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# Tree species for agroforestry enrichment of monoculture of *Calophyllum brasiliense* Cambess in a floodplain

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**ABSTRACT:** To restore degraded floodplains with agroforestry systems (AFS), more ecological knowledge about native species is needed. This research aimed to evaluate the survival, growth, and biomass input of native trees planted and managed in an AFS to enrich a monoculture of *Calophyllum brasiliense*. The findings, which are encouraging for the future of agroforestry, revealed that available light did not limit survival and growth in these groups. The pioneers grew faster, although the greatest height was in *Sesbania virgata*, *Schinus terebinthifolius*, *Handroanthus impetiginosus*, *Inga vera* and *Citharexylum myrianthum*. However, the higher relative growth rates indicate that *E. verna*, *P. grandiflorum*, and *Anadenanthera colubrina* have grown more in the last 15 months than *S. virgata*. The three species with the largest canopy radius were *S. terebinthifolius*, *I. vera* and *C. myrianthum*, the most significant contribution of the phytomass supply during pruning was from *S. virgata* and *S. terebinthifolius*. *Euterpe edulis* and *S. virgata* intercropping supported the palm tree in overcoming climatic extremes between the lines of *C. brasiliense*. This research highlights the potential of AFS to innovate for a sustainable agricultural and forestry production future that aligns with ecological restoration requirements.
**Keywords:** Atlantic Forest; forest landscape restoration; native tree; *Euterpe edulis*; agroforestry management.

## Espécies arbóreas para enriquecimento agroflorestal da monocultura de *Calophyllum brasiliense* Cambess em várzea

**RESUMO:** Para restaurar planícies aluviais com sistemas agroflorestais (SAF), é necessário mais conhecimento ecológico sobre as espécies nativas. Esta pesquisa teve como objetivo avaliar a sobrevivência, o crescimento e o aporte de biomassa de arbóreas plantadas e manejadas em SAF para enriquecimento de uma monocultura de *Calophyllum brasiliense*. Foram avaliadas oito espécies pioneiras e oito não pioneiras, totalizando 375 árvores em oito parcelas de 216m². A luz disponível não limitou a sobrevivência e o crescimento nestes grupos. As pioneiras cresceram mais rápido, embora a maior altura tenha sido observada em *Sesbania virgata*, *Schinus terebinthifolius*, *Handroanthus impetiginosus*, *Inga vera* e *Citharexylum myrianthum*. Contudo, as maiores taxas de crescimento relativo indicam que *E. verna*, *P. grandiflorum* e *Anadenanthera colubrina* cresceram mais nos últimos 15 meses do que *S. virgata*. As três espécies com maior raio de copa foram *S. terebinthifolius*, *I. vera* e *C. myrianthum*, e a maior contribuição no aporte de fitomassa na poda foi de *S. virgata* e *S. terebinthifolius*. O consórcio de *Euterpe edulis* e *S. virgata* apoiou a palmeira a superar o estresse térmico e hídrico nas entrelinhas de *C. brasiliense*. Os SAF inovam para um futuro de produção agrícola e florestal sustentável alinhada com as exigências de restauração ecológica.
**Palavras-chave:** Mata Atlântica; restauração da paisagem florestal; árvore nativa; *Euterpe edulis*; manejo agroflorestal.

## 1. INTRODUCTION

Agroecology is an emergent science that intends to plan and manage sustainable agroecosystems with ecological principles (GLIESSMANN, 2001). Intercropping multi-species shrubs and trees is one the basis of a sustainable agroecological system. Diversified agroecosystems may reduce the dependence on external inputs (STEENBOCK; VEZZANI, 2013). It may also increase resilience in the climate change scenario (ALTIERI; NICHOLLS, 2017) and provide ecological support for restoration through ecosystem services (PONTES et al., 2019), such as carbon fixation, to improve environmental quality and human well-being (MARTINS; RANIERI, 2014; PONTES et al., 2019).

The United Nations General Assembly of 2019 declared 2021-2030 as the 'UN Decade on Ecosystem Restoration' (ROMANELLI et al., 2023). Forest landscape restoration is a relatively new approach involving stakeholders in all affected land-use sectors. It relies on participatory decision-making processes that have been used to define the process of regaining ecological functionality and enhancing human well-being in rural deforested landscapes by embracing a broad range of 'restorative practices' that include ecological restoration, agroforestry, and monoculture tree plantations, among others practices (SABOGAL et al., 2015).

Successional agroecosystems or agroforestry systems - AFS that are based on agroecology, biodiversity, and succession can return the degraded environment to its natural state after a transitional period of management of native and exotic species (ASSIS et al., 2013; MARTINS; RANIERI 2014; PONTES et al., 2019). Diversifying species may reduce costs, extend management time, and connect farmers to restoration activities. AFS considers each location's natural potential (MELI et al. 2019). Pruning of shrubs and trees is a common practice to supply organic matter, recycle nutrients, and increase light exposure to raise photosynthesis and productivity (VAZ da SILVA, 2000; STEENBOCK; VEZZANI, 2013; MARTINS; RANIERI, 2014; PONTES et al., 2019).

For successional AFS to play its essential role in restoring degraded landscapes, they must assume certain principles and practices, such as restoring the structure, function, and composition of the ecosystem; increasing resilience; restoring connectivity; reclaiming cultural values and practice, and ensuring research and continuous monitoring (MELI et al., 2019). Therefore, AFS that adopt intensive management in the transitional phases must be led over time to complete restoration. When biotic and abiotic resources become sufficient for self-maintaining such systems' structure and function, resistance to regular environmental disturbance without human assistance will be unveiled.

The global interest in nature conservation, ecological restoration, and supplies of forest products has given rise to different trends in silviculture using native species: enriched tree crops, AFS, homogeneous and heterogeneous plantations of native trees, and management of natural regeneration. Although farmers and companies prefer tree monocultures, which are more convenient to manage, multiple species provide many ecosystem services (SCHWEIZER; BRANCALION, 2020). Exploiting non-timber forest products (NTFP) is often considered a low-impact activity in tropical forests like *Euterpe edulis* Mart. For producing the pulp of palm fruits (MULER et al., 2014). Because landscapes combine various land uses, both productive and protective, restoration interventions must use various forest cover approaches to recover degraded ecosystems, including AFS and commercial tree crops, in a multifunctional approach.



Restoration of riparian forests is a priority worldwide. In Brazil's southeastern region, the São Paulo portion of the Paraíba do Sul hydrographic basin stands out (COUTINHO et al., 2018). These formations are the most affected by the growth of cities, industries, agriculture, and extensive pastures (MELI et al., 2019) they favor erosion, reduce soil fertility, and impact biological resource conservation by interfering in the community dynamics, such as promoting the extinction of numerous plant and animal species. AFS is among the most sustainable ways to restore forests in protected spaces. According to Brazilian environmental law, AFS is an alternative to restoration and use of legal reserves (RL) (MARTINS; RANIERI, 2014). They demand research using participatory methods to generate useful adapted trees and productive local arrangements (GLIESSMANN, 2012; SABOGAL et al., 2015; MELI et al., 2019). Plant species' behavior changes considerably in soils with water saturation due to reduced oxygen content available to the roots and changes in nutrient dynamics (OLIVEIRA; JOLY, 2010). Research into new models of sustainable exploitation, such as AFS, can help restore vegetation in fragile floodplain ecosystems (BARBOSA et al., 2017). Studies of this sort will make it possible to estimate, from an ecological and genetic point of view, how or to what extent tree species respond to the different pressures from the environment or even by human action, helping to improve future recommendations effectively.

The revegetation of floodplains that had their original cover removed should first restore the primary levels of biodiversity, improving soil and water conservation. By homogenizing the land's surface with the plant component, flood control and reduction in surrounding areas would occur, reconstituting water functions, which include recharge during flooding and water discharge during drought, when groundwater is released.

This research aims to evaluate the growth of tree species planted in a monoculture of Guanandi (*Calophyllum brasiliense* Cambess) converted into an agroforestry system in temporarily water-saturated areas and describe the agroforestry management practices. The hypothesis is that differences in the behavior of pioneer and non-pioneer trees can support agroforestry management strategies under these conditions.

## 2. MATERIAL AND METHODS

### 2.1. Site Description

The experiment was carried out in an alluvial plain with an average altitude of 540 m and temporary water saturation typical of riverside forest areas, bypassed by the Capituba stream (coordinates 22º53'S and 45º23'W), an affluent of the Paraíba do Sul River. It took place on a century-old farm in Pindamonhangaba, state of São Paulo, Brazil. The mesothermal climate (Cwa), generally with hot and rainy summers and cold and dry winters, was monitored from January 2011 to December 2014.

Since the 1950s, the area has been cultivated with rice (Oryza sativa L.). In 2007, an experimental plot with Guanandi (*Calophyllum brasiliense* Cambess) was established for wood production. This tree species of the Calophyllaceae family naturally inhabits floodable soils from southern Brazil to Central America (OLIVEIRA; JOLY, 2010). *Calophyllum brasiliense* Cambess is recommended for homogeneous plantations, agroforestry systems, and restoration of riparian forests.

Four soil classes were identified: Planosol (Planossolo), Ultisol (Argissolo), Inceptisol (Cambissolo), and Gleysol (Gleissolo). Due to past use, these soils present high density and poor drainage with average values of clay, sand, and silt of 288, 546, and 166 g kg-1, respectively. Low levels of bases and high total acidity characterize the low fertility of these soils, determined in pH (water) = 5.1; H+Al = 3.6 cmolc $dm^{-3}$; P = 8.08 mg $dm^{-3}$; K = 0.19 cmolc $dm^{-3}$; Ca = 1.24 cmolc $dm^{-3}$; Mg = 0.7 cmolc $dm^{-3}$; S.B. = 8.64 cmolc $dm^{-3}$; and organic matter = 2.25 g $kg^{-1}$.

### 2.2. Implementation of the experiment

*Calophyllum brasiliense* Cambess planted in remaining rice terraces, in a 4 x 3 m spacing on windrows raised to 30 cm (833 individuals $ha^{-1}$), providing an environment with more oxygen supply to the roots, as Marconato et al. (2015) proposed. At 54 months of age, the canopy of *Calophyllum brasiliense* Cambess showed a pyramidal shape, an average height of 3.10 m (± 0.43 m), and a radius of 0.90 m (± 0.40 m). They did not cover the soil, favoring weeds controlled with mowing and herbicides.

The research began with participatory methods, recommended by Gliessman (2001) and Sabogal et al. (2015), in July 2011. Farmers participated in planning the successional AFS, selecting known short-cycled plant species for the agroforestry conversion phase. They also helped select tree species to diversify *Calophyllum brasiliense* Cambess monoculture, aiming for landscape restoration and soil management, as proposed by Meli et al. (2019).

The soil was tilled with a plow and a rotary hoe to incorporate dolomitic limestone (2.0 Mg ha-1) and organic compost (1.0 Mg ha-1) at 15 cm depth between the lines of *Calophyllum brasiliense* Cambess, forming a windrow (ca 2.0 x 0.20 m high) where the short-cycle crops and trees were planted.

The experiment contained eight plots of AFS (two plots in each soil class) of 216 m² formed by four rows with six trees of *Calophyllum brasiliense* Cambess on each row. The complete design of the AFS can be seen in Figure 1, and the densities of all plant species in Table 1.

The enrichment planting was carried out between the rows of the annual crop [1st year with artemisia (*Artemisia annua* L.) and in subsequent years in rotation with taro (*Colocasia esculenta* (L.) Schott)] with banana seedlings (*Musa* sp.) and native tree species: 8 forest species of the pioneer successional class [*Bixa orellana* L., *Croton floribundus* Spreng, *Citharexylum myrianthum* Cham., *Inga vera* Willd., *Joannesia princeps* Vell., *Schizolobium parahyba* (Vell.) Blake, *Sesbania virgata* (Cav.) Pers. and *Schinus terebinthifolius* Raddi.]; and eight non-pioneers [*Anadenanthera colubrina* (Vell.) Brenan, *Ceiba speciosa* (A. St.-Hil.) Ravenna, *Erythrina verna* Vell, *Euterpe edulis* Mart., *Handroanthus impetiginosus* (Mart. ex DC.) Mattos, *Handroanthus umbellatus* (Sond.) Mattos, *Magnolia ovata* (A.St.-Hil.) Spreng. and *Pseudobombax grandiflorum* (Cav.) A.Robyns]. The trees were spaced 1.5 m apart and alternated with *Sesbania virgata* (Cav.) Pers. and *Euterpe edulis* Mart. were also planted in the line between the *Calophyllum brasiliense* Cambess. trees and interspersed with the native shrub *Aeschynomene* sp.

The seeds of *Sesbania virgata* (Cav.) Poir. and *Aeschynomene sesban* L. was collected locally on the floodplain. The three tree species [*Handroanthus impetiginosus* (Mart. ex DC.) Mattos, *Anadenanthera colubrina* (Vell.) Brenan, and *Schizolobium parahyba* (Vell.) Blake] were chosen for their potential for the timber industry; of NTFP: the shrubs (*Schinus terebinthifolius* Raddi and *Bixa orellana* L.) for the production of spices; and *Euterpe edulis* Mart. (palm heart). A native palm tree is included in the sustainable economic exploitation of fruits and the value of ecological importance as a bioindicator of environmental resilience (MULER et al., 2014). *Colocasia esculenta* (L.) Schott, banana shrub (*Musa* X *paradisiaca* L.), *Euterpe edulis* Mart., *Inga vera* Willd., *Bixa orellana* L., *Croton floribundus* Spreng., *Handroanthus impetiginosus* (Mart. ex DC.) Mattos and *Magnolia ovata* (A.St.-Hil.) Spreng. are all recommended for AFS focused on restoring riparian forests (MICCOLIS et al., 2016). The species names follow the Flora of Brazil nomenclature pattern (http://floradobrasil.jbrj.gov.br/).

### 2.3. Agroforestry management practices

The weeds received selective weeding: the most abundant species were removed for a year until canopy coverage was plentiful. Maintenance was carried out in the rainy and hot seasons, with a time interval that did not exceed two months. The control of leaf-cutting ants at the beginning of the experiment was necessary, and it was carried out using ant killer baits with protectors to prevent rain and birds' ingestion.

The agroforestry management consisted of formation pruning in the trees to adjust the size, lowering, stratification, and cleaning of the treetop, as proposed by Steenbock, Vezzani (2013) and Miccolis et al. (2016). The amount of biomass and carbon from the aerial part and pods for *Sesbania virgata* (Cav.) Pers. was determined for the first two years (2012/2013). The biomass from the ten tree species reaching the pruning size, including *Sesbania virgata* (Cav.) Pers., was determined in December/2014. Vegetable residues were weighed in the field with a dynamometer and separated into light (semi-woody) and lignified (woody) biomass. The dry mass was estimated in chopped subsamples brought to the oven at 65 ºC until constant mass. The conversion to Mg ha-1 was performed based on the survival rate of each species. The estimate of carbon input in Mg ha$^{-1}$ was determined according to Equation 1:

$$C = Ms * 0.5 \quad (01)$$

where: C = organic carbon, in g/cm$^3$; $M_s$ = dry mass, in g.

### 2.4. Tree growth

Tree growth was determined 26 months after planting. In this case, a tape measure was used to measure the circumference of the trunk at ground height (CGH) and the average crown radius (Crad) based on two measurements taken from the trunk to the lateral projection of the crown towards the line and between planting rows. For multi-branched species, such as *Schinus terebinthifolius* Raddi, the CGH was considered using the sum of the CGH of each branch. For height from ground level to the top of the canopy (H), a wooden ruler was used with markings every 20 cm.

The relative growth rate (RGR) was obtained for each plant and parameter (height from the ground to the top of the canopy - H and trunk circumference to the height of the ground - CGH) and expressed as an average per species to discover the amplitude of the last 15 months between the first evaluation carried out 12 months after planting, aiming to minimize the effect of the influence of differences in plant size at the beginning of the experiment, and the last evaluation, which was calculated according to the equation used by Marconato et al. 2015 (Equation 2).

$$RGR = [\left(\frac{Mf}{Mi}\right) \Delta t - 0.05]*100 \quad (02)$$

where: Mf represents the final variable value (H and CGH), Mi represents the initial variable value (H and CGH), and Δt is the time interval in months between evaluations.

### 2.5. Data analysis

The forest species' growth analysis (H, CGH, and Crad) used boxplot graphs referenced by the median with a confidence interval of 25% - 75% (minimum-maximum). Pearson correlation was used to estimate the relationship between the RGR datasets of H and CGH. RGR H and CGH data were compared with the Kruskal-Wallis (KW) non-parametric test. Once the null hypothesis was rejected, the Mann-Whitney U (MW-U) test was performed to identify differences between pairs of species. The effect of pruning on the regrowth and fruiting of *Sesbania virgata* (Cav.) Pers. was compared between years with the Wilcoxon test ($p < 0.05$).

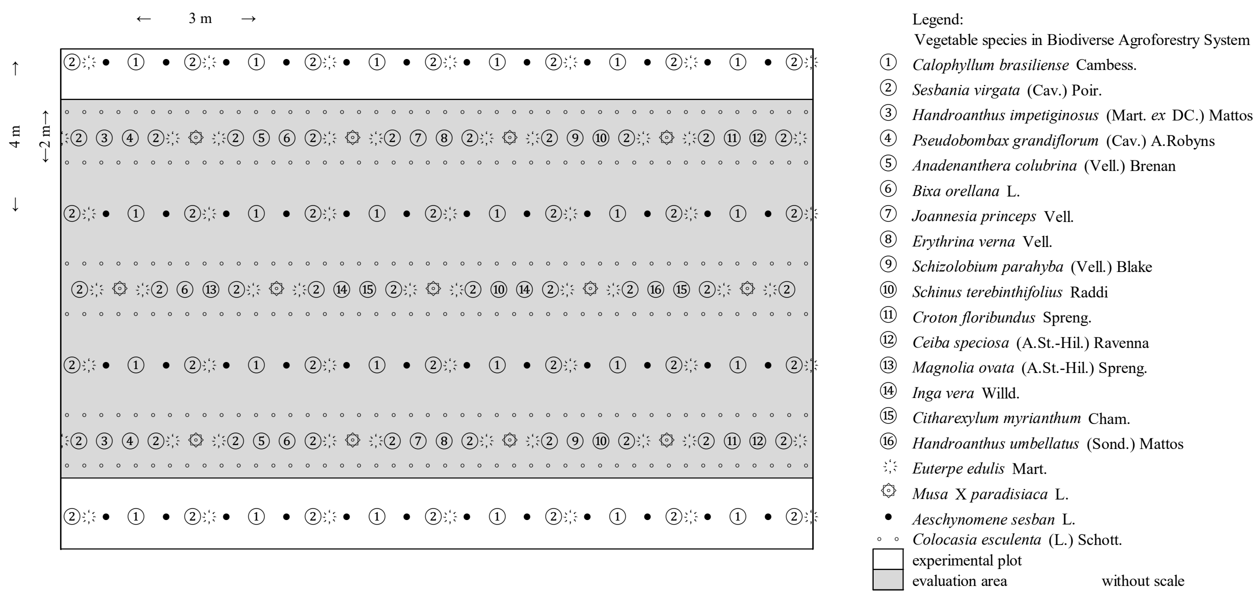


Figure 1. Arrangement of species in agroforestry system with *Calophyllum brasiliense* Cambess. in floodplain.
Figura 1. Arranjo de espécies no Sistema agroflorestal com *Calophyllum brasiliense* Cambess. em planície aluvial inundável.

Table 1. Ecological information and survival of arboreal species in agroforestry system.
Tabela 1. Informação ecológica e sobrevivência de espécies arbóreas no sistema agroflorestal.

| Species | Famility | Density/ hectare | Number of trees evaluated | Survival | Category¹ | Group² | Leaf habit³ |
|---|---|---|---|---|---|---|---|
| *Bixa orellana* L. | Bixaceae | 139 | 24 | 100 | P | D | P |
| *Handroanthus impetiginosus* (Mart. *ex* DC.) Mattos | Bignoniaceae | 93 | 16 | 100 | NP | D | D |
| *Inga vera* Willd. subsp. *affinis* (DC.) T.D.Penn. | Fabaceae | 93 | 16 | 100 | P | R | P |
| *Pseudobombax grandiflorum* (Cav.) A.Robyns | Malvaceae | 93 | 16 | 100 | NP | D | D |
| *Magnolia ovata* (A.St.-Hil.) Spreng. | Magnoliaceae | 46 | 8 | 100 | NP | D | P |
| *Calophyllum brasiliense* Cambess. | Calophyllaceae | 1111 | 46 | 96 | NP | D | P |
| *Citharexylum myrianthum* Cham. | Verbenaceae | 93 | 15 | 94 | P | D | D |
| *Schinus terebinthifolius* Raddi | Anacardiaceae | 139 | 21 | 88 | P | R | P |
| *Anadenanthera colubrina* (Vell.) Brenan | Fabaceae | 93 | 14 | 88 | NP | D | SP |
| *Euterpe edulis* Mart. | Arecaceae | 926⁴;1204⁵ | 13⁴; 37⁵ | 27⁴/77⁵ | NP | D | P |
| *Sesbania virgata* (Cav.) Pers. | Fabaceae | 926⁴;1389⁵ | 29⁴; 34⁵ | 61⁴/71⁵ | P | R | D |
| *Ceiba speciose* (A.St.-Hil.) Ravenna | Malvaceae | 93 | 11 | 69 | NP | R | D |
| *Erythrina verna* Vell. | Fabaceae | 93 | 11 | 69 | NP | D | D |
| *Joannesia princeps* Vell. | Euphorbiaceae | 93 | 10 | 63 | P | R | D |
| *Handroanthus umbellatus* (Sond.) Mattos | Bignoniaceae | 46 | 5 | 63 | NP | D | D |
| *Schizolobium parahyba* (Vell.) Blake | Fabaceae | 93 | 4 | 25 | P | D | D |
| *Croton floribundus* Spreng. | Euphorbiaceae | 93 | 1 | 6 | P | R | SP |

(¹) P – pioneer, NP – non-pioneer; (²) R – recovering, D – diversity; (³) P – perennial, D – deciduous, SP – semi-perennial; (⁴) lines e (⁵) between the lines.
(¹) P – pioneira, NP – não -pioneira; (²) R – recobrimento, D – diversidade; (³) P – perene, D – decídua, SP – semi-perene; (⁴) linhas e (⁵) entre linhas.



## 3. RESULTS

### 3.1. Tree survival rate

The overall survival rate was 62%, with a weighted average of 67% for pioneers and 51% for non-pioneer survivors. Eight species showed survival rates greater than 88%: pioneers (*Bixa orellana* L., *Inga vera* Willd., *Citharexylum myrianthum* Cham., *Schinus terebinthifolius* Raddi) and non-pioneers (*Handroanthus impetiginosus* (Mart. ex DC.) Mattos, *Pseudobombax grandiflorum* (Cav.) A.Robyns, *Magnolia ovata* (A.St.-Hil.) Spreng and *Anadenanthera colubrina* (Vell.) Brenan) (Table 1). *Euterpe edulis* Mart. (77%), in association with *Sesbania virgata* (Cav.) Pers. (71%) showed superior survival between the rows of *Calophyllum brasiliense* Cambess.

*Pseudobombax grandiflorum* (Cav.) A.Robyns and *Ceiba speciosa* (A.St.-Hil.) Ravenna was the most attacked by leaf-cutting ants and *Ceiba speciosa* (A.St.-Hil), and its survival rate was reduced. The roots contained and entangled during planting may have been one factor that impaired the survival of *Schizolobium parahyba* (Vell). Blake and *Croton floribundus* Spreng.

### 3.2. Tree growth

Available light did not limit tree growth between *Calophyllum brasiliense* Cambess rows. Differences in growth at three years of age resulted in the formation of three strata: a high stratum with 3.5 m to 5.5 m in height, occupied mainly by pioneer species that showed uniformity in the distribution of data [*Sesbania virgata* (Cav.) Pers., *Schinus terebinthifolius* Raddi, *Schizolobium parahyba* (Vell.) Blake, *Handroanthus impetiginosus* (Mart. Ex DC.) Mattos, *Inga vera* Willd. and

*Citharexylum myrianthum* Cham.] (Figure 3a); a middle stratum composed of species with more significant variation in data [*Erythrina verna* Vell., *Bixa orellana* L., *Ceiba speciosa* (A.St.-Hil.) Ravenna, *Croton floribundus* Spreng., *Joannesia princeps* Vell., *Anadenanthera colubrina* (Vell.) Brenan and *Pseudobombax grandiflorum* (Cav.) A.Robyns.]; and a low stratum with less than 1.50 m [*Magnolia ovata* (A.St.-Hil.) Spreng., *Handroanthus umbellatus* (Sond.) Mattos and *Euterpe edulis* Mart.].

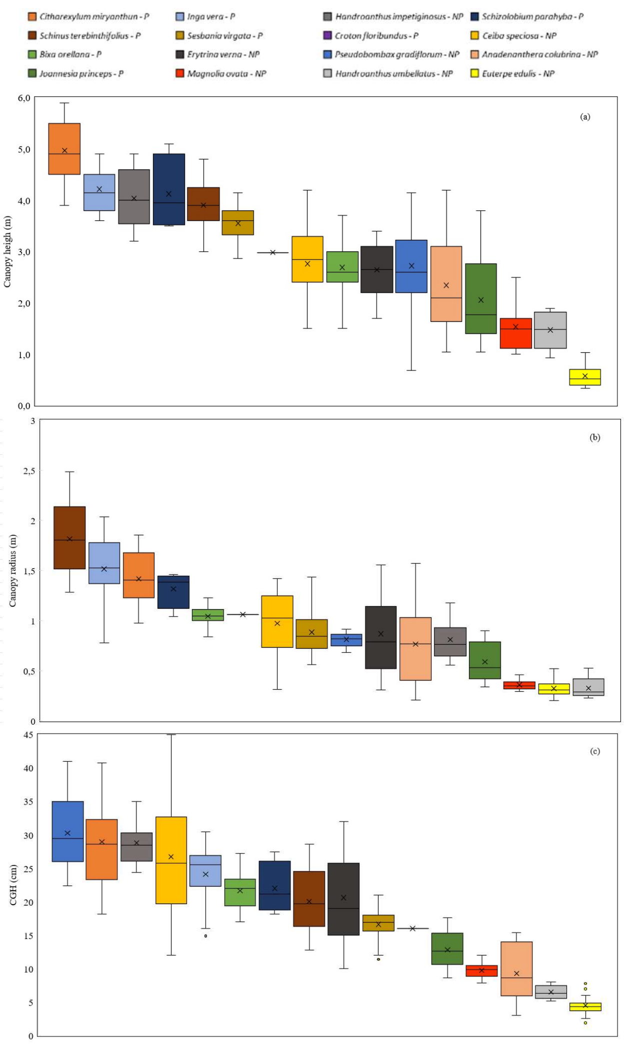


Figure 3. Boxplot of canopy height (a), canopy radius (b), and circumference at ground height—CGH (c) of 16 forest species in an agroforestry system in a floodplain.
Figura 3. Box-plot da altura da copa (a), raio da copa (b) e circunferência do tronco na altura do solo – CGH (c) de 16 espécies florestais em sistema agroflorestal em planície aluvial.

The highest canopy rays (1.30 m to 2.40 m) were verified on pioneer species *Schinus terebinthifolius* Raddi, Inga vera Willd., and *Citharexylum myrianthum* Cham. Most species presented intermediate values of canopy rays [*Bixa orellana* L., *Croton floribundus* Spreng., *Ceiba speciosa* (A.St.-Hil.) Ravenna, *Sesbania virgata* (Cav.) Pers. and *Pseudobombax grandiflorum* (Cav.) A.Robyns], whereas the late species *Euterpe edulis* Mart., *Magnolia ovata* (A.St.-Hil.) Spreng. and *Handroanthus umbellatus* (Sond.) Mattos naturally contributed little to the area's covering (Figure 3b).

Differences were found in stratification patterns and emission of lateral branches of emerging species: *Joannesia princeps* Vell. produced low verticalized sprouts; *Ceiba speciosa* (A.St.-Hil.) Ravenna emitted lateral branches from 1.0 m height; *Pseudobombax grandiflorum* (Cav.) A.Robyns branched the trunk 2.0 m from ground level, and *Schizolobium parahyba* (Vell.) Blake did not branch. With the potential for wood exploitation, *Handroanthus impetiginosus* (Mart. Ex DC.) Mattos produced a slightly branched cylindrical stem, late side sprouts, and *Anadenanthera colubrina* (Vell.) Brenan bowed the trunk with the weight of high lateral branches and the *Citharexylum myrianthum* Cham. With branches located below 1.5 m in height.

The highest CGH values (Figure 3c) from 20-35 cm were obtained from *Croton floribundus* Spreng., *Sesbania virgata* (Cav.) Pers., *Schinus terebinthifolius* Raddi, *Erythrina verna* Vell., *Schizolobium parahyba* (Vell.) Blake, *Bixa orellana* L., *Inga vera* Willd., *Ceiba speciosa* (A.St.-Hil.) Ravenna, *Handroanthus impetiginosus* (Mart. ex DC.) Mattos, *Pseudobombax grandiflorum* (Cav.) A.Robyns and *Citharexylum myrianthum* Cham.

Pearson's correlation was positive (0.73) for the RGR of canopy height (H) and RGR of CGH of 16 tree species evaluated in an agroforestry system in a floodplain (Figure 4). According to the value of the KW test statistic, there are significant differences between the RGR of H ($p$=0.000162) and the RGR of CGH ($p$=0.000295). The tree species in the upper stratum that preserved high RGR of H were *Erythrina verna* Vell., *Citharexylum myrianthum* Cham., *Handroanthus impetiginosus* (Mart. Ex DC.) Mattos, *Schinus terebinthifolius* Raddi, *Pseudobombax grandiflorum* (Cav.) A.Robyns, *Inga vera* Willd. and *Anadenanthera colubrina* (Vell.) Brenan.

The species that maintained high basal growth rates were *Ceiba speciosa* (A.St.-Hil.) Ravenna, *Erythrina verna* Vell., *Euterpe edulis* Mart., *Pseudobombax grandiflorum* (Cav.) A.Robyns., *Citharexylum myrianthum* Cham., *Inga vera* Willd., *Anadenanthera colubrina* (Vell.) Brenan, *Bixa orellana* L and *Joannesia princeps* Vell.

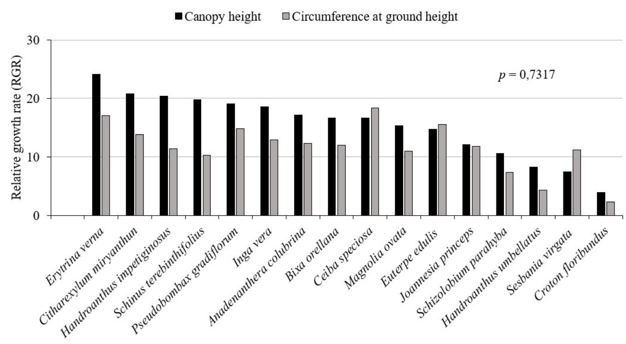


Figure 4. Pearson correlation for relative growth rate (RGR) of canopy height (H) and RGR of circumference at ground height (CGH) of 16 tree species evaluated in an agroforestry system in the floodplain.
Figura 4. Correlação de Pearson para a taxa de crescimento relativo (RGR) da altura da copa (H) e RGR da circunferência à altura do solo (CGH) de 16 espécies arbóreas avaliadas em sistema agroflorestal em planície aluvial.

### 3.3. Agroforestry Management Practices

Pruning *Sesbania virgata* (Cav.) Pers. compacted and raised its canopy to 1.50 m from the ground level, which facilitates agricultural management in the lower stratum, resulting in the contribution of 4.79 Mg ha$^{-1}$ of fresh biomass and 1.98 Mg ha$^{-1}$ of dry mass, which is equivalent to 1.0 Mg C ha$^{-1}$ (Table 2), keeping reproduction stable with a total of 71 kg ha$^{-1}$ of dry pods.

When pruning was performed at three years of age, *Sesbania virgata* (Cav.) Pers. and *Schinus terebinthifolius* Raddi provided high inputs of aerial biomass (Table 3), with a total of 3.76 Mg ha$^{-1}$ of carbon. 56% (2.11 Mg ha$^{-1}$) of this total was accumulated by Sesbania virgata (Cav.) Pers., and 77% of this amount was obtained between the rows of *Calophyllum brasiliense* Cambess.

After regenerating from the first pruning, *Sesbania virgata* (Cav.) Pers. produced a canopy radius of 1.0 m with raised fan-shaped branches that fit and filled the spaces between the *Calophyllum brasiliense* Cambess. Canopy. Low rainfall, the attack of phytophagous coleopters of the Family Chrysomelidae, and the removal of branches that contained many growth buds hampered the regrowth of *Sesbania virgata* (Cav.) Pers., which resulted in differences in the supply of fresh matter between the two years of evaluation.

In contrast, the *Schinus terebinthifolius* Raddi pruning had the purpose of promoting thinning of the highly branched basal multi-stem with the selection of the most vigorous upright branches and reduction of the amplitude of lateral branches, facilitating the management of agricultural species in the AFS, and *Anadenanthera colubrina* (Vell.) Brenan bowed the trunk with the weight of high lateral branches, which were pruned. The branches of *Citharexylum myrianthum* Cham., located below 1.5 m in height, needed to be pruned since its branches dried naturally, causing the top of its canopy to accumulate on the canopy of *Calophyllum brasiliense* Cambess.

Table 2. Differences in the production of aerial biomass, carbon, and fruits of *Sesbania virgata* (Cav.) Pers. in two consecutive years in the agroforestry system.
Tabela 2. Diferenças na produção de biomassa aérea, carbono e frutos de *Sesbania virgata* (Cav.) Pers. em dois anos consecutivos em sistema agroflorestal.

| Assessments | Unity | Years | | W ($p$ <0,05) |
|---|---|---|---|---|
| | | 1 | 2 | |
| Fresh matter | Mg ha$^{-1}$ | 3.28a (±2.18) | 1.51b (±0.51) | 0.0391 |
| Dry matter | Mg ha$^{-1}$ | 1.37a (±0.98) | 0.61a (±0.20) | 0.0547 |
| Carbon | Mg ha$^{-1}$ | 0.69 (±0.49) | 0.31 (±0.10) | - |
| Dried pods | kg ha$^{-1}$ | 35.88a (±11.89) | 34.78a (±12.06) | 0.4609 |

Table 3. Percentage of pruned trees and biomass (sheets and timber) of 10 species cultivated in an agroforestry system in the alluvial plain.
Tabela 3. Percentagem de árvores podadas e biomassa (sheets e madeira) de 10 espécies cultivadas em sistema agroflorestal em planície aluvial.

| Species | Pruned trees | | Dry matter | | | Carbon |
|---|---|---|---|---|---|---|
| | | | Semi-woody | Woody | Total | |
| | % | tree ha$^{-1}$ | Mg ha$^{-1}$ | | | |
| *Sesbania virgata* (Cav.) Pers. (1) | 100 | 1,049 | 2.08 | 1.19 | 3.27 | 1.63 |
| *Schinus terebinthifolius* Raddi | 100 | 121 | 0.77 | 0.55 | 1.32 | 0.66 |
| *Sesbania virgata* (Cav.) Pers. (2) | 100 | 512 | 0.68 | 0.28 | 0.96 | 0.48 |
| *Inga vera* Willd. | 94 | 86 | 0.47 | 0.35 | 0.82 | 0.41 |
| *Bixa orellana* L. | 100 | 138 | 0.28 | 0.13 | 0.41 | 0.20 |
| *Citharexylum myrianthum* Cham. | 100 | 86 | 0.25 | 0.10 | 0.35 | 0.18 |
| *Handroanthus impetiginosus* (Mart. *ex* DC.) Mattos | 94 | 86 | 0.07 | 0.11 | 0.18 | 0.09 |
| *Erythrina verna* Vell. | 100 | 63 | 0.07 | 0.03 | 0.10 | 0.05 |
| *Pseudobombax grandiflorum* (Cav.) A.Robyns | 44 | 40 | 0.03 | 0.02 | 0.05 | 0.02 |
| *Ceiba speciosa* (A.St.-Hil.) Ravenna | 73 | 46 | 0.03 | 0.02 | 0.05 | 0.02 |
| *Anadenanthera colubrina* (Vell.) Brenan | 57 | 46 | 0.03 | 0.03 | 0.06 | 0.03 |

(1) between the lines and (2) lines of *Calophyllum brasiliense* Cambess.
(1) entre linhas e (2) linhas de *Calophyllum brasiliense* Cambess.



## 4. DISCUSSION

### 4.1. Tree survival rate

Sixteen native tree species from nine botanical families of regional occurrence in Semideciduous Seasonal Forest (SSF) were evaluated as recommended by Barbosa et al. (2017) to recover degraded areas in the state of São Paulo. Eight of them were pioneers (five covering species and three from the diversity group), and eight were non-pioneers (one covering species and seven from the diversity group), as proposed by Barbosa et al. (2017) (Table 1).

The priority for native species is to reduce the risk of non-native species becoming invasive. In the SSF domains in the state of São Paulo, which includes studies in the Paraíba do Sul basin, the proportion of one exotic for every three native species exists in the areas of riparian restorations (ASSIS et al., 2013). The use of the non-native *Schizolobium parahyba* (Vell.) Blake, in this study, intends to accelerate the covering ground. It will be cut for wood after the transitional phase of the restoration, as recommended by Assis et al. (2013) and Pontes et al. (2019).

The concept of a successional group or group of species similar in their functional attributes was proposed by Budowski (1965) and is related to shade tolerance and the succession stage in which each species occurs naturally. Four groups of species are recognized: pioneer, early secondary, late secondary, and climaxes. Nowadays, legislation in the State of São Paulo classifies these species into pioneers and non-pioneers (SÃO PAULO, 2008). Recently, Schweizer and Brancalion (2020) detected positive aspects of the association of distinct species based on phylogeny in introducing native trees in the forest monoculture understory, and these principles are adopted in this research.

Conversion to agroforestry benefited *Calophyllum brasiliense* Cambess. To interrupt tree mortality due to 'downward drought,' a disease verified by Devide et al. (2017) in the monoculture areas in flooded plains before the experiment was implemented. According to Piotto et al. (2010), *Calophyllum brasiliense* Cambess is susceptible to vascular diseases due to death from fungal diseases after being listed for 13 years as the most promising pure and mixed reforestation species with native species in Costa Rica. Another publication records the growth of *Calophyllum brasiliense* Cambess. In floodplains, morphological similarity was present in homogeneous planting and agroforestry systems, and the total height reached, on average, 5.40 m at seven years of age. The relative growth rate was similar in the three treatments, with higher values attributed to the canopy radius (2.59%) and the circumference at 1.30 m above ground level (1.86%) (DEVIDE et al., 2021a).

The results were obtained after three years of agroforestry management in clayey soils with highly altered physical and hydraulic properties by more than 50 years of cultivation of irrigated rice and extreme climatic events with flooding of the soils in spring-summer due to the high rainfall in the years 2011 (1307 mm) and 2012 (1497 mm) contrasting with prolonged drought in the years 2013 (1158 mm) and 2014 (619 mm) that caused the dryness of the soil and the interruption of the stream in the driest and warmest period of the last 80 years in the Paraíba do Sul basin. Extreme climate events in the last two decades have revealed that resilience to climate disasters is closely linked to high on-farm biodiversity (ALTIERI; NICHOLLS, 2017), a typical feature of agroforestry systems.

Four factors in agroforestry management help support tree survival: (i) the elevation of the surface in the planting rows avoids direct contact with water. It increases the oxygenation on the roots in the early stages of development, as Marconato et al. (2015) verified in establishing native species in permanently damp soils. Under natural conditions, seeds float and germinate in areas with sedimentary accumulation or small elevations without direct contact with water (Marques; Joly, 2002); (ii) the biodiversity and structural complexity of the tree canopies in the AFS reduces water evaporation and the effects of high temperatures in the understory, making this system more productive and resilient in the climate change scenario; (iii) the choice of species with the regional occurrence of SSF, since, according to studies by Barbosa et al. (2017), possibly better adapted to the low natural fertility of soils in the Paraíba Valley, in other words, less demanding and more efficient in the use of nutrients; and (iv) the combination of different species maximizes the performance and ecosystem functionality of the tree monoculture, as verified by Schweizer; Brancalion (2020) in the enrichment of the forest monoculture understory with contrasting leaf habit (deciduous and perennial).

The species *Citharexylum myrianthum* Cham., *Schinus terebinthifolius* Raddi, and *Ceiba speciosa* (A.St.-Hil.) Ravenna, the genus *Inga* sp., and *Anadenanthera* sp. are more frequent in restoring riparian vegetation in SSF in the state of São Paulo (ASSIS et al., 2013). *Anadenanthera colubrina* (Vell.) Brenan, *Handroanthus umbellatus* (Sond.) Mattos, *Inga vera* Willd. subsp. affinis (DC.) T.D.Penn., *Magnolia ovata* (A.St.-Hil.) Spreng., *Pseudobombax grandiflorum* (Cav.) A. Robyns occur naturally in riparian forests of the Paraíba Valley and *Sesbania virgata* (Cav.) Pers. and *Aeschynomene sesban* L. infest neighboring rice-growing areas. Such information increased the knowledge of experienced farmers who contributed to the selection of rustic species adapted to the flooding of the soil, helping to restore the forest cover of the floodplain and improve the edaphic attributes, according to Meli et al. (2019) who defend a pact with the participation of these actors to restore large expanses of riparian vegetation in Latin America.

They benefited from the wet substrate for a longer time in the dry period due to the covering of the trees and the banana (*Musa* X *paradisiaca* L.), a species that added residues rich in sap (21.4 Mg ha$^{-1}$) (data not presented) after cutting the pseudostems on tile shape and lying on the ground around the *Euterpe* palm trees.

The high density of *Sesbania virgata* (Cav.) Pers. produced forest structure in the short term and covered the soil with small leaflets that intercepted part of the light energy, letting through photons essential for the growth of species of the stage future of succession, such as *Pseudobombax grandiflorum* (Cav.) A.Robyns and *Euterpe edulis* Mart.

Although the seedlings of *Euterpe edulis* Mart. Require moist habitats in the establishment (Nakazono et al., 2001; Muler et al., 2014; Benchimol et al., 2017), older seedlings and juvenile plants grow more in well-drained locations; those that survive stress become more tolerant to cycles of recurrent water deficits, as verified by Oliveira et al. (2017). In addition, *Sesbania virgata* (Cav.) Pers, in association with non-leguminous plants, transfers part of the biologically fixed N to the nearby species (SANTIAGO et al., 2009). Thus, *Sesbania virgata* (Cav.) Pers. and *Euterpe edulis* Mart. are arranged. It becomes strategic to reintroduce this essential endemic threatened palm of the Atlantic Forest (OLIVEIRA et al., 2017). This palm species provides the most important non-NTFP exploitation in the Brazilian Atlantic Forest hotspot (MULER et al., 2014).

In AFS in riparian zones, the sustainable exploitation of this palm can be extended beyond the transitional phase, as Meli et al. (2019) proposed, similar to the traditional populations in secondary forests on the coast of São Paulo. They collect the fruit bunches to extract the pulp, generating income that indirectly inserts farmers in the restoration process. Besides, various frugivorous vertebrates consume the fruits and disseminate *Euterpe edulis* Mart. in other areas (MULER et al., 2014; BENCHIMOL et al., 2017). Thus, a combination of economic benefits and conservation biology (Oliveira et al., 2017) occurs.

The high density of *Sesbania virgata* (Cav.) Pers. (72% of the total pioneer species) was carried out to reproduce what occurs in natural conditions where this species forms pure massifs when colonizing degraded flooded areas. Pioneer species are essential to cover the area in the short term, while non-pioneer species are crucial for gradually replacing senescent species (RODRIGUES et al., 2011). In this study, non-pioneers should come to occupy the spaces left by *Calophyllum brasiliense* Cambess during thinning until the final cut for the economical use of wood. The diverse group species, the most adapted to regenerate clearings of different sizes, can occupy the open spaces where the canopy of *Calophyllum brasiliense* Cambess, does not. This group included three pioneer and seven non-pioneer species (Table 1). The diversity of species from different successional stages in the AFS is essential to make the agro-ecosystem the most similar in form, structure, and dynamics to the natural and original ecosystem (VAZ da SILVA, 2000; STEENBOCK; VEZZANI, 2013; PONTES et al., 2019).

The moderate survival of non-pioneer species in the diversity group *Erythrina verna* Vell., *Handroanthus umbellatus* (Sond.) Mattos and *Ceiba speciosa* (A.St.-Hil.) Ravenna (Table 1) can impair succession and demand new studies on enrichment in the AFS.

**4.2. Tree growth**

According to the results, Rappaport and Montagnini (2014) also registered superiority in the growth of pioneer species in monoculture enrichment of *Hevea brasiliensis* Willd. ex A. Juss. in the lowlands of the southern coast of Bahia, Brazil. Understanding tree species' growth is essential when restoration is concerned.

A species stratification pattern is formed by height classes, which is one of the principles of AFS seeking to reproduce the architecture of natural ecosystems. In biodiverse AFS, each species' successional order and life cycle guide the phases of the system, with each stage covering a succession cycle of pioneers and non-pioneers. In the successional dynamics, the species that initially show the lowest growth can be favored by the senescence of the pioneers and by changes in the chemical, physical, and biological factors of the soil, as verified by Vaz da Silva (2000) in the restoration of riparian forests with AFS in the municipality of Piracicaba-SP. The phase in which the AFS finds itself characterizes the transitional phase of colonization in a period of accumulation with maximum fixation of organic matter, allowing life to settle with more important structural requirements, with a prevalence of an extensive system in the next phase, as explained Vaz da Silva (2000).

As Rappaport and Montagnini (2014) verified, short-cycle trees develop the strategy of rapid growth and prolificacy and create conditions for species of future stages to establish themselves. However, the effectiveness of covering the area in the first years of the life of *Calophyllum brasiliense* Cambess, when its canopy does not reach the amplitude and density necessary to shade the lines between cultivation, must be analyzed together with leafing. *Schinus terebentifolius* Raddi produced a canopy radius higher than *Bixa orellana* L.; nevertheless, both species accumulated dense foliage close to the ground level quickly and simultaneously initiated the production of pink peppercorns and a red-orange pigment, respectively, contributed to income by medicinal and condiment products. These species' growth habits improved the natural control of monocot weeds that exercise intense competition and harm the survival of trees in restoration. It helped reduce the area's maintenance period under restoration, according to Pontes et al. (2019).

*Pseudobombax grandiflorum* (Cav.) A.Robyns and *Euterpe edulis* Mart., which prefer diffused light, benefited from the forest structure of *Sesbania virgata* (Cav.) Pers. produced in the short term and covered the soil with small leaflets that intercepted part of the light energy, letting through photons essential for the growth of species of the stage future of succession. Due to its environmental plasticity, low demands on fertility, aptitude for degraded sites, efficiency in biological nitrogen fixation - BNF (SANTIAGO et al., 2009) and mycorrhization (SILVA et al., 2014), the inclusion of *Sesbania virgata* (Cav.) Pers. aimed to promote improvements in species' performance with economic interests dependent on mycorrhization such as *Calophyllum brasiliense* Cambess, *Euterpe edulis* Mart., banana shrub *Musa* X *paradisiaca* L. and *Colocasia esculenta* (L.) Schott.

Generally, emergent and deciduous species with straight, plump trunks, shallow roots, and an umbrella-shaped canopy occupying the upper strata above the forest are planted at a lower density than pioneers. Schweizer and Brancalion (2020) describe the advantages of associating perennial and deciduous species in enriching monocultural forests. Production forests are characterized by maintaining the initial stages of succession. Heterogeneous forest and enrichment plantations of tree monocultures (RAPPAPORT; MONTAGNINI, 2014; SCHWEIZER; BRANCALION, 2020) aim to lead the succession to rapid recovery, self-renewal, and permanence, relevant aspects for forests with protective objectives, which are also essential to flood plains (MELI et al., 2019).

Pioneer species grew faster than non-pioneer species, agreeing with a study by Rappaport and Montagnini (2014) on the diversification of *Hevea brasiliensis* Willd ex A. Juss monoculture. The highest RGR values were obtained for *Croton floribundus* Spreng., *Schizolobium parahyba* (Vell.) Blake, *Citharexylum myrianthum* Cham., *Schinus terebinthifolius* Raddi and *Inga vera* Willd., emphasizing the non-pioneer *Handroanthus impetiginosus* (Mart. Ex DC.) Mattos and *Pseudobombax grandiflorum* (Cav.) A. Robyns (Figure 4). In another study, Marconato et al. (2015) obtained better RGR results with *Croton urucurana* Baill., *Calophyllum brasiliense* Cambess - and *Citharexylum myrianthum* Cham. in a floodable area. In our study, *Ceiba speciosa* (A.St.-Hil.) Ravenna, *Joannesia princeps* Vell., *Bixa orellana* L. and *Anadenanthera colubrina* (Vell.) Brenan prioritized the growth of CGH and the low RGR height of *Sesbania virgata* (Cav.) Pers. resulted in trees that received pruning.

Relative growth rate studies are relevant because they predict plants' behavior in carbon allocation over time (MARCONATO et al., 2015). Long-term research is necessary, as young tree growth and survival are not always sustained in maturity, as Piotto et al. (2010) verified in *Calophyllum brasiliense* Cambess.

As the growth rates and ecological needs of trees in different stages of succession are different, it is necessary to know the response autecology to environmental events as a subsidy for planning the planting arrangement and pruning management strategies in biodiverse successional AFS (VAZ da SILVA, 2000; MICCOLIS et al., 2016).

**4.3. Agroforestry Management Practices**

Pruning management in trees is a strategy adopted in successional AFS to accelerate ecological restoration (DEVIDE et al., 2021a). However, it requires basic knowledge about each species' preference for light at the time and in the stratum it occupies (VAZ da SILVA, 2000; MICCOLIS et al., 2016), the canopy format, and ecophysiological aspects of the successional stage (ALMEIDA, 2016).

In general, pruning was carried out to adapt the size and shape of the canopies with the lowering, stratification, and cleaning that renew, synchronize, and increase the quantity and quality of consolidated life, favored by the entry of light that increases the photosynthetic activity in the lower stratus (STEENBOCK; VEZZANI, 2013) and to improve soil fertility by adding organic matter and recycling nutrients (MICCOLIS et al., 2016; DEVIDE et al., 2021b). Another publication records the AFS to enrich a monoculture of *Calophyllum brasiliense* Cambess improved fertility of floodable soils, mainly in the superficial layer, and K and Mg contents were higher in the biodiverse AFS (DEVIDE et al., 2021b).

Pruning *Sesbania virgata* (Cav.) Pers. and other pioneer tree species also aim to compact and raise its crown to 1.50 m above ground level to facilitate the agricultural management of *Colocasia esculenta* (L.) Schott in the lower stratum. These environmental conditions created by agroforestry management were essential for *Euterpe edulis* Mart., the 'key species' of this study that prefers typical clearing conditions with 20% - 30% of total sunlight irradiance, while excess shade would impair their survival (NAKAZONO et al., 2001; BENCHIMOL et al., 2017). The residues of *Sesbania virgata* (Cav.) Pers. with a high content of nutrients, especially nitrogen, were allocated around *Euterpe edulis* Mart.

Self-sowing of *Sesbania virgata* (Cav.) Pers. and other pioneer species can also be important to reduce labor costs in replanting, as highlighted by Vaz da Silva (2002). This is due to the decline of pioneer species before future-stage species (secondary and species of the late secondary forest transitional to the primary forest) are ready to assume their role in succession or when planting fails to occur.

Despite frequent pruning, *Sesbania virgata* (Cav.) Pers. maintained its reproduction stable, enabling the collection of seeds that can be sold as NTFP for forest restoration projects. Pastures occupy approximately 175 thousand hectares, and 69,709 hectares of environmental preservation area need to be restored in the Paraíba Valley in São Paulo (PADOVEZI, 2018).

Over 1,000 million hectares of AFS are planted worldwide, with 200 to 357 million hectares in Latin America. The AFS fixes more carbon with perennial crops than annual crops depending on location, design, species, age, and management, restoring about 0.29 to 15.21 Mg of C ha-1 year-1 in the aerial component. In contrast, the pure commercial reforestations fix from 10 to 14 Mg C ha-1 in 10-year rotation intervals (SALATI et al., 1999). By restoring biodiversity, the agroforestry system fixes more carbon dioxide in producing certified wood and improves soil fertility.

The main factors that limit restoration through enrichment planting are the few studies that have tested specific techniques (MANGUEIRA et al., 2019). The results obtained on the adaptation and growth habits of tree species help to fill the scarcity of silvicultural and ecological knowledge on the management of native flora in conservationist actions in the alluvial plain of the Paraíba do Sul River, where transformations in land use have favored the growth of forestry activity and ecological restoration with AFS (COUTINHO et al., 2018). This study helps fill in the gaps with technical information for recommendations on planting enrichment, focusing on forest restoration (Rappaport; Montagnini, 2014) and forest monocultures (SCHWEIZER; BRANCALION, 2020; DEVIDE et al., 2021a).

## 5. CONCLUSIONS

Planting native trees to enrich the monoculture of *Calophyllum brasiliense* Cambess, is a promising restoration technique in a floodplain, obtaining a balance in the survival of pioneer and non-pioneer species. The available light did not limit the growth of tree species in the understory, and the pioneer ones grew faster than the non-pioneer ones.

Height was the most differentiated parameter, and the five most successful were *Citharexylum myrianthum* Cham., *Inga vera* Willd., *Handroanthus impetiginosus* (Mart. Ex DC.) Mattos, *Schinus terebinthifolius* Raddi and *Sesbania virgata* (Cav.) Although the higher relative growth rates indicate that *Erythrina verna* Vell., *Pseudobombax grandiflorum* (Cav.) A.Robyns and *Anadenanthera colubrina* (Vell.) Brenan is growing more in the last 15 months than *Sesbania virgata* (Cav.) Pers.

The most contribution to the supply of phytomass came from *Sesbania virgata* (Cav.) Pers. and *Schinus terebinthifolius* Raddi. The intercropping of *Euterpe edulis* Mart. with *Sesbania virgata* (Cav.) Pers favored the palm survival to overcome climatic extremes with the possibility of sustainable exploitation of the fruits between the lines of *Calophyllum brasiliense* Cambess.

The agroforestry system emerges with innovative proposals for a sustainable future in agricultural and forestry production in line with ecological restoration demands. Long-term studies are necessary to carry out more suitable plantings with native species to elucidate the relationships between agroforestry systems and ecosystem services obtained in floodplains.

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## SUPPLEMENTARY DATA

Table 1. Differences in RGR of H using the Mann-Whitney U test to analyze which pairs differ between 16 forest species in an agroforestry system in an alluvial plain.
Quadro 1. Diferenças de RGR de H pelo teste U de Mann-Whitney para analisar quais pares são diferentes entre 16 espécies florestais em sistema agroflorestal em planície aluvial.

| RGR H | *Erytrina verna* | *Citharexylum miryanthun* | *Handroanthus impetiginosus* | *Schinus terebinthifolius* | *Pseudobombax gradiflorum* | *Inga vera* | *Anadenanthera colubrina* | *Bixa orellana* | *Ceiba speciosa* | *Magnolia ovata* | *Euterpe edulis* | *Joannesia princeps* | *Schizolobium parahyba* | *Handroanthus umbellatus* | *Sesbania virgata* | *Croton floribundus* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Erytrina verna* | | | | | | | | | | | | | | | | |
| *Citharexylum miryanthun* | 0,318 | | | | | | | | | | | | | | | |
| *Handroanthus impetiginosus* | 0,156 | 0,958 | | | | | | | | | | | | | | |
| *Schinus terebinthifolius* | 0,172 | 0,793 | 0,495 | | | | | | | | | | | | | |
| *Pseudobombax gradiflorum* | 0,270 | 0,270 | 0,128 | 0,156 | | | | | | | | | | | | |
| *Inga vera* | 0,104 | 0,564 | 0,431 | 0,104 | 0,564 | | | | | | | | | | | |
| *Anadenanthera colubrina* | 0,227 | 0,564 | 0,318 | 0,318 | 0,637 | 0,495 | | | | | | | | | | |
| *Bixa orellana* | 0,104 | 0,128 | 0,036 | 0,041 | 0,958 | 0,189 | 0,875 | | | | | | | | | |
| *Ceiba speciosa* | 0,093 | 0,318 | 0,495 | 0,344 | 0,793 | 0,958 | 0,958 | 0,793 | | | | | | | | |
| *Magnolia ovata* | 0,066 | 0,128 | 0,041 | 0,041 | 0,713 | 0,227 | 0,958 | 0,875 | 0,431 | | | | | | | |
| *Euterpe edulis* | 0,052 | 0,128 | 0,031 | 0,052 | 0,495 | 0,083 | 0,875 | 0,431 | 0,270 | 0,793 | | | | | | |
| *Joannesia princeps* | 0,059 | 0,041 | 0,010 | 0,021 | 0,227 | 0,031 | 0,431 | 0,189 | 0,227 | 0,270 | 0,637 | | | | | |
| *Schizolobium parahyba* | 0,106 | 0,183 | 0,365 | 0,388 | 0,263 | 0,424 | 0,263 | 0,365 | 0,518 | 0,424 | 0,424 | 0,590 | | | | |
| *Handroanthus umbellatus* | 0,020 | 0,013 | 0,003 | 0,015 | 0,031 | 0,007 | 0,155 | 0,024 | 0,044 | 0,082 | 0,082 | 0,290 | 1,000 | | | |
| *Sesbania virgata* | 0,014 | 0,007 | 0,001 | 0,014 | 0,002 | 0,001 | 0,004 | 0,001 | 0,014 | 0,004 | 0,001 | 0,104 | 0,424 | 0,494 | | |
| *Croton floribundus* | 0,014 | 0,007 | 0,010 | 0,025 | 0,007 | 0,010 | 0,010 | 0,010 | 0,025 | 0,010 | 0,010 | 0,025 | 0,334 | 0,117 | 0,010 | |



Table 2. Differences in RGR of CGH using the Mann-Whitney U test to analyze which pairs differ between 16 forest species in an agroforestry system in an alluvial plain.
Quadro 2. Diferenças de RGR de CGH pelo teste U de Mann-Whitney para analisar quais pares são diferentes entre 16 espécies florestais em sistema agroflorestal em planície aluvial.

| RGR CGH | *Ceiba speciosa* | *Erytrina verna* | *Euterpe edulis* | *Pseudobombax gradiflorum* | *Citharexylum miryanthun* | *Inga vera* | *Anadenanthera colubrina* | *Bixa orellana* | *Joannesia princeps* | *Handroanthus impetiginosus* | *Magnolia ovata* | *Schinus terebinthifolius* | *Sesbania virgata* | *Schizolobium parahyba* | *Handroanthus umbellatus* | *Croton floribundus* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Ceiba speciosa* | | | | | | | | | | | | | | | | |
| *Erytrina verna* | 0,916 | | | | | | | | | | | | | | | |
| *Euterpe edulis* | 0,431 | 0,637 | | | | | | | | | | | | | | |
| *Pseudobombax gradiflorum* | 0,462 | 0,599 | 0,958 | | | | | | | | | | | | | |
| *Citharexylum miryanthun* | 0,156 | 0,431 | 0,564 | 0,495 | | | | | | | | | | | | |
| *Inga vera* | 0,066 | 0,431 | 0,156 | 0,318 | 0,713 | | | | | | | | | | | |
| *Anadenanthera colubrina* | 0,066 | 0,189 | 0,189 | 0,318 | 0,637 | 0,564 | | | | | | | | | | |
| *Bixa orellana* | 0,074 | 0,344 | 0,189 | 0,207 | 0,637 | 0,958 | 0,875 | | | | | | | | | |
| *Joannesia princeps* | 0,115 | 0,248 | 0,227 | 0,344 | 0,875 | 0,958 | 0,958 | 0,916 | | | | | | | | |
| *Handroanthus impetiginosus* | 0,046 | 0,344 | 0,128 | 0,207 | 0,318 | 0,958 | 0,958 | 0,462 | 0,753 | | | | | | | |
| *Magnolia ovata* | 0,065 | 0,127 | 0,065 | 0,169 | 0,082 | 0,018 | 0,371 | 0,082 | 0,371 | 0,082 | | | | | | |
| *Schinus terebinthifolius* | 0,027 | 0,207 | 0,083 | 0,115 | 0,227 | 0,372 | 0,564 | 0,344 | 0,401 | 0,674 | 0,317 | | | | | |
| *Sesbania virgata* | 0,014 | 0,041 | 0,014 | 0,041 | 0,018 | 0,004 | 0,031 | 0,018 | 0,083 | 0,024 | 0,562 | 0,156 | | | | |
| *Schizolobium parahyba* | 0,106 | 0,106 | 0,098 | 0,196 | 0,220 | 0,424 | 0,311 | 0,518 | 0,450 | 0,518 | 0,262 | 0,590 | 0,424 | | | |
| *Handroanthus umbellatus* | 0,008 | 0,011 | 0,003 | 0,011 | 0,003 | 0,001 | 0,003 | 0,008 | 0,020 | 0,008 | 0,013 | 0,020 | 0,031 | 1,000 | | |
| *Croton floribundus* | 0,007 | 0,007 | 0,005 | 0,014 | 0,005 | 0,010 | 0,007 | 0,025 | 0,018 | 0,025 | 0,007 | 0,025 | 0,010 | 0,334 | 0,117 | |