Nativa, Sinop, v. 7, n. 6, p. 800-806, nov./dez. 2019.
Pesquisas Agrárias e Ambientais
DOI: http://dx.doi.org/10.31413/nativa.v7i6.7919
http://www.ufmt.br/nativa
ISSN: 2318-7670

# Timber species performance in secondary forests with over used soils in Eastern Amazonia

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Recebido em fevereiro/2019; Aceito em maio/2019.

**ABSTRACT:** This study had as objective to find appropriate timber species to recover secondary forests on over used soils in Eastern Amazonia, Brazil. Survival and growth of 5,383 seedlings, from eight species planted in the raining season of 1993 through enrichment planting, were monitored during 15 years. Each seedling was planted on East-West 3-m-wide lines opened in secondary forest, fertilized with cow dung and NPK, and liberated against lianas and non-commercial species. The species (treatments) were compared through a GLM with ANOVA and means through the Scheffé test ($p \leq 0.05$). Crown quality, bole commercial usage, bole bifurcation and inclination, resprouts, defoliation, lianas, and attacks by termites and fungi were also assessed and compared using multivariate analysis. All species presented survival percentages > 95% in year 1 and ≥ 90% in year 15 with *Schizolobium parahyba* var. *amazonicum* having the highest total and bole heights, 15.71 ± 5.22 m and 11.68 ± 3.91 m, respectively. *S. parahyba*, *C. goeldiana*, *H. courbaril*, and *T. grandis* were the most appropriated species to recover secondary forests on over used soils in Eastern Amazonia.
**Keywords:** silvicultural treatments; fast growing species; *Schizolobium parahyba*; *Cordia goeldiana*; *Hymenaea courbaril*.

## Performance de espécies madeireiras em florestas secundárias com solos sobre utilizados na Amazônia Oriental

**RESUMO:** Este estudo teve como objetivo encontrar espécies madeireiras apropriadas para recuperar florestas secundárias sobre solos sobre utilizados na Amazônia Oriental, Brasil. Sobrevivência e crescimento de 5.383 mudas, de oito espécies plantadas na estação chuvosa de 1993 por meio de plantio de enriquecimento, foram monitoradas durante 15 anos. Cada muda foi plantada em linhas Leste-Oeste de 3 m de largura abertas em floresta secundária, adubada com esterco de gado e NPK e liberada contra lianas e espécies não comerciais. As espécies (tratamentos) foram comparadas por meio de um GLM com ANOVA e as médias com o teste de Scheffé ($p \leq 0,05$). Qualidade da copa, uso comercial do fuste, bifurcação do fuste e inclinação, rebrotações, desfolhamento, lianas e ataques por cupins e fungos também foram avaliados pelo uso de análise multivariada. Todas as espécies apresentaram percentagens de sobrevivência > 95% no ano 1 e ≥ 90% no ano 15 com *Schizolobium parahyba* var. *amazonicum* tendo maiores alturas total e de fuste, 15,71 ± 5,22 m e 11,68 ± 3,91 m, respectivamente. *S. parahyba*, *C. goeldiana*, *H. courbaril* e *T. grandis* foram as espécies mais apropriadas para recuperar florestas secundárias sobre solos sobre utilizados na Amazônia Oriental.
**Palavras-chave:** tratamentos silviculturais; espécies de rápido crescimento; *Schizolobium parahyba*; *Cordia goeldiana*; *Hymenaea courbaril*.

## 1. INTRODUCTION

In the tropics, agriculture and livestock are the current main forces to promote the replacement of primary forests by secondary forests (CHAZDON, 2012). In this situation, the soil initially covered by primary forests is intensively used with crop fields and pastures under no conservation practices, which results in remarkable losses in its natural fertility (JOSLIN et al., 2011). Low soil fertility is the main cause of land abandonment by farmers. Abandoned lands, with over used soils after agriculture and livestock activities, are currently the most important environments in the tropics to offer space and conditions for a secondary forest to start and get established (ASNER et al., 2009).

Secondary forests on over used soils normally have low ecological productivity (FIGUEIREDO et al., 2014). This reflects in low ecological productivity and low growth rates of the established trees. As a consequence, possible economic uses of these forests, especially for timber-products are undermined. One alternative to recover low ecological productivity and unprofitable economic returns of secondary forests in the tropics is the application of enrichment planting with timber species. These species must be well adapted to the local conditions in order to succeed the forest recovery.

Enrichment planting speeds up forest recovery and nutrients transference from lower soil layers to the soil surface through litter storage (RIBEIRO et al., 2011). Regarding the tree species conservation, enrichment planting can: a) improve the regeneration of logged forests (SCHWARTZ et al., 2013; SCHWARTZ et al., 2017); b) recover the species composition of degraded forests; c) increase densities of rare commercial species; and d) protect endangered species. Besides these ecological advantages, enrichment planting in secondary forests can also bring higher economic returns when high value timber species are planted and tended (SCHWARTZ; LOPES, 2015). Among the ways how enrichment planting is applied, lines opened in the established secondary vegetation filled by fast growing and high economic value species can be an effective alternative. This treatment can not only speed up growth rates of the planted species but the growth rates of individuals belonging to commercial species that naturally occur in managed forests.

Enrichment planting to recover ecological productivity and improve economic profitability of secondary forests, especially those on over used soils, is a feasible alternative in the tropics. This becomes even more important due to the fact that secondary forests are dominant in most of the forest landscapes in the tropical ecosystems. In Brazilian Amazonia, although there are primary forests covering 80% of its territory, secondary forests have increased rapidly in terms of area and economic importance (CORDEIRO et al., 2017). The Eastern and Southern portions of Amazonia in Brazil are the areas mostly covered by secondary forests in this biome, which demand better silvicultural treatments and techniques to become more productive.

The objective of this study was to find the most appropriate timber species for recovering secondary forests raised on over used soils in Eastern Amazonia. From a set of eight tested species, growth and mortality were assessed through an experiment of enrichment planting in a secondary forest. The authors have the hypothesis that the timber species *Schizolobium parahyba* var. *amazonicum*, *Cordia goeldiana*, and *Hymenaea courbaril* are the most appropriate to recover secondary forests in the region due to their following features: a) high survival; b) fast growth; c) growth over chemically poor soils.

## 2. MATERIALS AND METHODS

### 2.1. Study area

This study was carried out in the Northeast of Pará state, Brazil, Eastern Amazonia, the most important agriculture frontier in the Brazilian Amazonia from 1800 to 1950. After nearly 200 years of slash-and-burn agricultural practices in the region, its naturally poor soils in nutrients lost even more fertility and capacity of water retention.

These over used soils currently do not permit a satisfactory regeneration of native and commercial tree species. In the region, abandoned lands are rapidly dominated by aggressive and opportunist species of herbs, lianas and grasses as *Acalypha arvensis*, *Elephantopus mollis*, *Veronia scabra*, *Cyperus diffusus*, *Mimosa pudica*, *Memora flavida*, and *Brachiaria* spp.

The study area, Fazenda Tramontina, is part of the hydrographic basin of the lower river Capim, sub-basin of the river Candiru-Miri. It is located at Km 60, BR-010 highway (2°10’02”S and 47°32’00”W), municipality of Aurora do Pará, Pará state, Brazil. An experiment was set up in a 30-year secondary forest raised after the abandonment of pastures on over used soils. The original dominant vegetation was equatorial rain forest (RIZZINI, 1963). *Hymenaea coubaril*, *Hymenolobium* spp., *Pouteria* spp., *Protium* spp., *Copaifera reticulata*, and *Simarouba amara* are the most common tree species naturally found in the region.

According to the Köppen classification, the climate is humid tropical Am3 (ANDRADE et al., 2017), with rainy season from January to June. Using a station placed at 2,000 m from the experiment, the following climatological information was obtained for the time interval of 2000 to 2014: a) precipitation = 2,900 mm, b) temperature = 26 to 35 ºC, and c) average air humidity = 74%. The relief is flat to lightly undulated with sandy-clayey yellow Latossols having low values of pH, N, and P (CORDEIRO et al., 2015; CORDEIRO et al., 2016).

### 2.2. Study species, experimental design, and statistical analysis

Six native tree species from Eastern Amazonia, and the exotic species *Myracrodruon urundeuva* and *Tectona grandis* (Table 1) were planted through enrichment planting in lines. The experiment was set up in a 62.5-ha area, where each treatment was represented by one species. East-West 3-m-wide lines separated 5 m from each other were opened into the secondary forest that replaced the abandoned pasture. A total of 94 lines were planted with 5,383 seedlings measuring 45 cm in average height. Seedlings from the eight tested species were planted along the raining season of 1993 and distributed randomly in distances of 4 m between each individual. Each seedling, when planted, was fertilized with 500 g of cow dung.



Table 1. Family, ecological group, growth speed, number of planted individuals, and survival in years 1 and 15 of eight timber species in an enrichment planting experiment in secondary forest, Fazenda Tramontina, Pará state, Eastern Amazonia, Brazil.
Tabela 1. Família, grupo ecológico, velocidade de crescimento, número de indivíduos plantados e sobrevivência nos anos 1 e 15 de oito espécies madeireiras em um experimento de plantio de enriquecimento em floresta secundária na Fazenda Tramontina, estado do Pará, Amazônia Oriental, Brasil.

| Species | Family | EG | GS | PI | S (%) | |
|---|---|---|---|---|---|---|
| | | | | | Year | |
| | | | | | 1 | 15 |
| *Schizolobium parahyba* var. *amazonicum* | Fabaceae | LLP | F | 1,638 | 100.0 | 94.6 |
| *Tectona grandis* L.f. | Lamiaceae | LLP | F | 20 | 95.9 | 90.0 |
| *Cordia goeldiana* Huber | Boraginaceae | PST | F | 25 | 100.0 | 92.0 |
| *Myracrodruon urundeuva* Allemão | Anacardiaceae | PST | F | 856 | 98.0 | 93.7 |
| *Handroanthus serratifolius* (Vahl) S.O. | Bignoniaceae | PST | M | 1,278 | 95.7 | 91.9 |
| *Hymenaea courbaril* L. | Fabaceae | PST | M | 286 | 99.0 | 94.4 |
| *Cedrela odorata* L | Meliaceae | PST | S | 50 | 96.4 | 94.0 |
| *Swietenia macrophylla* King | Meliaceae | PST | S | 1,230 | 97.2 | 94.0 |
| Total | - | - | - | 5,383 | 97.9 | 93.6 |

EG= Ecological group, GS = Growth speed (F = Fast, M = Medium, S = Slow), PI= Planted individuals, S=Survival, LLP = long-lived pioneer, PST = partially shade tolerant, and TST = totally shade tolerant.

After planting, nine applications with 150 g of NPK (10:28:20) per plant were distributed in three times per year along the years 1, 2, and 3 from the experiment establishment. Liberation of the planted seedlings against the competing vegetation (lianas and non-commercial pioneer species) was done once a year in the years 4 to 8. Non-competing individuals of commercial species naturally regenerated inside the experimental area were maintained. Survival (percentage of live individuals) and total height of the planted seedlings were measured at years 1 and 15. Bole height (commercial height) and the diameter at the breast position (DBH) at 1.30 m from the ground were assessed only at year 15. Total and bole height was measured using the method of angles overlap (SILVA; PAULA NETO, 1979). From the data collected at year 15, the individuals were arranged in five DBH classes to assess the homogeneity of growing for each tested species as follows: (1) DBH < 10 cm; (2) 10 cm ≤ DBH < 20 cm; (3) 20 cm ≤ DBH < 30 cm; (4) 30 cm ≤ DBH < 40 cm; and (5) DBH ≥ 40 cm.

Crown quality and bole commercial usage were also evaluated. Crown quality was ranked according to the Dawkins' method adapted by Synnott (1979) in three categories: (1) full crown well distributed around the bole; (2) crown with a few broken branches; and (3) incomplete crown with more than 50% of the branches broken or absent. Bole commercial usage was evaluated through the percentage of the bole able for commercial use, in three categories: (1) 80-100%; (2) 50-79%; and (3) less than 50%.

In each individual, at year 15, was recorded the presence of bole bifurcation and inclination, resprout, defoliation, lianas, and attacks of termites and fungi. Continuous variables were compared through a general linear model (GLM) with ANOVA. Means were compared using Scheffé test ($p \leq 0.05$). To define a global classification, a factor analysis was used considering continuous and discrete variables. The eingen-values selection of the principal components was applied according to the Kaiser method (JOHNSON; WICHERN, 1998) with $|\lambda| \geq 0.40$.



## 3. RESULTS

### 3.1. Survival and growth

High survival percentages were observed in all tested species (Table 1), from a total of 5,383 planted individuals, 5,041 were alive at year 15. The fast-growing species *Schizolobium parahyba* var. *amazonicum*, *Tectona grandis*, and *Cordia goeldiana* showed the highest total height in both years 1 and 15. These three species and *Hymenaea courbaril* had the highest bole height (Table 2). *S. parahyba* presented the best growing performance with the highest percentages of individuals in the size classes 3, 4, and 5 while *Handroanthus serratifolius* had no individuals in these classes (Figure 1).

### 3.2. Qualitative variables

*S. parahyba* had the best performance in crown quality and bole commercial usage (classes 1 and 2), followed by *Swietenia macrophylla* and *H. courbaril*. The other species had high percentages of low crown quality and bole commercial usage (class 3). With almost 80% of the individuals in class 4, *H. serratifolius* had the worst performance in bole commercial usage (Figure 2).

Table 2. Total height (TH) and bole height (BH) of eight timber species in years 1 and 15 (mean ± SD) of an enrichment planting experiment in secondary forest, Fazenda Tramontina, Pará state, Eastern Amazonia, Brazil. Note that BH was not measured in year 1.

Tabela 2. Altura total (TH) e altura do fuste (BH) de oito espécies madeireiras nos anos 1 e 15 (média ± DP) de um experimento de plantio de enriquecimento em floresta secundária na Fazenda Tramontina, estado do Pará, Amazônia Oriental, Brasil. Note que BH não foi medida no ano 1.

| | Year 1 | Year 15 | |
|---|---|---|---|
| Species | TH (m) | TH (m) | BH (m) |
| *SPA* | 1.37 ± 0.35ª | 15.71 ± 5.22ª | 11.68 ± 3.91a |
| *TGR* | 1.26 ± 0.25ª | 12.11 ± 3.76b | 5.78 ± 2.41cd |
| *CGO* | 1.26 ± 0.27ª | 12.22 ± 4.12b | 7.09 ± 2.72bc |
| *MUR* | 0.79 ± 0.13c | 5.77 ± 2.47c | 3.85 ± 1.66cd |
| HSE | 0.78 ± 0.17c | 4.40 ± 2.7 c | 2.65 ± 3.02d |
| HCO | 1.10 ± 0.27b | 10.87 ± 3.96b | 6.77 ± 2.52bc |
| COD | 1.12 ± 0.24b | 10.34 ± 3.67b | 5.51 ± 1.98cd |
| SMA | 0.82 ± 0.17c | 7.88 ± 3.99bc | 5.10 ± 2.78cd |

Letters indicate significant differences in the Scheffé test ($\alpha = 0.05$). Species = SPA (*S. parahyba*), TGR (*T. grandis*), CGO (*C. goeldiana*), MUR (*M. urundeuva*), HSE (*H. serratifolius*), HCO (*H. courbaril*), COD (*C. odorata*), SMA (*S. macrophylla*).

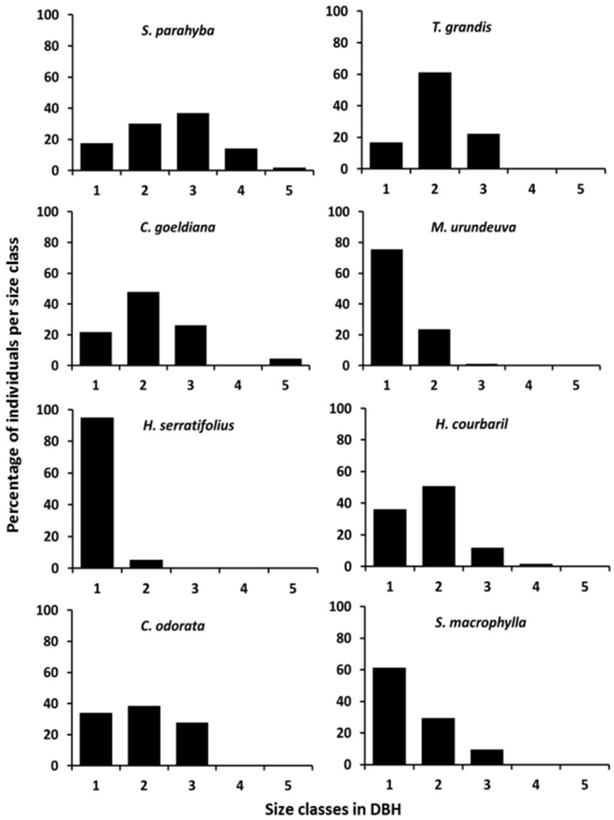


Figure 1. Distribution in size classes of individuals belonging to eight study species in an enrichment planting experiment over secondary forest in Fazenda Tramontina, Pará state, Eastern Amazonia, Brazil. The size classes are: (1) DBH < 10 cm; (2) 10 cm ≤ DBH < 20 cm; (3) 20 cm ≤ DBH < 30 cm; (4) 30 cm ≤ DBH < 40 cm; and (5) DBH ≥ 40.

Figura 1. Distribuição diamétrica de indivíduos pertencentes a oito espécies estudadas em um experimento de plantio de enriquecimento em floresta secundária na Fazenda Tramontina, estado do Pará, Amazônia Oriental, Brasil. As classes diamétricas são: (1) DAP < 10 cm; (2) 10 cm ≤ DAP < 20 cm; (3) 20 cm ≤ DAP < 30 cm; (4) 30 cm ≤ DAP < 40 cm; and (5) DAP ≥ 40.

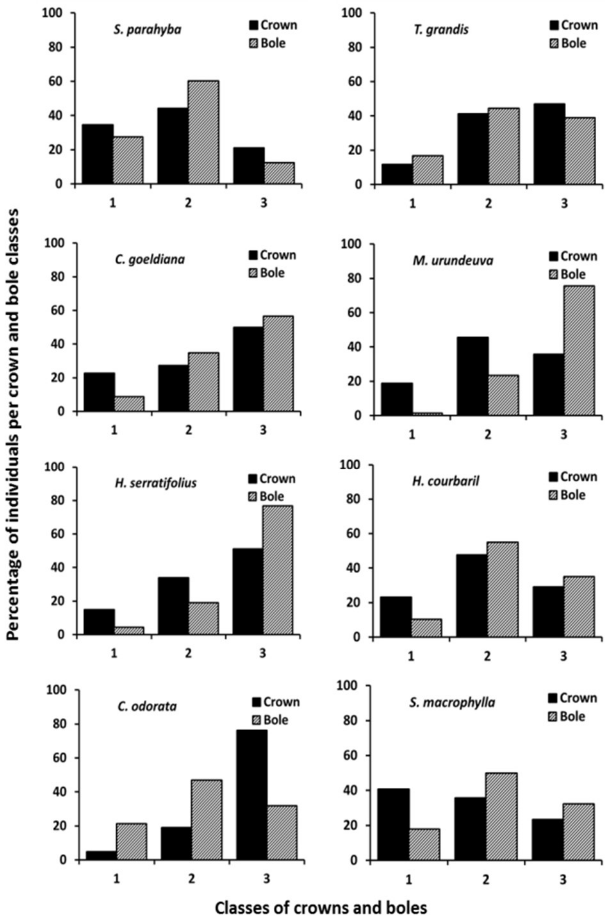


Figure 2. Distribution of individuals in eight study species per classes of crown quality ("1" full and well distributed, "2" with a few broken branches, and "3" more the 50% of branches broken) and bole percentage for commercial usage ("1" 80-100% commercial, "2" 50-79% commercial, and "3" less than 50% commercial) in an enrichment planting experiment on a secondary forest in Fazenda Tramontina, Pará state, Eastern Amazonia, Brazil.
Figura 2. Distribuição de indivíduos e oito espécies estudadas por classes de qualidade da copa ("1" cheia e bem distribuída, "2" com alguns galhos quebrados e "3" mais de 50% de galhos quebrados) e percentagem de uso comercial ("1" 80-100% comercial; "2" 50-79% comercial e "3" menos de 50% comercial) em um experimento de plantio de enriquecimento em floresta secundária na Fazenda Tramontina, estado do Pará, Amazônia Oriental, Brasil.

*T. grandis*, *C. goeldiana*, and *S. parahyba*, had more than 5% of bole bifurcation, inclination, and resprout. Defoliation was higher than 5% in *T. grandis* and *Cedrela odorata* while the presence of lianas was substantially high in all tested species. Sanitary conditions of the planted individuals were very good, only *T. grandis* had more than 5% of the individuals attacked by termites while no species were significantly infested by fungi (Table 3).

In the principal component analysis (PCA), PCA I responded by 39.5% of the global variation and significant eingenvectors for DBH, bole height, bole commercial usage, and lianas. PCA II had 26.3% of the global variation and crown quality, bifurcation, defoliation, and termites as the significant eigenvalues (Table 4). From the PCA I and II results, the species and variables were ordinated as follows: (1) species with best dendrometric features, crown quality, and commercial bole – *S. parahyba*, *H. courbaril*, and *S. macrophylla*; (2) species with good dendrometric features but, with bifurcation, defoliation, and termites – *C. odorata* and *T. grandis*; (3) species with poor dendrometric features and high presence of lianas – *H. serratifolius* and *M. urundeuva* (Figure 3).

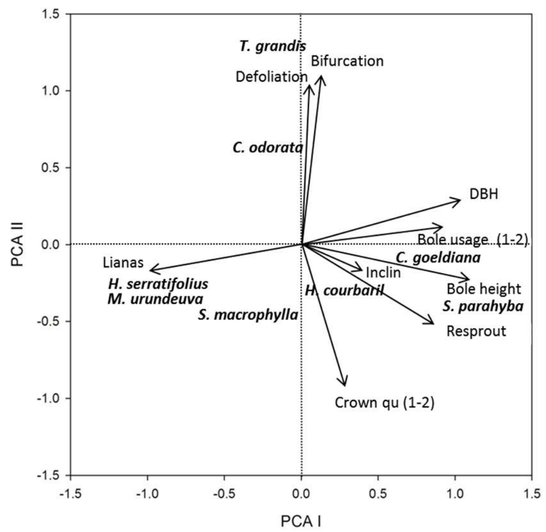


Figure 3. Ordination from the principal component analysis (PCA), which includes the eight study species and 11 growing, dendrometric, and sanitary variables.
Figura 3. Ordenação da análise de componente principal (PCA), a qual incluí as oito espécies estudadas e 11 variáveis de crescimento, dendrométricas e sanitárias.



Table 3. Percentage of individuals of eight timber species with bifurcation, resprout, inclination, defoliation, termites, lianas, and fungi in an enrichment planting experiment on a secondary forest in Fazenda Tramontina, Pará state, Eastern Amazonia, Brazil.
Tabela 3. Percentagem de indivíduos de oito espécies madeireiras com bifurcação, rebrotações, inclinação, desfolhamento, cupins, lianas e fungos em um experimento de plantio de enriquecimento em floresta secundária na Fazenda Tramontina, estado do Pará, Amazônia Oriental, Brasil.

| Species | Bif | Inc | Res | Def | Lia | Ter | Fun |
|---|---|---|---|---|---|---|---|
| *SPA* | 0.1 | 1.0 | 7.1 | 3.2 | 7.1 | 2.3 | 0.0 |
| *TGR* | 5.6 | 0.0 | 0.0 | 5.6 | 22.2 | 11.1 | 0.0 |
| *CGO* | 0.0 | 8.7 | 0.0 | 4.3 | 8.7 | 4.3 | 0.0 |
| *MUR* | 1.0 | 2.8 | 2.0 | 2.7 | 37.0 | 2.2 | 0.0 |
| HSE | 2.7 | 0.5 | 1.3 | 2.2 | 31.6 | 0.9 | 0.5 |
| HCO | 3.7 | 2.6 | 0.0 | 0.4 | 21.4 | 2.6 | 0.0 |
| COD | 0.0 | 0.0 | 0.0 | 17.0 | 19.1 | 2.1 | 0.0 |
| SMA | 1.1 | 3.3 | 1.9 | 0.4 | 27.3 | 1.9 | 0.0 |

B- Bifurcation, I-Inclination, R-Resprout, Def-Defoliation, Lia-Lianas, Ter-Termites, Fun- Fungi. Species = SPA (*S. parahyba*), TGR (*T. grandis*), CGO (*C. goeldiana*), MUR (*M. urundeuva*), HSE (*H. serratifolius*), HCO (*H. courbaril*), COD (*C. odorata*), SMA (*S. macrophylla*).

Table 4. Eingenvalues and eingenvectors of principal component analysis (PCA) with 11 growing, dendrometric, and sanitary variables of eight study species.
Tabela 4. Eingenvalues e eingenvectors da análise de componente principal (PCA) com 11 variáveis de crescimento, dendrométricas e sanitárias de oito espécies estudadas.

| Variable | PCA I | PCA II | PCA III | PCA IV |
|---|---|---|---|---|
| DBH | 0.467 | 0.143 | 0.164 | -0.075 |
| Bole height | 0.492 | -0.101 | -0.008 | -0.008 |
| Crown quality (1 and 2) | 0.133 | -0.405 | -0.449 | -0.310 |
| Bole commerc. usage (1 and 2) | 0.410 | 0.056 | -0.213 | 0.334 |
| Bifurcation | 0.055 | 0.504 | -0.299 | -0.370 |
| Inclination | 0.109 | -0.055 | 0.627 | -0.466 |
| Resprout | 0.371 | -0.222 | -0.238 | 0.148 |
| Defoliation | 0.030 | 0.486 | 0.141 | 0.517 |
| Lianas | -0.444 | -0.073 | -0.277 | 0.081 |
| Termites | 0.055 | 0.504 | -0.299 | -0.370 |
| Fungi | 0.000 | 0.000 | 0.000 | 0.000 |
| Eigen-values | 3.946 | 2.628 | 1.646 | 1.254 |
| Var. (%) | 39.456 | 26.275 | 16.462 | 12.540 |
| Var. (%) accumulated | 39.456 | 65.732 | 82.193 | 94.733 |

Underlined values indicate $|\lambda| \geq 0.40$.

# 4. DISCUSSION

## 4.1. Survival and growth

Elevated survival percentages of the study species can be related to the low competition for light faced by the planted seedlings. The favorable survival conditions in the experiment can be due to: a) East-West 3-m-wide lines opened into the secondary vegetation; b) further individual liberation treatment; and c) fertilization of the planted seedlings. These results were similar to the survivorship observed in monoculture commercial plantings (95 to 100%) in the region. *S. parahyba* has showed high survivorship in homogeneous plantings in Northern Amazonia (TONINI et al., 2008) and inside logging gaps in Eastern Amazonia (KEEFE et al., 2009; GOMES et al., 2010; SCHWARTZ et al., 2017). The high survival percentage of *C. goeldiana* is similar to values found by Sabogal et al. (2006) in enrichment planting through lines. *C. goeldiana*, in enrichment planting inside logging gaps, had 89% of survival in the first months after planted (GOMES et al., 2010).

High total heights of the long-lived pioneer *S. parahyba* and *T. grandis* and by the partially shade tolerant *C. goeldiana* in years 1 and 15 agree with results from several areas in Amazonia (SABOGAL et al., 2006; TONINI et al., 2008; GOMES et al., 2010). High values of total height and DBH for *S. parahyba* were also reported by Cordeiro et al. (2015) and Silva et al. (2011). Shade-intolerant species invest significantly in growing during their initial development phases. Species with such ecological strategy are recommendable for timber species assigned to recover degraded primary forests and secondary forests.

*Tectona grandis*, although being a fast-growing species, had low bole commercial height, which can indicate a still poor adaptation of this Asian species in Eastern Amazonia. This result is similar to most of the commercial plantings in the region, in which *T. grandis* does not show satisfactory growth and dendrometric features for timber production. *C. odorata* had intermediate growth in relation to the other study species, but higher than results from other studies in the region. *C. odorata* naturally presents intermediate survival percentages and slow growth rates (SOUZA et al., 2010). These variables have improved under experimental enrichment plantings (GOMES et al., 2010; RONDON NETO et al., 2011, Figure 2). The good performance of *H. courbaril* comes from its shade-tolerance and low demand for soil fertility and humidity. *H. courbaril* normally presents low growth rates in the initial years, but with high survivorship. The species had high survival percentages 11 years after planting (SOUZA et al., 2008) and grew rapidly after 15 years under enrichment planting in Central Amazonia, where fertilization was applied (SILVA et al., 2013).

## 4.2. Qualitative variables

*S. parahyba*, *H. courbaril*, and *S. macrophylla* had best dendrometric results amongst the eight study species (Table 2, Table 3). *H. courbaril*, *S. macrophylla* are normally found in primary forests under extremely low densities. Plantings of these high financial value species have increased in Amazonia, but with little information on their use to enrich secondary forests. On the other hand, *S. parahyba* has been largely planted in monocultures, especially in Southeastern Amazonia. However, its use to enrich secondary forests is also poorly known.

Lianas strongly infested the whole experiment, even though their constant control through liberation. The liana control was the most time-costly activity in the experiment, done exclusively physically with machetes. Liana infestation was constant along all time of the experiment monitoring. Massive presence of lianas can undermine plantings for commercial and recovery purposes in secondary forests due to the strong competition for light.

Bifurcation, defoliation, and the presence of lianas, termites, and fungi can be related to high levels of forest degradation (SCHUHLI; PALUDZYSZYN FILHO, 2010). This was the case of the experimental site used in this study, which had a long history of soil degradation. Defoliation is related to phenological features of the species, soil, and climate conditions where the plant grows. As indicated by the PCA analysis, *S. parahyba*, *H. courbaril*, and *S. macrophylla* presented the best dendrometric characteristics throughout the experiment (Figure 3). In opposition to these species, *H. serratifolius* and *M. urundeuva* did not seem to be good species to recover secondary forests in initial successional stages. Their survival, however, was high by the year 15, which may indicate that the individuals will remain growing slowly but constantly after year 15.

## 4.3. Recommendations

Species with survival percentages higher than 75% can succeed to recover degraded forests. Based on growth, survivorship, dendrometric, and sanitary results during 15 years of monitoring eight species, *S. parahyba*, *C. goeldiana*, *H. courbaril*, and *T. grandis* can be recommended to recover secondary forests on over used soils in Eastern Amazonia. *S. parahyba* and *C. goeldiana* had great performance in growth (the two highest total and bole height amongst the study species) and survivorship. *H. courbaril* is recommended due to its good growth and survival performance. Moreover, the species demands little soil fertility and humidity. *T. grandis* did not perform well in dendrological and sanitary variables but had good growth and survivorship. Trees planted through enrichment planting can also bring economic returns, since they belong to high financial value species. After 15 years, the planted individuals are still not ready to be harvested for commercial timber production. However, if their growth performance remains, commercial returns can come within 25 years after planting.

A combination of several fast-growing with a few resistant slow-growing tree species is an enrichment planting arrangement that can be recommend for forests in Eastern Amazonia. Such arrangement can also be used in other tropical forests worldwide. A species combination permits the recovery of soil nutrients, formation of a complex canopy, and it also brings perspectives of financial returns.

## 5. CONCLUSIONS

Fifteen years after planting, the study timber species had a good performance in growth and survivorship. The study species, except *T. grandis*, are adapted to the conditions of the region's climate and soil and to the silvicultural treatments applied. The species also showed good dendrometric features, but with high presence of lianas. *S. parahyba*, *C. goeldiana*, *H. courbaril*, and *T. grandis* presented best performances to be used in enrichment planting for recovering secondary forests on over used soils in Eastern Amazonia. Planting arrangements including several fast-growing species with a few slow-growing species can be an effective alternative to recover fertility, forest structure, and timber production of secondary forests on over used soils.

## 6. ACKNOWLEDGEMENTS

We are grateful to the company Tramontina Belém S.A for its support in infrastructure and logistics in both the establishment and monitoring of the experiment.

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