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Survival and Growth of Mangrove Tree Seedlings in Different Types of Substrate on the Ajuruteua Peninsula on the Amazon Coast of Brazil

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Abstract

The present study investigated the growth and survival of seedlings of *Rhizophora*, *Avicennia*, and *Laguncularia* raised in three different substrates: mangrove soil, latosol, and sand. The study was based on an entirely random factorial design (3 × 3) × 3, with three tree species, three substrates, and three replicates. The experiment was conducted in a nursery installed in the municipality of Bragança, in the northern Brazilian state of Pará. The seedlings were grown in 17 cm × 27 cm polyethylene containers. Survival was calculated based on the percentage of germinated propagules surviving after 270 days. Seedling heights were evaluated using an analysis of variance (ANOVA) and morphological parameters were compared using Tukey's test. All three species were ready for replanting after 270 days. The *R. mangle* and *A. germinans* seedlings presented better rates of survival and growth on the substrates tested. All three species grew well in the substrates tested, and the production of seedlings in yellow latosol would appear to be the most effective approach.

Keywords

Replanting, Soil, Production of Seedlings, Mangrove, Brazilian Amazon

Subject Areas: **Plant Science**

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1. Introduction

Worldwide, mangrove forests cover a total area of approximately 152,000 km^2 [1], of which 8.5% (13,000 km^2) is found in Brazil, which is the country with the second largest area of this type of ecosystem. Approximately half of this area (6516 km^2) is found on the Amazon coast, between the states of Pará and Maranhão [2]. In Pará, the mangroves form an almost continuous tract of forest lining the coast for 300 km, with a total area of 2176.78 km^2. The decline of these forests around the world is becoming increasingly evident, however, given the progressive growth of impacts such as the predatory extraction of the lumber produced by these systems [3].

A number of authors believe that unmanaged logging in mangrove forests may cause considerable alterations to the composition of these ecosystems or even their total elimination from some areas [4]-[7]. In Brazil, the exploitation of these systems has involved even more drastic impacts, such as the installation of shrimp farms at many locations in the northeast of the country [8], deforestation and lumbering in the southeast [9], and the construction of highways in the extreme north [10].

Despite these impacts, there have been a number of initiatives for the recuperation of mangrove forests in many areas around the Brazilian coast [11]. These efforts include the replanting of native species and the investigation of different techniques related to the recuperation of habitats, such as the care of the propagules, the production of seedlings, evaluation of the optimum period for planting propagules and transplanting seedlings, planting procedures and post-planting monitoring.

The development of adequate technologies for the production of the seedlings of native plants, including seed germination, seedling management, and the type of substrate used, is essential for the recuperation of degraded ecosystems [12]. Furthermore, the substrate used for the production of seedlings in degraded environments should present physical and chemical characteristics appropriate for the retention of both humidity and nutrients required by the plants [13]. In Brazil, only one study [11] has analyzed the relative value of different types of substrate for the production of mangrove tree seedlings, and this study was in the southeast of the country, where the climate and edaphic conditions are quite distinct from those found on the Amazon coast.

One other important consideration for the production of seedlings is the cost of production, which is considerable when compared with direct sowing. In conclusion, nurseries are only necessary when regeneration is unsuccessful by direct sowing, or when a certain degree of seedling development is necessary to guarantee recruitment [14]. As the maintenance of mangrove forests is dependent on seedling recruitment [15], the production of seedlings is essential in order to enhance the recruitment process and guarantee the viability of the new individuals, and thus accelerate the regeneration process for the ecosystem as a whole.

The region's growing human population has been the primary factor determining the ongoing degradation of the mangrove forests of the Brazilian Amazon region [10]. Given this, the present study investigated the viability of the production of seedlings of the three principal local mangrove species—*Rhizophora mangle* L., *Avicennia germinans* (L.) L., and *Laguncularia racemosa* (L.) C.F. Gaertn.—focusing in particular on the effects of different types of soil on the growth and survival of seedlings, and the potential of this procedure for the restoration of degraded mangrove forests on the Brazilian Amazon coast.

2. Materials and Methods

2.1. Study Site

The present study was developed in the village of Taperaçu-Campo (00˚56'55.07"S, 46˚46'00.82"W), on the Ajuruteua Peninsula, 12 km north of the town of Bragança, in the northern Brazilian state of Pará (**Figure 1**). The region's climate is hot and humid, with a distinct dry season, from July to December, and a rainy season, between January and June, with mean annual precipitation of between 2500 mm and 3000 mm, and mean temperatures of approximately 26˚C [16]. The rivers are characterized by a semidiurnal macrotidal regime, with spring tide of over 5 m and neap tides of around 3 m in height [17] [18].

Four of the seven mangrove tree species found in the Neotropical region are present on the Ajuruteua Peninsula, although only three of these species—*R. mangle*, *A. germinans*, and *L. racemosa*—dominate the landscape, while *Avicennia schaueriana* Stapf and Leechman ex Moldenke is more sparsely distributed. It is important to note that the construction in the 1970s of the PA-458 state highway, which connects Bragança to the village of Ajuruteua, bisected 26 km of the local mangrove forest [10], and impacted an area of 3.8 km^2 of this ecosystem [19]. These authors concluded that he primary source of this impact was the obstruction of the tidal creeks on the east of the peninsula, that drain into the Caeté River.

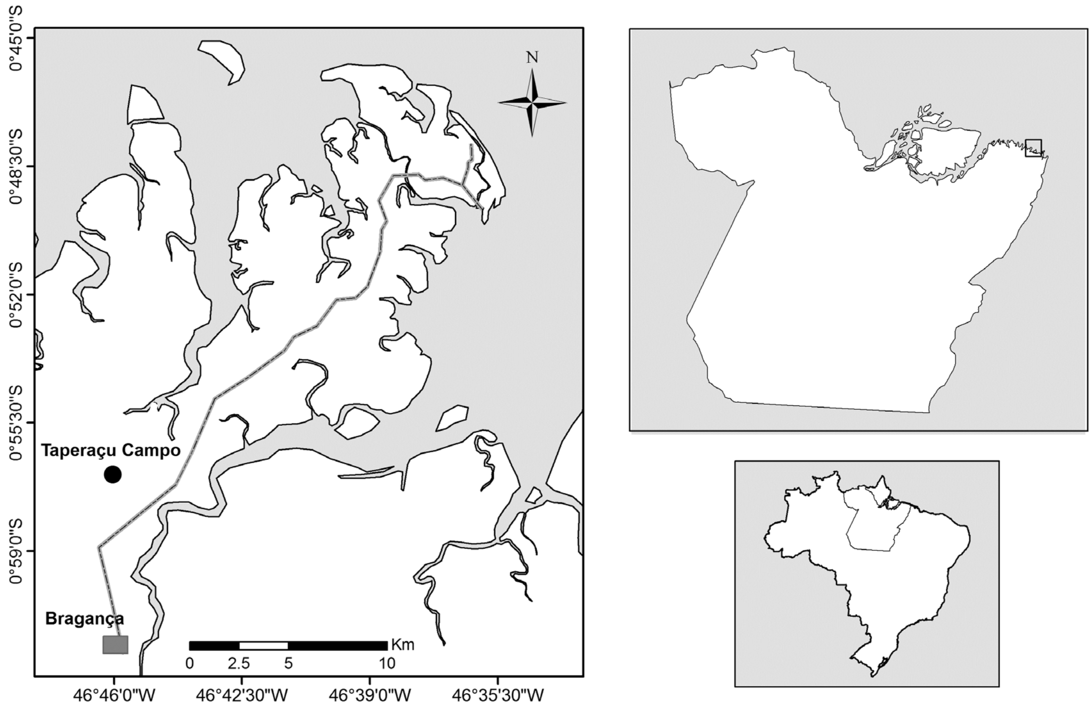

Figure 1. Map of the study area, showing the Taperaçu-Campo village on the Ajuruteua Peninsula in Bragança, Pará, Brazil.

2.2. Seedling Production

The nursery was established near a tidal creek, where a small ditch was dug to provide a water source, imitating a daily regime of inundation by tidal waters. The nursery occupied a total area of 32 m^2 (8 m × 4 m, with a depth of 40 cm), and was placed in the intertidal zone, where they have access to brackish water [20].

Peak fruiting in the mangrove tree species of the Amazon region corresponds to the rainy season [21]. Given this, the propagules of *R. mangle*, *A. germinans*, and *L. racemosa* were collected for the present study during the peak fruiting month of March. The propagules were either collected from the forest floor shortly after abscission or directly from the mother-tree, when known to be mature in *R. mangle*, the distal portion of the ripe propagule (hypocotyl) is brown in color [22], while those of *A. germinans* are green [15], the propagules of *L. racemosa* are brown in color when mature [23]. Mature propagules still attached to the tree can be identified easily because they fall readily when touched [24].

The *A. germinans* propagules were immersed in water for 24 hours in order to facilitate the removal of the tegument, while those of *L. racemosa* were immersed for approximately seven days, until the radicle emerged. The *R. mangle* propagules were not treated in any way.

The propagules were planted in 17 cm × 27 cm polyethylene containers filled with one of three types of substrate—(i) mangrove soil, (ii) latosol, and (iii) sand. An average of four propagules were planted directly into the substrate of each container in order to compensate for losses, and guarantee the production of at least one seedling per container. Surplus seedlings were removed after 30 days, leaving only the best-developed seedling in each container.

2.3. Experimental Design

The seedlings selected for the three mangrove species were tested in relation to the effects of substrates on their survival and growth. The experimental design adopted for the present study was completely randomized, based on a 3 × 3 factorial (3 species × 3 types of substrate). Each treatment included three replicates, each composed of 80 seedlings (total = 240), and nine treatments were evaluated. Each of the different substrates tested in the present study were analyzed chemically in the EMBRAPA (Brazilian Agricultural Research Corporation for eastern Amazonia) soils laboratory in Belém, Brazil. For this, samples of 1 kg were obtained from a depth of 20 cm and stored in plastic bags labeled according to their origin.

Seedling survival rates were calculated based on the percentage of containers with seedlings 270 days after planting. For the assessment of growth, the height (cm) of the seedlings was first measured 30 days after planting, and then every month over the nine months of the study period.

2.4. Data Analyses

The data were analyzed using standard statistical tests [25]. The effect of the different substrates on the survival and growth of the seedlings was evaluated using an Analysis of Variance (ANOVA), following the *a priori* testing of the data for normality (Lilliefors test for k samples) and homogeneity of variance (Cochran's test). The data are presented as means ± standard deviations, while differences between treatments were considered significant at the 5% ($p < 0.05$) level.

3. Results and Discussion

3.1. Physical and Chemical Characteristics of the Substrate

A good quality substrate, in both chemical and physical terms, is essential for the production of healthy seedlings of native forest species [26]. In the present study, the different substrates presented contrasting granulometric characteristics (**Table 1**), based on their textural fractions (sand, silt, and clay). This variation affected the survival rates and growth of the seedlings in the different substrates tested in the nursery.

In the mangrove soil, the survival rates recorded for *A. germinans* (98%) and *R. mangle* (90%) were higher than those observed for the sandy substrate (85% for both species). These findings contrast with those of Abrahão [27], who obtained a survival rate of only 37% for *A. schaueriana* seedlings grown in different types of substrate (compost + clay, compost + sand, and clay + sand), as well as clay and sand separately. This author nevertheless obtained much better results for *A. schaueriana* seedlings grown in nurseries—survival rates of up to 82%—using a mixture of sand and fertilizing compost (N, P, K).

With the exception of Al and Zn, the highest values for the different nutrients analyzed were recorded in the mangrove soil (**Table 1**), reflecting its high fertility, which results from the high levels of P, K, Ca, and Mg, and reduced Al. A number of other studies have evaluated the affects of fertilization with N:P:K on the growth and accumulation of dry matter in mangrove tree species. In western Arabia, for example, authors demonstrated that the application of K resulted in a significant increase in the number of branches per plant in the later stage of development, while the addition of N had a similar effect on the dry weight of the leaves [28]. In another study, the production of seedlings in the nursery applied inorganic fertilizer (N:P:K—17:17:17, di-ammonia phosphate and urea) after 60 days in order to stimulate the growth and establishment of the roots [20]. In the present study, however, no fertilizer was applied, and seedling growth was dependent on the natural physical and chemical properties of the substrates tested.

3.2. Seedling Survival

In mangrove soil (**Figure 2(a)**), the survival rate recorded for *A. germinans* seedlings (95%) was significantly higher than that those recorded for *R. mangle* and *L. racemosa*, which returned the lowest rate, at 60% (**Table 2**). High survival rates, of above 85%, have been recorded in other studies of mangrove recuperation [29]. In a study of *R. mangle* in degraded mangroves on the coast of Chiapas, Mexico, for example, it was recorded a 100% survival rate after 120 days of growth in nurseries, with low mortality (<5%) being recorded following transplantation [30].

In the sandy substrate (**Figure 2(b)**), the highest survival rates were recorded for *R. mangle* and *A. germinans*, while the lowest value (37%) was recorded for *L. racemosa*, with a highly significant difference between the means values recorded for the former two species and that for *L. racemosa* (**Table 2**). These results are different from the results of Ellison & Farnsworth [31], who found no significant difference in the survival rates of the three species.

In the latosol (**Figure 2(c)**), a survival rate of 75% was recorded for *R. mangle*, with much lower values being recorded for *A. germinans* (46%) and *L. racemosa* (42%). Trench & Webber [32] compared the production of seedlings (*R. mangle*, *L. racemosa*, *A. germinans*, and *Conocarpus erectus* L.) in a nursery with the natural

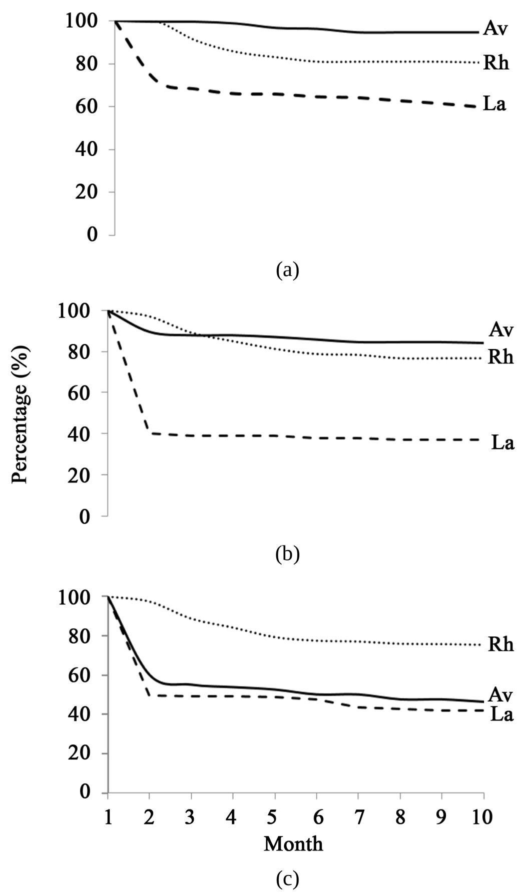

Figure 2. Survival rates of the seedlings of *Rhizophora mangle* (Rh), *Avicennia germinans* (Av), and *Laguncularia racemosa* (La) in mangrove soil (a); sand substrat (b) and latosol substrat (c) over a nine month period in the nursery at Taperaçu-Campo, Bragança, Pará, Brazil.

Table 1. Physical and chemical composition of the substrates used in the production of the seedlings of mangrove tree species. pH = Potential Hydrogen, P = Phosphorus, K = Potassium, Na = Sodium, Ca = Calcium, Ca + Mg = Calcium + Magnesium, Al = Aluminum, Cu = Copper, Mn = Manganese, Fe = Iron, and Zn = Zinc.

Component	Quantity found in:		
	Mangrove soil	Sand	Latosol
Coarse sand (g/kg)	8	1	17
Fine sand (g/kg)	571	979	762
Silt (g/kg)	182	0	121
Total Clay (g/kg)	240	20	100
pH	6.0	4.7	5.0
P (mg/dm^3)	16.0	8.0	3.0
K (mg/dm^3)	583	57	24
Na (mg/dm^3)	388	609	12
Ca (cmol/dm^3)	1.9	0.9	0.4
Ca + Mg (cmol/dm^3)	8.2	1.6	0.7
Al (cmol/dm^3)	0.1	0.1	1.4
Cu (mg/kg)	7.1	4.3	5.2
Mn (mg/kg)	14.8	12.8	14.6
Fe (mg/kg)	136.0	555.0	135.6

Extractor method. EMBRAPA-Belém.

Table 2. Results of the ANOVA for the survival (%) of the seedlings of the mangrove tree species (Rh = *Rhizophora mangle*, Av = *Avicennia germinans*, and La = *Laguncularia racemosa*) in the three types of substrate tested over the nine months of the study period. Values are the means ± standard deviation for each species. MS = mean square, F = F value (ANOVA), *p* = significance at the 5% level.

Source of variation	(Rh ± SD) × (Av ± SD) × (La ± SD)	MS	F	*p*
spp. × mangrove soil	(69.1 ± 05.99) × (77.7 ± 01.77) × (54.9 ± 08.76)	0.13	30.75	0.001
spp. × sand	(67.1 ± 06.61) × (70.2 ± 03.58) × (35.5 ± 14.86)	0.36	35.79	0.001
spp. × latosol	(66.6 ± 06.96) × (44.4 ± 12.08) × (41.2 ± 13.14)	0.19	13.73	0.01

rates observed in plots established within the forest. While a marked difference was recorded for *R. mangle*—93% in the nursery versus only 10% in the forest—similar survival rates were recorded for *C. erectus* and *A. germinans* in the two environments.

The survival of mangrove trees depends on a range of environmental factors. In a mangrove forest in Espírito Santo, Brazil, for example, mortality rates in *R. mangle* seedlings were determined by a combination of environmental factors and inter-individual competition, whereas in *L. racemosa* was affected only by competition. In this case, while the population density of *L. racemosa* was lower, this species appeared to be better adapted to the local abiotic conditions [33].

A number of biological processes may also affect the survival strategies of seedlings in mangrove forests, however. Unlike *R. mangle* and *A. germinans*, for example, *L. racemosa* is not viviparous, and germination often occurs during the dispersal process [15]. Viviparity may increase the chances of the propagules surviving in relatively saline, sludgy environments, with low levels of oxygen, in which the germination of seeds would normally be inhibited. While the present study was conducted in a nursery, the lowest survival rates were recorded for *L. racemosa*, indicating a germination pattern similar to that recorded in the natural environment.

It is important to note that the production of seedlings for the recuperation of degraded mangroves may result in increased survival and better development of the plants than those already present in the natural environment. Similar results were obtained in a more arid region [34]. These findings indicate that the establishment of a nursery for the production of mangrove seedlings within the natural environment is an essential complementary strategy for the recuperation of these habitats, especially where the natural regeneration process in relatively slow and discontinuous.

3.3. Seedling Growth

The results of the ANOVA for seeding growth (**Table 3**) indicated that there was no significant difference in growth (height) among the seedlings of *R. mangle*, *A. germinans* or *L. racemosa* analyzed from the mangrove substrate (ANOVA: F = 0.17, d.f. = 2, $p > 0.05$, **Figure 3(a)**). Similarly, no significant difference was recorded for the sandy substrate (F = 0.15, d.f. = 2, $p > 0.05$, **Figure 3(b)**) or latosol (F = 0.11, d.f. = 2, $p > 0.05$, **Figure 3(c)**). These findings contradict those reported by Castanheira and Carrasco [11], who recorded the highest growth rates in seedlings grown in a peat-sand mix.

Overall, then, the results of the present study indicated that an adequate chemical and physical composition of the substrate is essential for the rapid growth and development of the seedling of mangrove tree species (*R. mangle*, *A. germinans*, and *L. racemosa*). It is important to remember, however, that the propagules of these species are able to develop independently of the substrate tested. In fact, the propagules of these species retain sufficient reserves of nutrients in order to guarantee the establishment of their cotelydons, even after nine months. During the initial growth period, the cotelydons are fundamentally important for the absorption of resources prior to germination, and even after this process, when they emerge from the tegument of the seed to initiate photosynthesis [35]. Clearly, then, the mangrove species analyzed in the present study are highly productive under nursery conditions [36], which is highly advantageous for the recuperation and restoration of degraded mangrove habitats.

4. Conclusion

The results of the present study indicate that the seedlings of *R. mangle* and *A. germinans* survived at higher

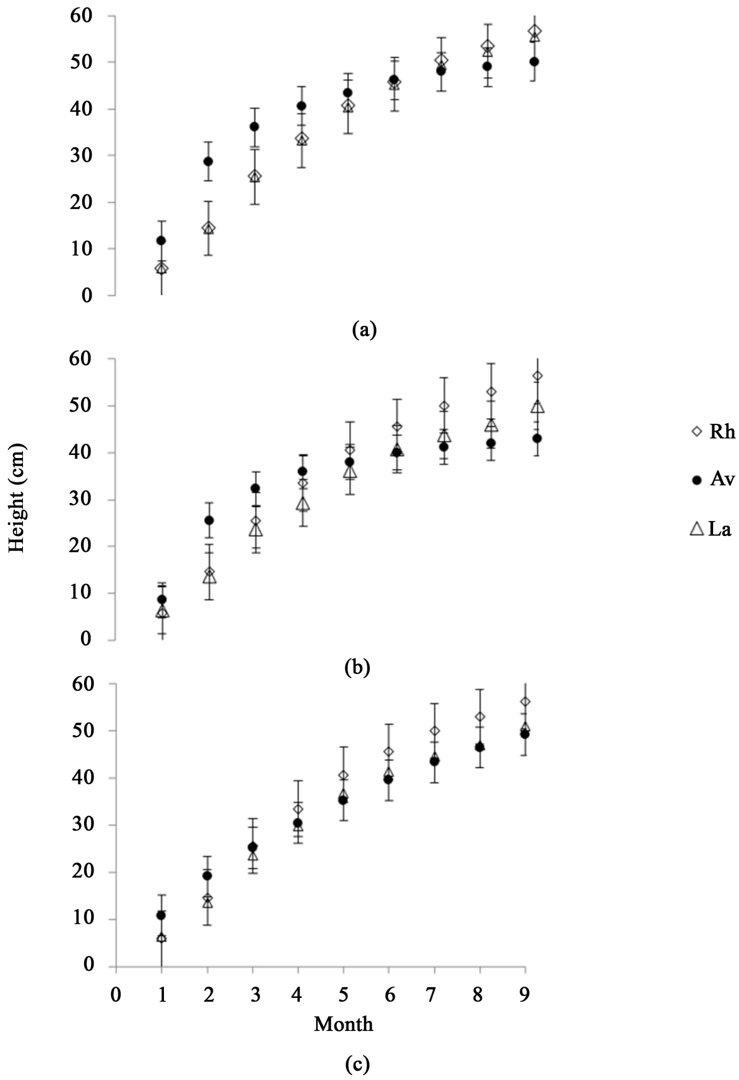

Figure 3. Growth of the seedlings of *Rhizophora mangle* (Rh), *Avicennia germinans* (Av), and *Laguncularia racemosa* (La) in mangrove soil (a); sand substrat (b) and latosol substrat (c) over a nine month period in the nursery at Taperaçu-Campo, Bragança, Pará, Brazil.

Table 3. Results of the ANOVA for the growth (cm) of the seedlings of the mangrove tree species (Rh = *Rhizophora mangle*, Av = *Avicennia germinans*, and La = *Laguncularia racemosa*) in the three types of substrate tested over the nine month period. Values are the means ± standard deviation for each species. MS = mean square, F = F value (ANOVA), *p* = significance at the 5% level.

Source of variation	(Rh ± SD) × (Av ± SD) × (La ± SD)	MS	F	*p*
spp. × mangrove soil	(36.32 ± 16.85) × (39.35 ± 11.74) × (35.82 ± 16.45)	41.23	0.17	0.83
spp. × sand	(36.10 ± 16.67) × (34.04 ± 10.33) × (32.82 ± 16.45)	34.89	0.15	0.85
spp. × latosol	(36.06 ± 16.63) × (32.29 ± 12.24) × (32.62 ± 14.62)	27.37	0.11	0.89

rates on the substrates tested in the nursery than *L. racemosa*. However, all three species grew well in the substrates tested, and the production of seedlings in yellow latosol would appear to be the most effective approach, considering the availability of this material on the Amazon coast and its ease of use, as well as the potential avoidance of further intervention into the mangrove ecosystem.

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