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Brief Report

Performance of Five Native Atlantic Forest Species Planted in Containers of Different Size for Restoring Degraded Areas in Minas Gerais

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Abstract: Forest restoration in Brazil has gained relevance in the country's environmental agenda, due to the need for forest recovery of large liabilities of existing forests and participation in several international vegetation restoration agreements. However, forest restoration management faces challenges, it being necessary to create a database of species-level performances to increase the success of these projects. The objective was to evaluate the survival and growth of five Atlantic Forest native species (*Anadenanthera macrocarpa*; *Ceiba speciosa*; *Cytharexyllum myrianthum*; *Hymenaea courbaril*; and *Peltophorum dubium*) in plastic bags (1177 cm^3) and tubes (180 cm^3). Ninety seedlings (18 of each species) were planted per container. Plant performance in the field consisted of evaluating the increase in the diameter and height of seedlings of the native forest species. Diameter at soil level (DSL) and plant height (H) were measured at 42 months after transplanting, and the monthly periodic increments (MPI) of the DSL and H were calculated. Plant survival (SV) of seedlings was affected by the type of container, registering the highest SV rates in those planted in plastic bags. *Cytharexyllum myrianthum* and *H. courbaril* presented high SV rates in tubes. The growth rate of the species at 42 months differed according to the containers tested. *Cytharexyllum myrianthum* presented the lowest SV rates (16.7–27.8%), regardless of the container used in this experiment. *Ceiba speciosa* was sensitive to the reduction in size of the container, showing low SV in tubes (27%) compared with plastic bags (61%); i.e., this species did not tolerate conditions with root growth restriction. *Anadenathera macrocarpa* and *H. courbaril* showed no differences in SV, regardless of the container used. The results assist the production of native species of the Atlantic Forest, reinforcing the need to understand performances in the field at the species level.

Keywords: growth; plastic bags; restoration forest; survival; tubes

1. Introduction

The implementation of forest restoration projects is one of the greatest challenges in Brazil. According to the New Forest Code, the country has an environmental liability of 21 million hectares that must be recovered in the next 20 years [1]. In the state of Minas Gerais alone, there are two million hectares to be restored [2]. On the other hand, Brazil signed two international commitments, the Paris Agreement and the Aichi Targets, to guide forest restoration efforts [3,4]. Thus, the country is expected to restore at least 12 million hectares of degraded areas with forests by 2030 [3].

Forest restoration has gained prominence after two major environmental disasters related to the rupture of two mining tailings dams in Minas Gerais, resulting in the need to carry out forest restoration in areas affected by the tailings [5,6]. Therefore, technical and scientific advances in forest management and restoration are necessary for Brazil to successfully achieve its goals for this issue [7]. The major challenge is to develop a consistent theoretical basis for ecological restoration, supported by knowledge of the best conditions for survival and growth at the species level for the plants that are used for this purpose [8]. Unfortunately, forest restoration, in addition to being expensive, requires time to establish consistent indicators on the survival and growth of forest species [9].

The creation of a database of performance at the species level can accelerate the success of forest restoration projects [10]. The production of native forest seedlings in tubes is a current trend, but the use of these containers often does not consider the different inherent growth strategies of the species [11]. For example, small containers may limit the root growth of plants, which may hinder the field adaptability of seedlings [11,12]. However, seedling production in tubes has advantages, such as the vertical friezes that direct the root system, as well as the possibility of automation of the nurseries, improving the ergonomic conditions of the employees [13,14] when compared with seedling production in plastic bags. However, plastic bags are cheap, easily pre-packed and do not need specialized workmanship for conducting production activities [15].

Both tubes and plastic bags have advantages and limitations in their use, which are widely evaluated in nurseries, but the contribution of container type to the field adaptability of seedlings is neglected or poorly studied, and species-level studies are needed to understand the individual behavior of species [14]. Therefore, the objective was to evaluate the survival and growth of seedlings of five native Atlantic Forest tree species propagated in plastic bags (1177 cm^3) and tubes (180 cm^3) in a nursery, as well as their field performance in a degraded area at 42 months after transplanting. The choice of the studied species is justified by the recommendation to use native tree species for forest restoration projects in southeastern Brazil [16]. This study will provide important information regarding the viability of seedlings of several species produced in different containers.

2. Materials and Methods

2.1. Plant Propagation in Nursery

Five native species (*Anadenanthera macrocarpa* (Benth.) Brenan, *Ceiba speciosa* (A. St. Hill) Ravenna, *Citharexylum myrianthum* Cham., *Hymenea courbaril* L. and *Peltophorum dubium* (Spreng.) Taub.) of the Atlantic Forest were propagated in plastic bags (1177 cm^3) and tubes (180 cm^3) in a nursery. Ninety seedlings (18 of each species) were planted per container type (one plant per container), totaling 180 individuals. Substrate formed by clayey subsoil, organic compost and sand, in the volumetric ratio of 6:3:1, was used to fill the containers, and the seedlings were irrigated daily during the nursery stage. Immediately after transplanting the seedlings in the field (experimental planting), the initial diameter at soil level (iDSL) and height (iH) were measured (Table 1). The iDSL was measured in millimeters using a precision digital caliper, and the iH was measured in centimeters with a graduated tape.

Table 1. Initial diameter at soil level (iDSL) in millimeters and height (iH) in centimeters at planting. Means with different letters between containers for each species are statistically different at 95% probability, determined by the Tukey test. ± standard deviation of the mean (n = 18).

Species	Container	iDSL	iH
Anadenanthera macrocarpa	Plastic bags	5.1A ± 1.0	52.6A ± 9.3
	Tubes	4.5A ± 0.8	34.1B ± 7.2
Ceiba speciosa	Plastic bags	13.2A ± 2.3	74.8A ± 18.3
	Tubes	12.1A ± 3.3	44.5B ± 6.6
Citharexylum myrianthum	Plastic bags	9.7A ± 2.2	63.4A ± 5.6
	Tubes	7.3B ± 1.7	23.9B ± 4.8
Hymenaea courbaril	Plastic bags	6.8A ± 1.0	43.3A ± 4.4
	Tubes	5.6A ± 0.9	36.2B ± 4.6
Peltophorum dubium	Plastic bags	8.8A ± 1.3	37.6A ± 6.1
	Tubes	8.4A ± 1.0	25.6B ± 4.8

2.2. Characterization of the Area

Transplanting of seedlings was carried out in an area located in the Open Space of Events of the Federal University of Viçosa (UFV), Viçosa, Minas Gerais, Brazil (20°45′37.62″ S and 42°52′29.59″ W). This area was established in December 2014 and belongs to the Zero Carbon Program of the UFV [17]. The area has an altitude of 708 m, with regional vegetation classified as Semidecidual Seasonal Forest Montana and climate type Cwa (Köppen), i.e., with hot and rainy summers (precipitation surplus of 366 mm) and cold and dry winters (hydric deficit) [18]. During the period of evaluation of the experiment in the field, the accumulated annual precipitation and average annual temperature were 988.1 mm and 20.6 °C, respectively (Table 2).

Table 2. Average annual temperature and accumulated annual precipitation in Viçosa-MG, from implantation to data collection of the experiment.

Period	Temperature (°C)	Precipitation (mm)
2014	20.5	843.4
2015	21	1281.5
2016	20.9	1167.7
2017	20.9	841.1
2018	19.7	807
Averages	20.6	988.1

The topography presents a pedogeomorphological gradient, with dystrophic flat tops with access to colluvial ramps [19].

2.3. Characterization of the Planting

The area where the experiment was implemented was initially covered by *Urochola decumbens*, but it also had some areas with exposed soil. Weed management and control of leaf-cutting ants using glyphosate (Roundup Original, 36% *w*/*v*; Monsanto do Brasil Ltda., São Paulo, Brazil) and formicidal baits (Atta Mex-S, 0.3% *w*/*w* sulfluramide; Unibras Agro Química Ltda., São Paulo, Brazil) were performed. Pits (30 cm in diameter × 30 cm in depth), spaced at 2 × 2 m, were opened using a ground drill. Three hundred grams of P_2O_5 (18-18-18 NPK) was incorporated into the bottom of the pits 20 days before planting. Three cover fertilizations were performed (1, 13 and 25 months after planting), containing 100 g pit^{-1} of 20-5-20 (NPK). Soil chemical analyses were performed 3 years after planting (Table 3) to determine soil fertility during execution of the experiment. Elements such as phosphorus (P) and potassium (K) are important macronutrients for plant physiology. The variables Mg^{+2}, Al^{+3}, H+Al and pH in water are related to cationic load and soil acidity. The index (SB) refers to the sum of exchangeable bases. The indices (t) and (T) are the general and effective cation exchange capacity, and the soil saturation and aluminum indices are represented by (V) and (m), respectively.

Table 3. Soil chemical analysis of the experiment, performed in April 2017.

pH H_2O	**P**	**K**		**V**	**m**
	mg/dm^3	mg/dm^3		%	%
4.46	0.3	18		12	44
Mg^{2+}	**Al^{3+}**	**H+Al**	**SB**	**t**	**T**
cmolc/dm^3	cmolc/dm^3	cmolc/dm^3	cmolc/dm^3	cmolc/dm^3	cmolc/dm^3
0.1	0.5	4.6	0.6	1.1	5.2

Seedlings from the plastic bags and tubes were transplanted in rows, side by side. The experimental design was arranged in randomized blocks, with each row representing one block. Seedlings of the five native species were distributed randomly within each block perpendicularly to the topographic gradient of the terrain.

2.4. Variables Evaluated and Statistics

DSL and H were measured using a precision digital caliper and a graduated rod, respectively, immediately after transplanting in the field and 42 months after transplanting (MAT).

The percentage of survival (SV) of each species was estimated with the equation

$$\mathrm{SV}j = \left(\frac{Nfj}{N0j}\right) \times 100$$

where *Nfj* is the final number of surviving individuals at 42 MAT of the *j*th species and *N0j* is the number of individuals planted of the *j*th species.

The monthly periodic increments (MPI) in DSL was calculated as

$$\mathrm{MPI\ DSL}j = \frac{\left(\frac{\Sigma ji = 1\mathrm{DSL}j}{Nj}\right)}{I}$$

where DSL*j* is the DSL of the *j*th species (mm) at 42 MAT; *Nj* is the number of individuals of the *j*th species; and *I* is the planting age (42 MAT).

The MPI in *H* was calculated as

$$\mathrm{MPI}\ Hj = \frac{\left(\frac{\Sigma ji = 1Hj}{Nj}\right)}{I}$$

where *Hj* is the *H* of individuals of the *j*th species (cm) at 42 MAT; *Nj* is the number of individuals of the *j*th species; and I is the planting age (42 months).

Data of DLS and *H* and their respective MPIs were submitted to ANOVA (for $P < 0.05$). The Tukey test was used for mean comparison (95% confidence level) to test for significant differences between containers within each tree species.

3. Results

3.1. Survival at 42 Months

The type of container influenced the SV rate of the tree species evaluated. The SV of seedlings produced in plastic bags and tubes were 64.4 and 56.7%, respectively. This information can be useful for the practice of forest restoration, because if this set of species is used, the use of plastic bags can optimize the field survival of transplanted seedlings. *Anadenanthera macrocarpa, C. speciosa* and

P. dubium showed higher SV in seedlings produced in plastic bags. However, *C. myrianthum* and *H. courbaril* presented higher rates of SV in seedlings produced in tubes. *Ceiba speciosa* presented the highest differences in SV between plastic bags (61.1%) and tubes (27.8%). *Citharexylum myrianthum* presented the lowest percentages of SV in both types of containers evaluated (Table 4).

Table 4. Percentage of survival (SV), average diameter at soil level in mm (DSL), monthly periodic increments of DSL in mm month^{-1} (MPI), average height in cm (H) and MPI of H in cm month^{-1} (MPI-H) at 42 months after planting. Means with different letters between containers for each species are statistically different at 95% probability, determined by the Tukey test. ± standard deviation of the mean (n = 18).

Specie	Container	SV	DSL	MPI	H	MPI-H
Anadenanthera macrocarpa	Plastic bags	77.8	107.8A ± 66.9	2.4A	486.7A ± 185.4	10.3A
	Tubes	66.7	117.8A ± 98.4	2.7A	468.8A ± 299.6	10.3A
Ceiba speciosa	Plastic bags	61.1	177.1A ± 89.6	3.9A	465.2A ± 216	9.2A
	Tubes	27.8	91.7A ± 41.1	1.9A	214.1B ± 189.3	4.1A
Citharexylum myrianthum	Plastic bags	16.7	69.6A ± 37.9	1.5A	444.4A ± 313.9	8.9A
	Tubes	27.8	50.1A ± 28.8	1.0A	151.8A ± 91.5	3.1A
Hymenaea courbaril	Plastic bags	66.7	64.4A ± 28.1	1.4A	380.8A ± 169.2	8A
	Tubes	72.2	41.5B ± 20.8	0.8B	229.5B ± 129.9	4.9B
Peltophorum dubium	Plastic bags	100	160.7A ± 39.9	3.6A	648.8A ± 155.7	14.6A
	Tubes	88.9	104.2B ± 43.1	2.4B	439.4B ± 186.4	10.1B

3.2. Growth at 42 Months

The parameters DSL, H, MPI and MPI-H showed great variability (according to the standard deviation) between individuals within each species at 42 MAT, regardless of the type of container in which they were propagated in a nursery. Therefore, although MPI and MPI-H were generally greater for seedlings from plastic bags than tubes, there were no differences in the growth of the species evaluated, except for *H. courbaril* and *P. dubium*. The DSL was greater in *H. courbaril* and *P. dubium* from plastic bags than seedlings from tubes, as well as the MPI, at 42 MAT. At this time, the H of the seedlings of all species produced in plastic bags was greater than that of seedlings produced in tubes, except for *A. macrocarpa* and *C. myrianthum*, which presented similar H in both containers. However, the H of *C. myrianthum* had great variability. Finally, the MPI-H followed the same trend observed for MPI-DSL, with clear differences only in *H. courbaril* and *P. dubium* (higher MPI-H for seedlings from plastic bags) (Table 4).

4. Discussion

Tubes offer a higher yield in planting operations compared with other container types and are a more economical alternative [20]. However, according to the results of this study, a deeper knowledge in this regard is necessary to achieve more consistent conclusions. Therefore, detailed studies at the species level focused on determining the volume and container suitable for the production of seedlings are necessary [21,22].

Seedlings produced in tubes with high SV rates (*C. myrianthum* and *H. courbaril*) probably adapted efficiently to the field conditions, presumably due to a greater rusticity and the axomorphic development of the root system of these species [14,23]. The greater rusticity refers to the high intrinsic capacity to tolerate adverse conditions (solar radiation, water deficit and high temperatures) in the field, while the axomorphic development is the growth of a main root that grows in depth and lateral roots that grow horizontally for efficient soil exploration and water absorption. However, the low SV of *C. myrianthum*, regardless of the type of container, requires a better understanding of the adaptability of this species on the site.

Citharexylum myrianthum is adapted to regions of humid plains [24]. Taking into account the dry winter conditions of Viçosa, the area of the Zero Carbon Program undergoes periods of drought (June to September), which could have contributed to the low SV of this species [18]. *Citharexylum myrianthum* does not have the same degree of specialization for water deficits between the trunk and roots, with the roots being more sensitive to drought than the trunk; i.e., this species does not tolerate water deficit conditions, requiring silvicultural treatments, such as those related to the irrigation [25]. The low adaptability of *C. myrianthum* has been corroborated in nearby areas at the site of study [16,26,27]. In addition, the survival rate of this species is reduced as the size of the container decreases [28].

Seedlings from plastic bags presented higher SV, DSL and H, indicating that larger containers promote a greater success for these species. The low volume of containers reduces the availability of water and nutrients for seedlings and, consequently, root system architecture [29]. Contrarily, larger containers provide more space, favoring the length and spatial distribution of the roots [20]. This more voluminous root system has a large number of root apices, responsible for the absorption and transport of water and, mainly, the production of growth regulators [30,31]. This study showed that the SV of *A. macrocarpa*, *C. speciosa* and *P. dubium* can be increased if its propagation is conducted in larger containers. *Enterolobium contortisiliquum* seedlings, produced in plastic bags (1248 cm^3) and larger tubes (280 cm^3), had 100% survival at five months after planting; however, the survival of seedlings from smaller tubes (180 cm^3) decreased [14].

The success of *P. dubium* (high survival rate) may be related to the high phenotypic plasticity, related to high irradiance and low incidence of pests and disease in this species [32–34]. In addition, *P. dubium* is a pioneer species that presents a pronounced growth of the root system and, consequently, develops a larger leaf area and a balanced aerial part [35]. The production of seedlings of *P. dubium* in tubes (180 cm^3) and plastic bags (1177 cm^3) presented satisfactory results, considering the 20% mortality rate accepted for forest restoration projects established in INEA Law N° 89—Rio de Janeiro (2014) [36]. Thus, the use of tubes for the propagation of seedlings of this species may represent a reduction of financial expenses related to production and transportation, among others.

Some species equalize the growth rate of the diameter and height of seedlings from plastic bags and tubes after a certain planting period [37]. However, for the *H. courbaril* and *P. dubium* species, this trend was not verified at 42 MAT, and it can be stated that the volumetric restriction to which these species were submitted in the tubes reduced the growth of the diameter of the seedlings, compared with those from plastic bags. The other species (*A. macrocarpa*, *C. speciosa* and *C. myrianthum*) showed no differences in relation to MPI-DSL, indicating that the volume and container type did not affect the growth rates of these species. Similar results were reported for *E. contortisiliquum* seedlings propagated in containers of different sizes [14].

The highest MPI-H observed in *H. courbaril* and *P. dubium* for seedlings from plastic bags showed that these containers may offer advantages to these species, especially in places where competition is determinant in the success of its adaptation in the field. In addition, seedlings from plastic bags can have higher heights, resulting in higher survival rates and reducing the cost of forest restoration projects [38]. Other forest species have shown similar results to those observed for *P. dubium*, where the highest growth and survival rates were recorded in seedlings propagated in containers with larger dimensions, both in nurseries and in the field [29,39,40].

5. Conclusions

The initial growth and survival rates were higher in seedlings produced in plastic bags (1177 cm^3) than tubes (180 cm^3); i.e., the production of native seedlings for restoration plantations in degraded areas is better when they produce in larger containers.

The field performance of seedlings produced in plastic bags or tubes differed for each species. Regardless of the type of container, the survival of *P. dubium* was within the accepted limits (<80%) for forest restoration projects, while *C. myrianthum* had the lowest survival rates (>30%). *Ceiba speciosa* was sensitive to the reduction of the container size; that is, this species did not tolerate the restriction of the growth of the root system in tubes. Seedlings of *A. macrocarpa* and *H. courbaril*, grown in tubes or plastic bags, showed similar survival and growth rates in the field.

The growth rates of *H. courbaril* and *P. dubium* seedlings were influenced by the container in which they were produced. Therefore, some native tree species can present greater increases in diameter and height if they are produced in larger containers.

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