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ORIGINAL ARTICLE – Silviculture

Production time and container size for *Simarouba amara* Aubl. seedlings

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Abstract

This study aims to determine the effect of nursery production time and container size on the quality standards of production of *Simarouba amara* seedlings based on nursery and field performance. The work was conducted in two phases: evaluation of nursery growth and field performance. A completely randomized design was used in both phases. Three container sizes (55, 180 and 280cm³) and four nursery production times (105, 125, 135 and 145 days) were tested. Height, collar diameter and survival were evaluated. *S. amara* seedlings can be produced in a 180 cm³ container with a maximum nursery production time of 125 days. The quality standard for seedlings corresponds to collar diameter ≥ 4.2 and height ≥ 9.1 cm.

Keywords: Production seedlings, field performance, seedling quality.

1. INTRODUCTION AND OBJECTIVES

The amendments to the Brazilian forest code by the bill 12,651/2012 have modified the criteria for the protection of native vegetation (Brasil, 2012), optimizing the restoration process of altered areas, thus increasing the demand for seeds and seedlings of native species. In Brazil, at least 12 million hectares are expected to be restored by 2030 (Benini & Adeodato, 2017). Obtaining seeds and information for propagation of these species is an obstacle encountered by producers and researchers. To produce large amounts of quality seedlings it is necessary to understand production factors, such as: type and volume of container, substrate, irrigation, light conditions, sowing depth and nursery production time (Mendonça & Souza, 2018).

Selecting container size depends mainly on the species characteristics, its nursery production time and the optimal time for planting in the field (Oliveira et al., 2016; Viana et al., 2008). The size and type of container for seedling production directly influence the development and architecture of the root and aerial tissues of the seedling (BRACHTVOGEL et al., 2006), in addition to impacting the amount of substrate, arrangement in the nursery, labor, transport, and the amount of inputs used (CARNEIRO, 1995; LISBOA et al., 2012). In turn, nursery production time influences the quality of seedlings (BAMBERG et al., 2013), and consequently their survival after planting in the field. The time the seedling stays in the nursery is variable and depends mainly on the growth of each species and on the time for planting in the field (OLIVEIRA et al., 2016).

According to Carneiro (1995), the criteria for seedling quality classification are based on increasing the percentage of plant survival after planting and minimizing the frequency of crop maintenance treatments. Quality criteria commonly assessed are height, collar diameter, shoot-to-collar ratio, root and shoot dry mass, root system length and Dickson quality index (Dickson et al., 1960), and the values for such criteria are usually based on the performance of exotic species, generically applied to native species.

Simarouba amara Aubl. is a tree species belonging to the Simaroubaceae family. It has an arboreal size ranging from 10–25 meters in height (DEVICCHI & PIRANI, 2016).

Classified as early secondary in the Atlantic Forest (LIMA et al., 2014), *S. amara* trees have been recorded from Central America to the southeastern region of Brazil and are popularly known as "pau paraíba" (paraiba wood), with timber and pharmacological potential and indicated for the restoration of degraded areas (Mendonça et al., 2018). Despite the importance of the potential use of *S. amara*, there is no information in the literature about the procedures for producing seedlings of this species.

This study aims to determine the nursery production time, quality standards and container size for *S. amara* seedling production, based on nursery and field performance.

2. MATERIALS AND METHODS

2.1. Nursery phase

The experiment was carried out in a greenhouse (50% of sunlight) in the experimental field of the Federal University of Recôncavo da Bahia (UFRB), located in Cruz das Almas, Bahia (39º06'22" W;12º40'19" S), at an altitude of 220 meters. According to the Köppen-Geiger classification (Alvares et al., 2013), the climate is classified as Af (hot climate), with an average annual temperature of 24°C, an average annual relative humidity of 80% and an average annual rainfall of 1200 mm.

The seeds used in this study were collected in January 2018 from five *S. amara* parent trees located in the Environmental Protection Area Joanes Ipitanga in Simões Filho-BA (12°47'04" S 38°24'14" W). Ripe purple fruits were collected and, during processing, their pulp was removed using a sieve and the seeds were washed in distilled water. The seeds were sown in seedbeds and, when the seedlings reached 1.0 to 1.5 cm, they were pricked out into the containers.

The design was completely randomized, and the treatments consisted of three container sizes: 55 cm^3 (12.5cm length x 2.9cm internal diameter), 180 cm^3 (13.5 x 5.2) and 280 cm^3 (19.0 x 5.2) with four repetitions. Each repetition consisted of a tray with 34 seedlings. The containers were filled with commercial substrate (dry basis density of 260 kg m^{-3}; EC 1.2 (mS/cm); pH 6), consisting of: pine bark, vermiculite, charcoal and phenolic foam, plus humus (manure), in a 1: 1 ratio. The seedlings were irrigated twice a day, early in the morning and in the late afternoon, as required, until saturation of 60%.

At 145 days, fifteen seedlings from each repetition were randomly selected and measured for diameter and height. We used a caliper to measure collar diameter and a ruler graduated in mm to obtain height, considering the length from the soil to the insertion of the last pair of leaves. Four seedlings per treatment were randomly selected to evaluate leaf area, shoot and root dry mass, main root length and fine root length (diameter ≤ 2mm).

For the evaluation of the leaf area, the leaves were detached and arranged on a scanner to obtain the digitized images. These images were processed using ImageJ software (National Institutes of Health, 2004) to calculate the leaf area. To quantify the total length of fine roots, the substrate was removed in a 500 µm-mesh sieve. The roots were placed on a scanner to obtain scanned images, which were processed using Safira Software (Embrapa, 2018) to calculate the total length of fine roots.

To obtain shoot and root dry mass, these parts were placed in paper bags and dried in an oven with air circulation at a temperature of 75°C for 72 hours.

Dickson Quality Index (DQI) was calculated as a function of robustness coefficient (H/D), shoot dry mass (SDM) and root dry mass (RDM) expressed in grams (g) (Dickson et al., 1960).

Analysis of variance and means test, Scott-Knott were performed in R software version 3.5.3 (R Core Team, 2019).

2.2. Post-planting performance

The study was carried out between August 2018 and February 2019 at the Experimental Farm of the UFRB. The soil is classified as Cohesive Yellow Latosol, flat relief, medium texture (Rodrigues et al., 2009). Over the experimental period, the monthly rainfall varied from 20.8 to 133.3 mm (Figure 1) (INMET, 2019).

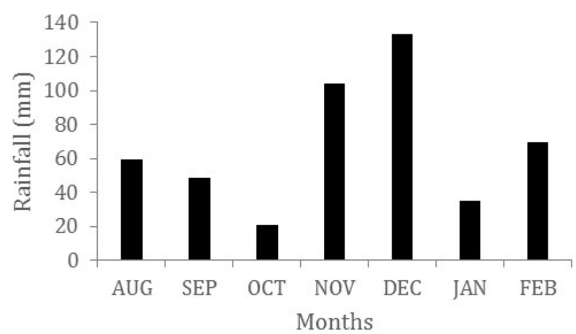

Figure 1. Monthly rainfall (August 2018 to February 2019). Sources: Instituto Nacional de Meteorologia.

As the germination of the species is irregular, after 180 days in the nursery, seedlings were obtained from different periods of permanence in the containers (105, 120, 135 and 145 days). The seedlings were irrigated with approximately four liters of water. These were evaluated at the time of planting for diameter and height, and monthly until the sixth month for survival, height and collar diameter.

The experiment was set up in a completely randomized design, in a 4x3 factorial scheme, corresponding to four nursery production times (105, 120, 135 and 145 days) and three container volumes (55, 180 and 280 cm³), with three repetitions, containing 18 plants each.

Before planting, the area was prepared by plowing at a depth of 30 cm. A manual digger was used to open the holes (20x20x20cm), spaced 1.0 m apart and 2.5 m between rows. Fertilization was carried out in the holes with 200 grams of NPK 10-10-10 plus 200 grams of humus (cattle manure). The seedlings were irrigated with approximately four liters of water, four times a week.

For survival analysis, we used variance analysis for factorial scheme (three container sizes and four nursery production times), for the qualitative factors, we used Scott-Knott test and for the quantitative factor, regression was employed. We performed the analysis using Exp.Des 1.2.0 package (Ferreira et al., 2019), available in R software version 3.5.3 (R Core Team, 2019).

For analysis of growth in height and diameter, we considered a split plot with double factorial in the plot (containers size and nursery production time) and the evaluation times (0, 30, 60, 90, 120, 150 and 180 days) in the subplot. The Wald test was performed for the fixed effects of the studied variables, employing the generalized linear mixed models. The nlme package (Pinheiro, 2019) was used in R software version 3.5.3. Regression analysis regarding curves of growth in height and diameter was performed using the exponential ($Y=a.e^{bx}$), logistic ($Y=a/(1+\exp(b+(x*c)))$) and simple linear ($Y=a+bx$) models, where: a, b and c = estimated parameters, x = time in days. The regression models were fitted using the gls (generalized least squares linear models) and gnls (nonlinear models' fit with generalized least squares) functions of the package *nlme* (Pinheiro, 2019), available in R software (R Core Team, 2019).

2.3. Relationship between morphological attributes and seedling survival in the field

With the diameter and height data measured at the time of planting, class intervals were defined for these two variables, using Sturges rule: the number of dead and surviving plants at six months after planting and classified by height and diameter. The same procedures were adopted for the robustness coefficient. For data analysis we used generalized linear models for contingency table for binomial distribution, logit link function and Chi-Square test (Cordeiro & Demétrio, 2013). Statistical analyses were performed using R software version 3.5.3 (R Core Team, 2019). The graphs were generated in R software version 3.5.3 and Excel.

3. RESULTS

3.1. Nursery production time

At 145 days in the nursery, the 280cm³ container promoted greater leaf area and fine root length (Table 1). Total dry mass (TDM), collar diameter (CD) and Dickson quality index (DQI) were higher for the 180cm³ and 280cm³ containers (Table 1). The 55cm³ container obtained results inferior to those of the other containers tested for most variables evaluated.

Table 1. Main root length (MRL), root dry mass (RDM), shoot dry mass (SDM^{-1}), total dry mass (TDM^{-1}), Dickson Quality Index (DQI), leaf area (LA), fine root length (FRL), height (H), collar diameter (CD), robustness coefficient (H/CD) and survival rate (% S) of *Simarouba amara* Aubl., in different container volumes at 145 days in the nursery.

Container	MRL(cm)	RDM(g)	SDM (g^{-1})	TDM (g^{-1})	DQI	LA (cm²)	FRL (mm)	H (cm)	CD (mm)	H/CD	% S
55cm³	11.48a	0.29b	2.76b	1.53b	0.18b	82.00c	223.20b	7.42a	2.92b	2.61a	76.67a
180cm³	11.25a	0.85a	0.63a	0.4a	0.55a	232.30b	460.00b	10.18a	4.20a	2.40a	98.30a
280cm³	11.68a	0.81a	0.57a	0.38a	0.56a	386.80a	952.65a	10.68a	4.22a	2.53a	90.00a
CV%	20.03	31.7	20.53	17.28	26.43	11.08	32.44	19.56	7.81	23.39	13.49
F/ANOVA	0.03	9.1	84.86	95.3	14.99	138.47	17.69	3.6	25.4	0.13	3.37
P-value	0.97	0.006	0	0	0.001	0	0	0.07	0.0002	0.8828	0.08

Means followed by the same letter in the column do not differ from each other by the Scott-Knott test (α = 0.05).

3.2. Post-planting performance

The survival of the seedlings in the field evaluated at 180 days was jointly influenced by the container sizes and nursery time. The lowest survival at all ages except 105 days was found for seedlings from the 55cm³ containers (Table 2).

For the seedlings that remained for 125 days in the nursery, the 180cm³ container resulted in a higher survival rate in the field. For 135-day nursery production time the highest survival rate was observed for seedlings produced in 280cm³ containers. For the 145-day nursery production time, no differences in survival rates were observed between 180 cm³ and 280cm³ containers (Table 2).

Table 2. Survival percentage of *Simarouba amara* Aubl. seedlings in the field at six months after planting, in different container sizes as a function of the nursery production time.

Nursery production time (days)	Container size			P-value
	$55cm^3$	$180cm^3$	$280cm^3$	
105	20.0 a	48.1 a	28.9 a	0.1200
125	22.2 b	75.7 a	41.7 b	0.0020
135	19.2 b	36.4 b	68.5 a	0.0042
145	8.3 b	71.9 a	61.1 a	0.0002
Variation coefficient %		39.3		

Means followed by the same letter in the row do not differ from each other by the Scott-Knott test (α = 0.05).

The regression analysis was not significant for the $55cm^3$ container (Figure 2). In the $180cm^3$ container, the maximum survival in the field occurred at 117 days (maximum point) of permanence in the nursery (Figure 2). The highest average value for field survival (75.7%) was found with seedlings from $180cm^3$ containers when kept in the nursery for 125 days (Table 2). While in the $280cm^3$ container, due to the trend of the fitted curve (Figure 1), the ideal seedling dispatch period exceeds 145 days. Therefore, the production of *S. amara* seedlings in the $180cm^3$ container resulted in a higher survival rate in a shorter production time, considering the evaluated nursery production times.

Field growth in diameter and height was influenced by the size of the container used (Table 3). Nursery production time had no significant effect on the diameter. It had an effect on height, but no satisfactory fits were obtained regarding height and nursery production time (Table 3).

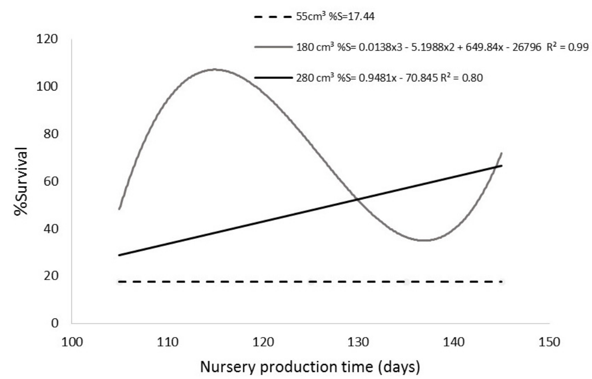

Figure 2. Survival of *Simarouba amara Aubl.* seedlings as a function of nursery production time Where %S = survival in percentage, x = nursery production time and R^2 = coefficient of determination.

Table 3. Wald F test for fixed effects on diameter and height variables.

Variation Source	Diameter (mm)		Height (cm)	
	Wald.F	P-value	Wald.F	P-value
Container (C)	108.81	<0.0001	75.43	<0.0001
Nursery production time (N)	2.1	0.151	5.38	0.0229
Evaluation period (E)	307.46	<0.0001	396.1	<0.0001
C x N	0.51	0.476	1.193	0.278
C x E	8.99	0.003	18.99	<0.0001
N x E	0.49	0.485	1.3	0.256
C x N x E	0.88	0.351	2.903	0.09

Table 4. Means and confidence intervals (α= 0.05) for collar diameter and height of *Simarouba amara* Aubl. seedlings, evaluated in the field over 180 days.

Diameter (mm)												
	$55cm^3$				$180cm^3$				$280cm^3$			
Time	Mean	SEM	LL	UL	Mean	SEM	LL	UL	Mean	SEM	LL	UL
0	3.2	0.1	3	3.3	4.4	0.1	4.3	4.6	4.7	0.1	4.5	4.9
30	3.8	0.1	3.6	4	5.1	0.1	4.9	5.2	5.4	0.1	5.1	5.6
60	3.9	0.4	3	4.7	5.5	0.1	5.3	5.7	6	0.1	5.7	6.4
90	4.7	0.5	3.7	5.7	6.8	0.3	6.2	7.3	7.2	0.3	6.6	7.7
120	5.7	0.6	4.3	7	8.2	0.3	7.5	8.8	8.4	0.3	7.7	9.2
150	6.3	1	4.1	8.6	9.3	0.3	8.7	9.8	9.7	0.4	8.7	10.6
180	6.6	1.1	4.3	9	9.7	0.3	9.1	10.3	10.2	0.4	9.2	11.1

Table 4. Continuation

Height (cm)												
	55cm³				180cm³				280cm³			
Time	Mean	SEM	LL	UL	Mean	SEM	LL	UL	Mean	SEM	LL	UL
0	6.7	0.2	6.3	7.1	7.8	0.2	7.4	8.2	8.2	0.2	7.8	8.7
30	7.9	0.2	7.4	8.3	8.8	0.2	8.3	9.2	9.6	0.2	9.1	10.1
60	8.3	0.8	6.5	10	9.8	0.2	9.4	10.2	11.2	0.2	10.7	11.8
90	9.2	0.9	7.3	11.2	11.9	0.3	11.2	12.6	12.4	0.3	11.6	13.2
120	11.5	1.2	8.9	14.1	14.9	0.4	14.1	15.7	15.8	0.5	14.6	16.9
150	12.8	2	8.4	17.3	17.2	0.5	16.1	18.3	19	0.8	17.3	20.7
180	14	2.2	9.2	18.8	18.8	0.5	17.6	20	21.2	0.8	19.4	23

SEM = standard error of the mean; LL = lower limit; UL = upper limit.

Height growth was lower for 55cm³ containers, but the upper limits of confidence intervals for seedling height in these containers, from 30 days, equaled or exceeded the lower limits for 180cm³ containers (Table 4). We also observed that the upper limits of the confidence intervals for height in the different evaluation periods for the 180cm³ containers exceeded the lower limits of those from 280cm³ containers, except for 60 days, when heights were statistically higher for seedlings of 280cm³ containers (Table 4).

The curve of growth in diameter over the six-month period in the field adhered to the exponential model for seedlings from 55cm³ containers (Figure 3 A) and to the logistic model for those from 180cm³ (Figure 3 B) and 280cm³ (Figure 3 C) containers.

Curves for growth in height over the evaluated period adhered to the exponential model for the 55cm³ (Figure 4 A) and 280cm³ (Figure 4 C) containers and to the logistic model for the 180cm³ (Figure 4 B) containers.

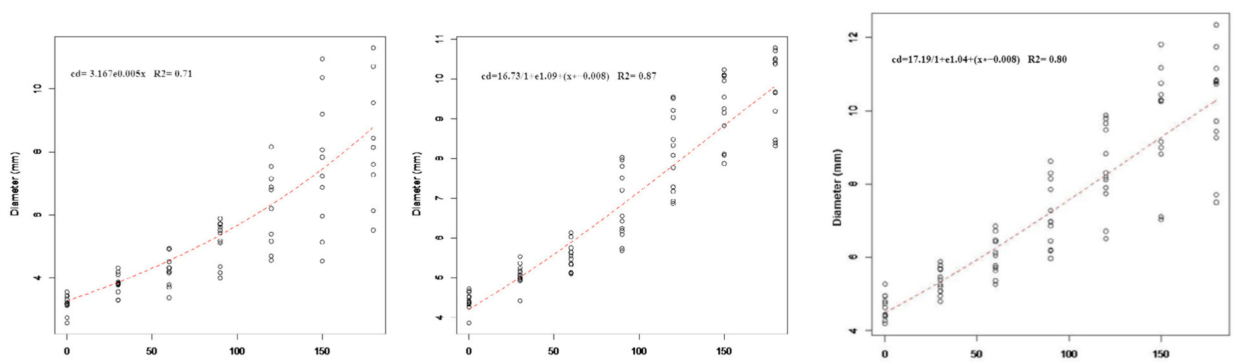

Figure 3. Curves of growth in collar diameter (CD) of *Simarouba amara* Aubl. seedlings from containers of 55cm³ (A), 180cm³ (B) and 280cm³ (C). Where: CD = collar diameter, x = period and R^2 = determination coefficient.

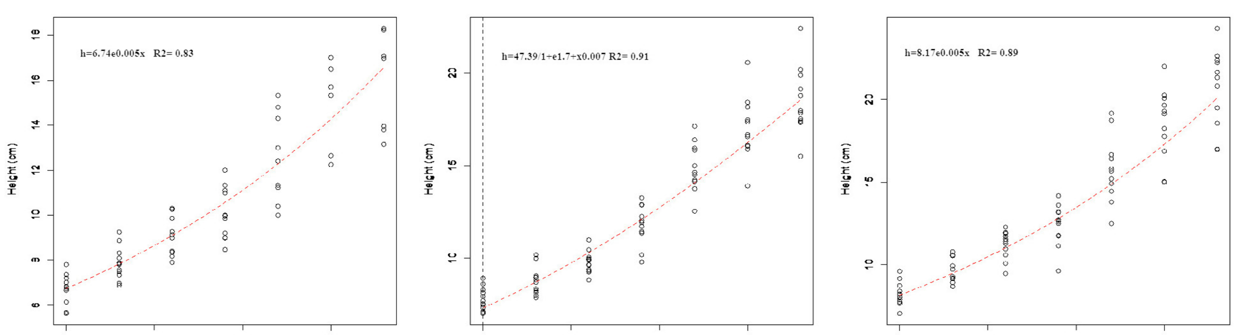

Figure 4. Curves of growth in height of *Simarouba amara* Aubl. seedlings from containers of 55cm³ (H), 180cm³ (B) and 280cm³ (C). Where: h = height, x = period and R^2 = determination coefficient.

3.3. Relationship between morphological attributes and seedling survival in the field

The proportion of surviving individuals depends on the height (p-value=4.96e-08), diameter (p-value=5.25e-08) and robustness coefficient (p-value=0.040) classes. Survival was favored from the 9.1 ├10.1 cm height class and 4.2 ├4.8 mm diameter class (Figure 5). While for the robustness coefficient (H / CD), the class in which survival occurred in the highest proportion was 2.0 ├ 2.4.

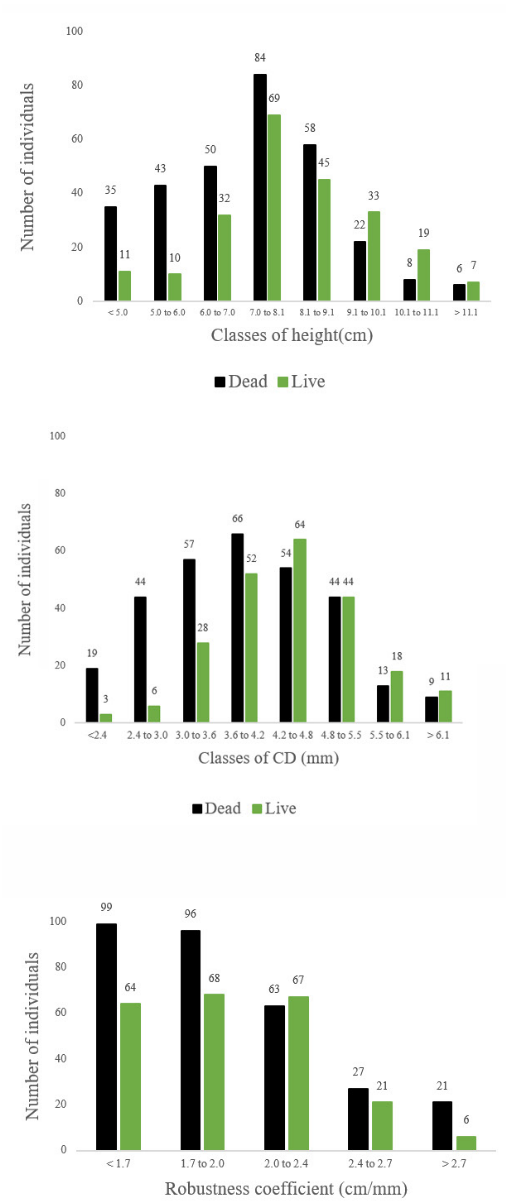

Figure 5. Number of dead and live *Simarouba amara* Aubl. seedlings, at six months after planting, as a function of the height, collar diameter (CD) and robustness coefficient classes

4. DISCUSSION

4.1. Nursery phase

In the nursery phase, the largest amount of leaf area was obtained in the seedlings produced in the 280cm³ tube, allowing greater production of photoassimilates, favoring the growth of the root system (Table 1). Smaller space for root growth and lower nutrient availability reduce seedling vigor in 55cm³ containers (Cunha et al., 2005; Ferraz and Engel, 2011; Freitas et al., 2013). The larger number of roots, especially the fine ones, facilitates greater nutrient and water absorption (Navroski et al., 2016). However, the other characteristics evaluated at this stage did not show a better performance of seedlings in the 280cm³ container compared to those in the 180cm³ container, but it was possible to observe the unsatisfactory performance of seedlings in the 55cm³ containers.

According to Araújo et al. (2014) and Gomes et al. (2003), the higher values of Dickson quality index (DQI) indicate better seedling quality. The DQI value depends on the species, the container used and seedling age (Melo et al., 2018). Hunt (1990) suggests a minimum DQI value of 0.20 for tube-grown seedlings, so *S. amara* seedlings produced in 55cm³ containers did not reach the minimum quality standard based on this index (Table 1).

The robustness coefficient (H/CD ratio) is used as an important quality indicator (Carneiro, 1995; Zida et al., 2008), besides being a non-destructive and easily measurable variable (Gomes et al., 2002). José et al. (2005) recommend that the H/CD ratio be below 10. Gomes et al. (2003) state that the lower this ratio, the greater the chance of initial seedling establishment. . For all the tested container sizes, the robustness coefficient was less than ten, which can be considered an appropriate value according to Jose et al. (2005). However, no significant differences were found for the robustness coefficient between the tested container sizes, which indicates that the simple comparison between different nursery treatments for this variable cannot be considered a conclusive finding.

Studies on container size for tree species allow us to infer that container sizes influence collar diameter, since the highest values are usually obtained in larger containers (Cunha et al., 2005; Ferraz & Engel, 2011; Freitas et al. al., 2013; Freitas et al., 2021; Navroski et al., 2016; Pias et al., 2015), which corroborates the results found in this study (Table 1). According to Souza et al. (2006), plants of the same species with a larger collar diameter have higher survival rates due to their capacity to form and grow new roots. Plants with greater increase in height tend to have a larger growth in diameter, as this mechanism reduces etiolation and prevents lodging of plants in the field (Abreu et al., 2015; Carneiro, 1995).

In general, the seedlings grown in the 55cm^3 container had worse performance. Similar results were found by Lima Filho et al. (2019), for *Ceiba speciosa* (A. St-Hil.) Ravenna seedlings, comparing four container sizes (55, 110, 180 and 280cm^3).

Therefore, with the results of the nursery phase it was possible to infer that the 55cm^3 container is not suitable for *S. amara* seedling production. However, these studies were not conclusive as to the choice between the 180cm^3 and 280cm^3 containers, as they performed similarly for most of the evaluated variables (Table 1). Considering that the costs of inputs and space in the nursery are lower for smaller containers, the assessment of post-planting performance is of great importance. In addition, the definition of the nursery production time requires field testing (Abreu et al., 2015; Correia et al., 2013; Gasparin et al., 2014; Mendonça et al., 2018). Thus, the results of post-planting performance complement the inferences obtained in the nursery phase.

4.2. Post-planting performance

Nursery production time depends on the size of the container, and the smaller the container, the lower the optimal expedition age of the seedlings (Storck et al., 2016). When the optimum age is exceeded, the seedling is restricted and its quality is compromised, and a longer nursery time results in higher production costs (Alfenas et al., 2009; Bamberg et al., 2013; Cunha et al., 2005).

The height and diameter growth results did not demonstrate the importance of nursery production time for *S. amara*; however, the survival data reveal the relevance of this factor. In tubes of 180cm^3, there was a reduction in survival after 117 days of permanence in the nursery, probably due to restrictions imposed by the container after the optimal expedition age (Alfenas et al., 2009). There is also evidence that a longer nursery time results in greater root system growth, which may lead to greater risk of root damage at the time of planting (Zaccheo et al., 2013). However, due to the behavior of the equation that describes the relationship between survival in the field and nursery production time, it is evident that longer nursery production time needs to be tested, increasing the number of periods evaluated.

For the 280cm^3 container, seedling survival rates increased linearly with nursery production time (Figure 1), indicating that the optimum expedition age for this container size is greater than 145 days, reinforcing the indication of testing nursery production times of more than 145 days. We also observed that along the nursery production time the diameter and height of the seedlings from the 280cm^3 and 180cm^3 containers did not differ (Table 1). According to Rodrigues, Brancalion and Isernhagen (2009), in reforestation with forest species native to the Atlantic Forest, when plant survival is less than 90%, replanting is necessary. In the present study, the survival of seedlings in the field was less than 90%, so future studies with longer nursery production time are indicated, in order to increase the survival rate in the field.

Therefore, 180cm^3 containers resulted in better quality seedlings than those planted in 280cm^3 containers. However, many studies indicate that larger container volumes produce better quality seedlings (Correia et al., 2013; Ferraz & Engel, 2011; Gasparin et al., 2014), as the larger container volume provides greater availability water nutrients, as well as space for root growth (Ferraz & Engel, 2011; Jose et al., 2005).

The 280cm^3 container was expected to result in better performing seedlings compared to that of 180cm^3. However, a study by Dominguez-Lerena et al. (2006), testing containers of different volumes and dimensions for *Pinus pinea* L., found that, in addition to container volume, length and width also influence seedling morphology. Deep and narrow containers can cause poor root aeration, impairing seedling growth (Domínguez-Lerena, 1997; Severino et al., 2007). It is assumed that the lower field performance of seedlings from 280 cm^3 containers is due to their greater length / width ratio (19/5.2) compared to the 180cm^3 containers (13.5/5.2). Therefore, the fact that the 280cm^3 container is deeper and narrower may have resulted in damage to the root system, minimizing the advantages provided by its larger volume.

A study conducted by Ferreira et al. (2017) evaluated different container volumes (20 x 15cm; 20 x 20cm; 23 x 20cm; 25 x 20cm; 30 x 20cm and 33 x 23cm) for two species *Mezilaurus itauba* Taub ex Mez and *Platymiscium ulei* Harms. These authors observed that the 20 x 25 cm container was the most suitable for the cultivation of *P. ulei*, while for *M. itauba*, the 33 x 23 cm container formed better quality seedlings. These results show that larger container volumes do not always result in better performance. Their dimensions, such as length and width, are also factors of influence on seedling quality.

S. amara seeds have a recalcitrant behavior (Santos et al., 2021). The impossibility of long-term storage coupled with the seasonal fruit availability will not always allow synchronization with the ideal field planting period. Thus, the production factors, container size and production time of the seedlings are fundamental for planning the planting. When the seed collection period allows the seedling production cycle to coincide with the best planting time, smaller containers can be used; otherwise, larger containers should be used (Jose et al., 2005). Therefore, the choice of container for

S. amara will depend on the planting schedule, as the seedlings produced in the 180cm³ containers began to be restricted after 117 days in the nursery.

Most studies that evaluate the quality standards in seedling production do not observe the field phase. However, the factors that promote the best growth of nursery seedlings will not always express the same post-planting performance. Survival in the field is the most important variable for indicating quality of seedlings and consequently more significant for choosing the most appropriate production factors. Studies point out that once survival in initial field establishment is ensured, the effects of production factors on post-planting growth overlap over time (Barbosa et al., 2013; Barros et al., 1978; Gasparin et al. al., 2014).

4.3. Relationship between morphological attributes and seedling survival rates in the field

Within the evaluated permanence periods, the seedlings had greater survival in the field with height and CD greater than 9 cm and 4 cm, respectively. Seedlings with a robustness coefficient ≥ 2.0 and less than 2.4 had better survival (Figure 4). However, to better define the quality standard of *S. amara* seedlings, studies with longer periods of permanence are recommended.

For eucalyptus the recommended dimensions for seedlings suitable for planting are height of 15 to 25 cm and minimum collar diameter of 2.5 mm, while for pine the recommendations are height of 15 to 35 cm and minimum diameter of 3.5 m (Sturion et al., 2000). Oliveira et al. (2016) recommend height between 20 and 30 cm for Cerrado species and 50 cm for species of forest environments. For Gonçalves et al. (2000), a good quality seedling should have the following dimensions: height of 20 to 35 cm and collar diameter between 5 and 10 mm. For Gomes & Paiva (2004), seedlings are suitable for planting in the field when their shoot height is between 15 and 30 cm. For *Quercus ilex* L., the standards set for quality seedlings were height of 12 to 17 cm and diameter of 3.5 to 4.8 mm (del Campo et al., 2010). The Ministry of Agriculture, Livestock and Food Supply determines the minimum standard of 3 mm in collar diameter and 20 cm in height for forest species. Therefore, it is evident that quality standards are species-specific and should be defined based on seedling field performance results, considering mainly survival data (Gomes et al., 2019).

5. CONCLUSIONS

Simarouba amara Aubl. seedlings can be successfully produced in a 180-cm³ (13.5x5.2cm) container with a maximum nursery permanence of 125 days. To ensure higher survival rates, *S. amara* seedlings should be taken to the field with a minimum collar diameter of 4.2 mm, a minimum height of 9.1 cm and a robustness coefficient of 2.0 to 2.4 cm/mm.

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REFERENCES

Abreu AH, Leles PSS, Melo LA, Ferreira DHAV, Monteiro FAZ. Produção de mudas e crescimento inicial em campo de *Enterolobium contortisiliquum* produzidas em diferentes recipientes. Floresta 2015; 45(1):141-150. DOI: 10.5380/rf.v45i1.28931.

Alfenas AC, Zauza EAV, Mafia RG, Asis TF. Clonagem e doenças do eucalipto. Viçosa: UFV, 2009.

Alvares, CA, Stape jl, Sentelhas PC, Gonçalves JLM, Sparovek, G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift 2013; 22(6):711-728. DOI 10.1127/0941-2948/2013/0507.

Araujo, EC, Costa RS, Lopes EC, Daher RF, Fernandes MEB. Qualidade das mudas de espécies arbóreas de mangue cultivadas em viveiro e diferentes substratos. Acta Ambiental Catarinense 2014;11(½): 21-32. DOI: https://doi.org/10.24021/raac.v11i1/2.3091

Bamberg R, Behling A, Perrando ER, Sanqueta CR, Nakajima NY, Schreiner T, Pelissari AL. Relação entre nutrição e tempo de permanência de mudas de *Bauhinia forficata* em casa-de-vegetação. Silva Lusitana 2013; 21(1): 87 - 101.

Barbosa TC, Rodrigues RR, Couto HTZ. Tamanhos de recipientes e o uso de hidrogel no estabelecimento de mudas de espécies florestais nativas. Hoehnea 2013; 40(3):537-556. http://dx.doi.org/10.1590/S2236-89062013000300013

Barros NF et al. Efeitos de recipientes na sobrevivência e no crescimento de mudas de *Eucalyptus grandis* no viveiro e no campo. Revista Árvore 1978; 2(2):141-151.

Benini RM, Adeodato S. Economia da restauração florestal. São Paulo: The Nature Conservancy. 2017.

Brachtvogel EL, Freiberger MB, Malavasi MM, Malavasi UC. Efeitos do uso de um fertilizante de lenta disponibilidade e do volume do recipiente na formação de mudas de *Peltophorum dubium*. Scientia Agraria Paranaensis 2006: 5: p.67- 71.

Brasil. Lei no 12.651, de 25 de maio de 2012. Dispõe sobre a proteção da vegetação nativa e dá outras providências. Brasília: Congresso Nacional, 2012.

Carneiro JGA. Produção e controle de qualidade de mudas florestais. Curitiba: UENF; UFPR; FUPEF, 1995.

Cordeiro GM, Demétrio CGB. Modelos lineares generalizados e extensões. 2013. Disponível em:<https://www2.esalq.usp.br/departamentos/lce/arquivos/aulas/2011/LCE5806/livro.pdf.> Acesso em: agosto, 2019.

Correia, ACG, Santana RC, Oliveira MLR, Titon M, Ataíde GM, Leite FP. Volume de substrato e idade: influência no desempenho de mudas clonais de eucalipto após replantio. Cerne 2013;19(2): 185-191. http://dx.doi.org/10.1590/S0104-77602013000200002

Cunha AO, Andrade LA, Bruno RLA, Silva JAL, Souza VC. Efeitos de substratos e das dimensões dos recipientes na qualidade das mudas de *Tabebuia impetiginosa* (Mart. Ex D.C.) Standl. Revista Árvore 2005; 29(4):507- 516. https://doi.org/10.1590/S0100-67622005000400002

Del Campo AD, Cerrilo RMN, Ceacero CJ. Seedling quality and field performance of commercial stocklots of containerized holm oak (*Quercus ilex*) in Mediterranean Spain: an approach for establishing a quality standard. New Forests2010; 39(1):19–37. https://doi.org/10.1007/s11056-009-9152-9

Devecchi MF, Pirani JR. Flora das cangas da Serra dos Carajás, Pará, Brasil: Simaroubaceae. Rodriguésia 2016, 67(5) (Especial): 1471-1476. http://rodriguesia.jbrj.gov.br. DOI: 10.1590/2175-7860201667551.

Dickson A, Leaf AL, Hosner JF. Quality appraisal of white spruce and white pine seedling stock in nurseries. Forest Chronicle1960; 36:10-13.

Domínguez Lerena S. La importancia del envase en la producción de plantas forestales. Quercus 1997; 134: 34-37.

Embrapa - EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA, 2018. Disponível em:< http://labimagem.cnpdia.embrapa.br/Ferramentas.aspx?ferramenta=4 > Acesso em: 05 março 2018.

Ferraz AV, Engel VL. Efeito do tamanho de tubetes na qualidade de mudas de jatobá (*Hymenaea courbaril* L. VAR. *stilbocarpa* (Hayne) Lee ET Lang.), ipê-amarelo (*Tabebuia chrysotricha* (Mart. ex DC.) SANDL.) e guarucaia (*Parapiptadenia rigida* (Benth.) Brenan). Revista Árvore 2011; 35(3):413-423. http://dx.doi.org/10.1590/S0100-67622011000300005.

Ferreira EB, Cavalcanti PP, Nogueira DA. 2018. Pacote Experimental Designs (Portuguese). R package version 3.5.3. 2019.

Ferreira MS, Santos JZL, Tucci CAF, Costa LV. Crescimento inicial de itaúba e macacaúba em recipientes de diferentes tamanhos. Ciência Florestal Santa Maria2017; 27(2): 499-508.

Freitas TAS, Silva PSP, Peixinho JB, Mendonça AVR, Santos LB. Crescimento e ciclo de produção de mudas de *Eucalyptus* em recipientes. Pesquisa Florestal Brasileira 2013; 33(76):419-428. http://dx.doi.org/10.4336/2013.pfb.33.76.575.

Freitas TAS, Lopes ECS, Araujo JFG, Santos LB, Mendonça AVR. Produção de mudas de *Senegalia bahiensis* Benth. em diferentes volumes de tubetes. Ciência Florestal 2021; 31(3):1105-1123. https://doi.org/10.5902/1980509829783

Gasparin E, Avila AL, Araujo MM, Cargnelutti Filho A, Dorneles DU, Foltz DRB. Influência do substrato e do volume de recipiente na qualidade das mudas de *Cabralea canjerana* (Vell.) Mart. em viveiro e no campo. Ciência Florestal 2014; 24(3):553-563. http://dx.doi.org/10.5902/1980509815731

Gomes SHM, Gonçalves FB, Ferreira RA, Pereira FRM, Ribeiro MMJ. Avaliação dos parâmetros morfológicos da qualidade de mudas de *Paubrasilia echinata* (pau-brasil) em viveiro florestal. Scientia Plena 2019; 15(1): 1-10. https://doi.org/10.14808/sci.plena.2019.011701

Gomes JM, Paiva HN. Viveiros florestais: propagação sexuada. Viçosa, MG: UFV, 2004.

Gomes JM, Couto L, Leite HG, Xavier A, Garcia SLR. Crescimento de mudas de *Eucalyptus grandis* em diferentes tamanhos de tubetes e fertilização NPK. Revista Árvore 2003; 27(2):113-127. http://dx.doi.org/10.1590/S0100-67622003000200001.

Gomes JM, Couto L, Leite HG, Xavier A, Garcia SLR. Parâmetros morfológicos na avaliação da qualidade de mudas de *Eucalyptus grandis*. Revista Árvore 2002; 26(4):515-523. https://doi.org/10.1590/S0100-67622002000600002.

Gonçalves JLM, Santarelli EG, Moraes Netto SP, Manara MP, Stape JL. Produção de mudas de espécies nativas: substrato, nutrição, sombreamento e fertilização. In: Gonçalves, JLM, Benedetti, V, editor. Nutrição e fertilização florestal. Piracicaba: ESALQ/USP, 2000.

Gregorio N, Herbohn J, Harrison S, Pasa A, Ferraren A. Regulating the Quality of Seedlings for Forest Restoration: Lessons from the National Greening Program in the Philippines. Small-scale Forestry 2017; 16(1):83–102. https://doi.org/10.1007/s11842-016-9344-z

Hunt GA. Effect of Styroblock Design and Copper Treatment on Morphology of Conifer Seedlings. In: ROSE, R. et al. editor Proceedings, Western Forest Nursery Association. Fort Collins: Department of Agriculture, Forest Service, 1990.

Inmet. Instituto Nacional de Meteorologia. Rede de Estações Climatológicas. Disponível em:<http://www.inmet.gov.br/projetos/rede/pesquisa/form_mapas_c_diario.php.>Acesso em: 12 mai. 2019.

José AC, Davide AC, Oliveira SL. Produção de mudas de aroeira (*Schinus terebinthifolius* Raddi) para recuperação de áreas degradadas pela mineração de bauxita. Revista Cerne 2005; 11(12): 187 - 196.

Lima Filho P, Leles PSS, Abreu AHM, Fonseca AC, Silva EV. Produção de mudas de *Ceiba speciosa* em diferentes volumes de tubetes utilizando o biossólido como substrato. Ciência Florestal 2019; 29(1):27-39. http://dx.doi.org/10.5902/1980509819340

Lima RBA, Silva RKS, Marangon LC, Feliciano ALP. Sucessão ecológica de espécies arbóreas, Igarassu, PE. In: VIII SIMPÓSIO BRASILEIRO DE PÓS-GRADUAÇÃO EM CIÊNCIAS FLORESTAIS. 22-24 de outubro de 2014, Recife, PE. http://dx.doi.org/10.12702/VIII.SimposFloresta.2014.96-682-1.

Lisboa AC, Santos OS, Oliveira Neto SN, Castro DN, Abreu HM. Efeito do volume de tubetes na produção de mudas de *Calophyllum brasiliense* e *Toona ciliata*. Revista Árvore 2012; 36(4): 603-609.

Melo LA, Abreu AHM, Leles PSS, Oliveira RR, Silva DT. Qualidade e crescimento inicial de mudas de *Mimosa caesalpiniifolia* Benth. produzidas em diferentes volumes de recipientes. Ciência Florestal 2018; 28(1):47-55. http://dx.doi.org/10.5902/1980509831574.

Mendonça AVR, Souza JS. Bases para a definição de protocolos para propagação de espécies das áreas de proteção ambiental (APA): Lago da Pedra do Cavalo e Joanes Ipitanga, Bahia. In: Mendonça, AVR et al. editor. Propagação de espécies florestais nativas da Bahia: uma contribuição para conservação das APAs de Joanes-Ipitanga e Lago Pedra do Cavalo. Cruz das Almas: UFRB, 2018.

Mendonça AVR, Souza, JS, Souza MO, Santos JPA. Propagação de espécies florestais nativas da Bahia: uma contribuição para conservação das APAs de Joanes-Ipitanga e Lago Pedra do Cavalo. Cruz das Almas: UFRB, 2018.

National Institutes of Health. ImageJ, 2004. Disponível em:<https://imagej.nih.gov/ij/>. Acesso em: 05 mar. 2018.

Navroski MC, Nicoletti MF, Lovatel QC, Pereira MO, Tonett EL, Mazzo MV, Meneguzzi A, Felippe D. Efeito do volume do tubete e doses de fertilizantes no crescimento inicial de mudas de *Eucalyptus dunnii* Maiden. Revista Agrarian 2016; 9(31):26-33.

Oliveira MC, Ogata RS, Andrade GA, Santos DS, Souza RM, Guimaraes TG et al. Manual de viveiro e produção de mudas: espécies arbóreas nativas do Cerrado. Brasília: Editora Rede de Sementes do Cerrado, 2016.

Pias OHC, Berghetti J, Somavilla L, Cantarelli EB. Qualidade de mudas de cedro em função da utilização de fertilizantes e recipientes de diferentes tamanhos. Revista Agroambiente 2015; 9(2): 208-213. http://dx.doi.org/10.18227/1982-8470ragro.v9i2.2210.

Pinheiro JC, Bates D, DebRoy S, Sarkar D, Heisterkamp S, Willigen BV et al. Linear and Nonlinear Mixed Effects Models. Versão do pacote R 3.5.3. Disponível em: http://cran.r-project.org. Acesso em 05 mar. 2019.

R Core Team, R: A language and environment for statistical computing. R Foundation for Statistical Computing. 2019. Disponível em:<https://www.R-project.org/ >. Acesso em: 09 dez. 2019.

Rodrigues MGF, Nacif PGS, Costa OV, Olszevski N. Solos e suas relações com as paisagens naturais no município de Cruz das Almas-BA. Revista de Biologia e Ciências da Terra 2009; 9(2):193-205.

Rodrigues RR, Brancalion PHS, Isernhagen I. (Ed.). Pacto pela restauração da Mata Atlântica – Referencial dos conceitos e ações de restauração florestal. São Paulo: LERF, 2009. 259 p.

Santos JPA, Mendonça AVR, Carvalho ES, Souza MDH, Souza MO. Storage of *Simarouba amara* Aubl. seeds. Bol. Mus. Para. Emílio Goeldi. Ciências Naturais 2021; 16(1): 89-95.

Severino LS, Lima RLS, Beltrão NEM. Avaliação de mudas de pinhão manso em recipientes de diferentes volumes. Embrapa Algodão. Boletim de Pesquisa e Desenvolvimento, 81, 14p. 2007.

Souza CAM, Oliveira RB, Martins Filho S, Lima JSS. Crescimento em campo de espécies florestais em diferentes condições de adubação. Ciência Florestal 2006; 16(3):243-249. http://dx.doi.org/10.5902/198050981905

Storck EB, Schorn LA, Fenilli TAB. Crescimento e qualidade de mudas de *Eucalyptus urophylla* x *Eucalyptus grandis* em diferentes recipientes. Floresta 2016; 46: 39 - 46. http://dx.doi.org/10.5380/rf.v46i1.38907

Sturion JÁ, Antunes, BMA. Produção de mudas de espécies florestais. In: GALVÃO, APM, editor. Reflorestamento de propriedades rurais para fins de produtivos e ambientais. Embrapa Florestas, DF, 2000.

Viana JS, Gonçalves EP, Andrade LA, Oliveira LSB, Silva EO. Crescimento de mudas de *Bauhinia forficata* Link em diferentes tamanhos de recipientes. Revista Floresta 2008; 38(4): 663-671.

Zaccheo PVC, Aguiar RS, Stenzel NMC, Neves CSVJ. Tamanho de recipientes e tempo de formação de mudas no desenvolvimento e produção de maracujazeiro-amarelo. Revista Brasileira de Fruticultura 2013; 35(2): 603-607. https://doi.org/10.1590/S0100-29452013000200032

Zida D, Tigabu M, Sawadogo L, Oden PC. Initial seedling morphological characteristics and field performance of two Sudanian savanna species in relation to nursery production period and watering regimes. Forest Ecology and Management 2008; 255(7):2151–2162. https://doi.org/10.1016/j.foreco.2007.12.029