zorzeto et al., 2014); and cattle manure, which provides high levels of nitrogen, ammonium, and potassium (Eckhardt et al., 2021). These materials were all used in this study. However, the combination of these products should be tested to meet the needs of each species.

The *S. paniculatum* seedlings produced in the 55 cm³ tube using substrate 3 and in any of the substrates evaluated for the species *V. polyanthes* exhibited higher values in the APRR variable than those produced in the 110 cm³ tube (Tables 2 and 3). This relationship should be observed since the upper part of the seedlings should not be significantly larger than the root area, so as not to hinder the absorption and transfer of water to the aerial part (Gomes et al., 2019). According to Afonso et al. (2017), the allocation of plant dry matter should occur proportionally among the plant organs in order to confer greater resistance to adverse environmental conditions. The higher the APRR value, the larger the leaf area, which can lead to imbalance in seedling growth and subsequent damping off, as well as impairing the absorption of water and nutrients (Caldeira et al., 2012). Thus, the results obtained indicate that in addition to not providing such rapid seedling growth, the 55 cm³ tube did not provide adequate distribution between the SDM and RDM.

Regardless of the substrate used, seedlings of the species *S. paniculatum* presented the highest DQI values when produced using the 110 cm³ tube (Table 3), demonstrating that a larger size and, consequently, a greater substrate availability are important for the initial growth of the species. The same finding was found by Silva et al. (2025) in seedlings of *Cordia trichotoma* (Vell.) Arrab. Ex Steud., where the conditions of the larger container (270 cm³) provided better DQI development.

The Dickson Quality Index is a good indicator of seedling quality, since several important morphological characteristics (H, SD, HDR, and APRR) are considered in its calculation. However, the DQI assessment should focus on more than the absolute values obtained for the species studied. It is also essential to consider the individual characteristics that comprise the index, which must meet minimum values to ensure the seedling is considered of high quality. These criteria vary among species, reflecting the differences in their needs and growth patterns (Binotto et al., 2010).

B. dracunculifolia seedlings showed higher values for the variables SDM, TDM, and DQI in the 110 cm³ tube using substrates 1 and 2, while they showed higher values for the RDM variable only using substrate 2 (Table 4). These results indicate that the species develops better in the absence or presence of low concentrations of CM in the substrate composition. A similar result was found by Silva et al. (2023), where lower percentages of cattle manure (20% and 30%) in the substrate composition showed a positive response for the production of *Hymenaea courbaril* L. seedlings, but excess cattle manure caused reduced seedling growth. The high organic matter content ensures a high number of porous spaces, increasing the water retention capacity (Carneiro & Vieira, 2020). However, this characteristic may not be favorable for the growth of *B. dracunculifolia* seedlings.

The seedling quality standards are influenced by species, substrate, nutrition, irrigation, density, and hardening. The operational criterion adopted by most nurseries that produce seedlings in tubes is that seedlings suitable for planting are those with a good root system, with new roots that allow removal from the tube without compromising the integrity of the root ball (Davide et al., 2015). Seedlings of the species *S. paniculatum* and *S. lycocarpum* obtained the highest RDM values found in this study (Tables 3 and 5), which may indicate that vigorous roots are characteristic of the Solanum family. An efficient root system increases the plant ability to explore the soil after transplanting; these seedlings will expand their root systems more easily, ensuring adequate soil exploration, nutrient supply, and water absorption (Matos et al., 2022). These species are found in unfavorable environmental conditions, with compacted and infertile soils (Silva et al., 2016), which may explain their early growth and development, with a vigorous root system capable of overcoming field adversities.

Several studies indicate stem diameter as the most reliable morphological attribute for predicting seedling survival and growth in the field, as it is positively correlated with seedling weight, root system size, and, consequently, robustness. It is considered the main indicator of seedling quality (Gasparin et al., 2014; Getman-Pickering et al., 2021; Grossnickle & MacDonald, 2018; Ivetić et al., 2016). Wendling & Dutra (2017) recommend that *Eucalyptus* seedlings have a minimum diameter of 2 mm for field planting. Although there is still no information on the recommended minimum value for the native seedlings studied, Davide et al. (2015) recommend that 3.0 mm could be considered a minimum standard for all native forest species. The species studied in this study reached this value 120 days after sowing, based on the averages of the two tube volumes and three substrates evaluated, demonstrating potential for the rapid production of quality seedlings.

In the evaluations performed for the variables H and SD, when there were differences between the means, the highest values were obtained in the 110 cm³ tube compared to the 55 cm³ tube for the four species evaluated. These results are consistent with those found in several studies involving native species (Cabreira et al., 2019; Freitas et al., 2022; Zuffo et al., 2018). According to Morais Júnior et al. (2020), the production of native seedlings for restoration planting in degraded areas yields better results when produced in larger containers, as they provide greater availability of nutrients that help stimulate the seedling growths.

The substrate formulation for seedling production must ensure its physical and chemical quality, in addition to providing the nutrients necessary for the seedling development. The organic materials tested were able to provide the nutrients necessary for the seedling development, highlighting that substrates 2 and 3 (15 and 30% cattle manure) obtained higher averages when combined with the 110 cm³ tube. These results corroborate the answer found by Rodrigues et al. (2021), who, producing *Moringa oleifera* Lam. seedlings, found that the substrates that presented the highest proportions of organic compost led to the greatest growth and Dickson quality index.

The success of projects aimed at restoring degraded areas depends on a series of environmental factors, especially local soil and climate conditions. However, one of the elements under the forester's greatest control is the quality of the seedlings used for planting, since selecting seedlings with appropriate morphophysiological attributes significantly increases the chances of establishment and development in impacted environments (Grossnickle & Macdonald, 2018). In this sense, the four species studied performed satisfactorily when produced with alternative substrates, allowing for the production of seedlings of adequate quality within 120 days. The use of tubes with a volume of 110 cm³ is recommended for obtaining more vigorous seedlings. The species *B. dracunculifolia* and *S. paniculatum* performed well in all substrates evaluated, while Substrate 2 was more suitable for *V. polyanthes*, and Substrate 3 for *S. lycocarpum*, when associated with the larger tube. These results reinforce the viability of using alternative inputs in the production of native seedlings and highlight the importance of continuing studies focused on the performance of these species under field conditions, aiming at their practical application in environmental restoration strategies.

5. CONCLUSION

It is concluded that substrates composed of coconut fiber, carbonized rice husk, and cured cattle manure, combined with 110 cm³ tubes, can be used in the production of *V. polyanthes*, *S. paniculatum*, *B. dracunculifolia*, and *S. lycocarpum* seedlings. Substrate 2 is recommended for the production of *V. polyanthes* seedlings and substrate 3 for *S. lycocarpum*. The species *B. dracunculifolia* and *S. paniculatum* performed well in all tested proportions and can be produced with any of the formulations evaluated in this study. It is also noteworthy that the use of these organic materials is an alternative for managing the agroindustrial waste, generating a byproduct for native seedling producers, contributing to sustainability and cost reduction.

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AUTHOR CONTRIBUTIONS

Souza, A. N.: Conceptualization, Data Curation, Research, Project Administration, Visualization, Writing – Original Draft, Writing – Review & Editing; Melo, L. A.: Conceptualization, Methodology, Validation; Botelho, S. A.: Conceptualization, Project Administration, Supervision, Writing – Review & Editing; Silva Junior, A. L.: Formal Analysis; Cortez, G. G.: Data Curation; Ferreira, M. F.: Data Curation; Souza, L. R.: Data Curation; Negreiros, M. L.: Formal Analysis, Writing – Review & Editing.

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DATA AVAILABILITY

The entire dataset supporting the findings of this study has been published within the article.

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