

Evaluation of Four Methods for Restoring a Degraded Swamp Forest

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Abstract

Swamp Forests occur in permanently wet soils, with specific ecosystem which contributes to the conservation of biodiversity and water resources. However, there are many gaps in knowledge about the restoration of these forests. The present study was conducted in a degraded wetland in the town of Mineiros do Tietê, located in the state of São Paulo, Brazil, in order to test the efficiency of four methods for restoring a Swamp Forest (small mound, acclimated seedling, dry season and conventional tillage), using six forest tree species typical of this type of forest: *Calophyllum brasiliense* Cambess., *Citharexylon myrianthum* Cham., *Cedrela odorata* L., *Tapirira guianensis* Aubl., *Ficus insipida* Willd. and *Croton urucurana* Baill. The least favorable methods for all plant species were: conventional and soil pit tillage in dry seasons. Analyzing the plant species individually, the best results in descending order were: *Croton urucurana* Baill. (acclimated seedling tillage in dry season), followed by *Calophyllum brasiliense* Cambess. (in small mounds), *Citharexylon mirianthum* Cham. (with acclimated seedlings), *Ficus insipida* Willd. and *Tapirira guianensis* Aubl. (in small mounds). *Cedrela odorata* L. presented low performance in all conditions, probably because it suffered the *Hypsipyla grandella* Zeller. The results have been successful for the establishment of Swamp Forest restoration strategies.

Keywords

Restoration Methods, Acclimatization, Soil Water Saturation, Riparian Zone

1. Introduction

Swamp Forests are common in hydromorphic soils with permanent occurrence of superficial water. Therefore,

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they are naturally fragmented and present structural, floristic and physiognomic particularities which differ from other forest types, including the Riparian Forest, or Gallery Forest which are temporarily subjected to soil water saturation (Torres et al., 1994; Ivanauskas et al., 1997; Toniatto et al., 1998, Teixeira et al., 2008). Swamp Forests are located in riparian areas which carry out an essential function on hydrological, ecological, and geomorphic processes. They keep the hydrographic micro watershed and the aquatic ecosystem healthy and resilient (Naiman & Décamps, 1997; Agnew et al., 2006; Allan et al., 2008; Burkhard et al., 2010; Attanasio et al., 2012; Matthews, 2013).

These forests carry essential role to the pursuit of sustainable development through the protection and maintenance of water resources and biodiversity. Therefore, the conservation, the study, and the improvement of methods for its restoration require special attention, especially in the current context of global discussions about the importance of protecting the environment for the quality of life of human beings (Ramsar Convention, 1971; Collins et al., 2013; Conference United Nations Conference on Environment and Development, “ECO-92”, 1992; the World Summit on Sustainable Development, Johannesburg, South Africa, “Rio + 10”, in 2002, the “Rio + 20”, 2012, are some examples).

In this paper, the definition of assumed ecological restoration is that presented by the Society for Ecological Restoration International (SER International; SER 2002; www.ser.org) and adopted by the International Union for the Conservation of Nature (IUCN): ecological restoration is the process of assisting the recovery of an ecosystem which was and has been degraded, damaged or destroyed.

Restoration methods have been tested to reverse the degrading condition; however, they are never meant for swampy areas, even though they are highly degraded and have extremely particular characteristics (Rodrigues et al., 2009).

In Swamp Forests, the permanent occurrence of soil water saturation represents a great difficulty for their restoration; therefore, it is important to carry out researches on the restoration, monitoring, dynamics and regeneration of this type of vegetation.

Some authors (Zedler, 2003; Rodrigues and Leitão-Filho, 2004; Rodrigues & Gandolfi, 2004) highlighted the necessity of intensifying the research development for restoring wetland areas since the government and farmers restoring initiatives are scarce or not so thriving, leading to a considerable biodiversity loss besides endangering the water resource quality.

The Convention on Wetlands of International Importance, called The Ramsar Convention (Irã), which took place in 1971, is an intergovernmental treaty which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. One of the main goals exposed in documents resulting from The Ramsar Convention is to aware people of the benefits of the planet’s wetlands. (Matthews, 2013; <http://www.ser.org/programs/global-partnerships/ramsar-convention-on-wetlands>).

Floristic and phytosociological surveys carried out in areas with remnants of Swamp Forests subsidize the selection of species for restoration actions (Torres et al., 1994; Ivanauskas et al., 1997; Toniatto et al., 1998; Joly et al., 2004; Teixeira & Assis, 2005).

Given that context, the importance of the development of studies on the restoration of Swamp Forests becomes clear, since there are many aspects to be investigated, especially when it comes to methods and specific techniques for conducting the practice of ecological restoration in water saturation areas.

This study aimed to evaluate four methods for restoring Swamp through the analysis of survival and development of six typical species of this forest type to obtain scientific information which may contribute to broadening the knowledge boundaries about the restoration of these areas, to provide grants and technical guidance for extension work, rural farmers and nurserymen, and to public politics that aimed at the conservation of water resources and biodiversity.

The hypothesis is that the methods for restoration which were developed for this research in order to minimize the seedling initial stress owing to permanent changes of soil water saturation, should present better results than conventional method. Considering the species selected for testing, the expectation was that they would have different performances due to the behavior they present in the reference ecosystem.

2. Materials and Methods

2.1. Study Area

This project was accomplished at Farm Santa Fé, in a degraded swampy area, located in the watershed of the

River São João (22°26'15.40"S and 48°27'11.28"W) in the town of Mineiros do Tietê (São Paulo, Brazil) (Figure 1).

About 10 years ago, this site, which had been drained and cultivated with pasture, was abandoned presenting a soggy ground characteristic, having its area occupied by invasive grass (*Urochloa decumbens* (Stapf.) RD Webster).

According to Setzer & Malingreau (1996), the region's climate is hot with dry winters. In the driest month, rainfall reaches, on average, 30 mm, while in the hottest month, the maximum temperature exceeds 22°C and in the coldest month, it is below 18°C.

2.2. Species Selection

The tree species were selected based on floristic lists of regional native species typical of Swamp Forests (Campos et al., 2011; Marques et al., 2003; Paschoal & Cavassan, 1999; Toniato et al., 1998, Ivanauskas, 1997, Oliveira-Filho & Ratter, 1995; Torres et al., 1994), as well as on their availability in nurseries, the following were selected: *Calophyllum brasiliense* Cambess. (Clusiaceae family), *Citharexylum myrianthum* Cham. (Verbenaceae family), *Cedrela odorata* L. (Meliaceae family), *Tapirira guianensis* Aubl. (Anacardiaceae family), *Ficus insipida* Willd. (Moraceae family) and *Croton urucurana* Baill. (Euphorbiaceae family).

2.3. Methods

Four restoration methods were implemented and evaluated: 1) *conventional method*: the seedlings were planted in pits with dimensions of 30 cm × 30 cm × 30 cm, dug at the ground level, in the traditional way; 2) *small mound (or inverted pits) method*: the seedlings were planted on small mounds of soil 30 cm high by 70 cm wide; therefore, staying raised from the saturated soil surface; 3) *acclimated seedling in nurseries method*: the seedlings received a treatment before being planted, stayed for 43 days in an environment with gradual water saturation, and then the tillage was done in pits as in the conventional model; 4) *planting during the dry season*

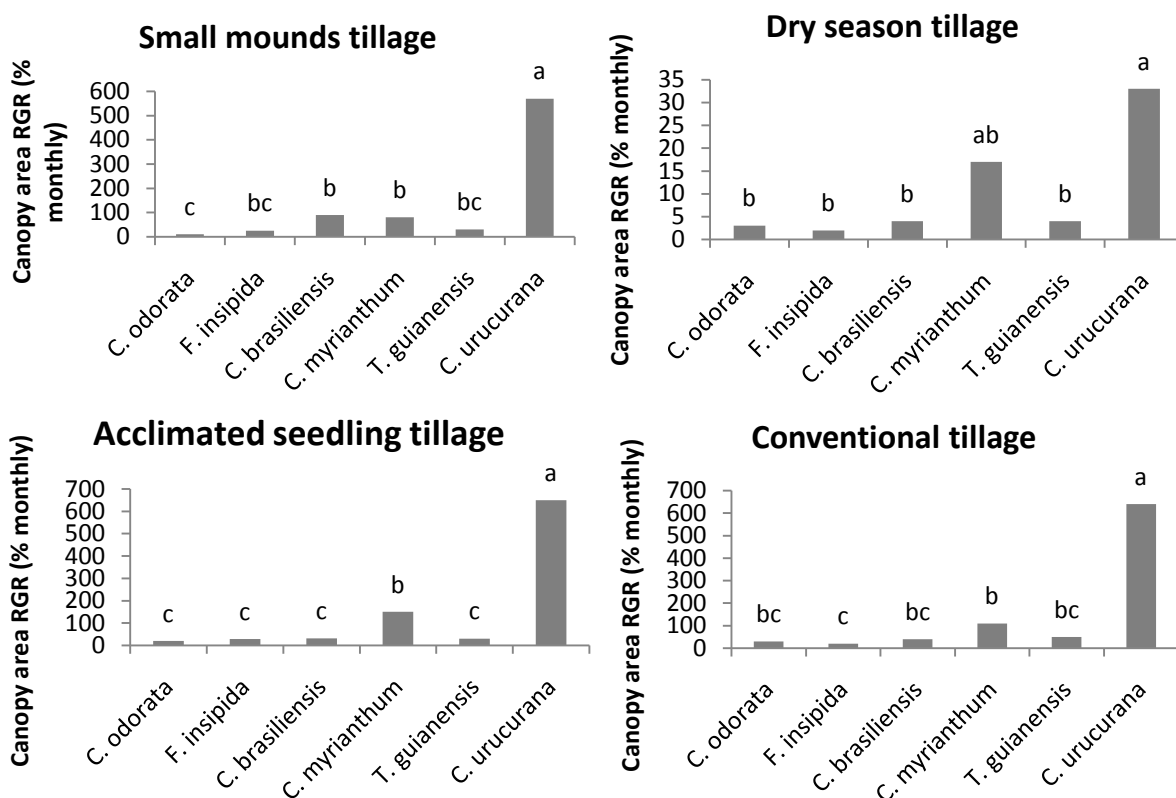


Figure 1. Average relative growth rate (RGR) for height increment of six tree species grown under four methods of tillage in a Swamp restoration area.

of the year, held four months after installing the first three treatments, with a less water-saturated soil due to the decrease of rainfall occurs in winter months.

In the acclimation method, the seedlings were kept in the nursery for 43 days in a tank with water, covered with a protection screen against direct solar radiation, with a 50% reduction. The tank was filled with water in three stages, adding 1/3 of its volume every 13 days on the first two stages. When it reached the maximum volume, and the seedlings were covered with water up to the neck, they remained in the tank for another 17 days. So, they were selected according to health and uniformity, and taken to the experiment installation area to be planted in pits, as in the conventional model.

The methods were designed to minimize the stress of seedlings due to soil water saturation, as observed in field experience with conserved Swamp Forests.

Procedures—In February, after cleaning the land, the project was implemented for the first three procedures. In July, the dry season method was implemented. The experiment occupied the area of 6400 m² and it was outlined in randomized blocks, in subdivided plots with four replications, testing the four restoration methods for the six selected species.

When the experiment was being implemented, the seedlings were about nine months and an average of 0.65 m high. Each method was implemented in a plot of 18 m × 25 m, in which the species were distributed after the randomization. A border without planting of 2.0 m was kept between plots and blocks. About 60 seedlings, 10 of each species, were planted in each plot with a spacing of 2 m × 3 m between the seedlings, following an order that was repeated consecutively.

There was not any soil correction or fertilization made. During the first year, the control of invasive plants was performed every three months by mechanized mowing in line, hand-weeding of the lines, and manual crowning of the seedlings. Maintenance was made every six months from the end of the first year and during the second one.

2.4. Survival and Growth Evaluation

The monitoring was carried out every two months for over 25 months (from March 2008 to March 2010) by observing the survival and development of the plants which were considered dead when they were without leaves and with the stem visibly dry. Each plant was evaluated in height (distance from the ground to the apical stem) and canopy area (ground cover), which was calculated by using the equation of the ellipse area:

$(D \times d \times \pi)/4$, where D = the largest diameter and d = the largest transverse diameter related to D .

The Relative Growth Rate (RGR) was obtained for each plant and parameter, and expressed as an average per species in every tillage method, aiming to minimize the effect of the plant size at the beginning of the experiment which was calculated according to the equation used by Zamith & Scarano (2006):

$$RGR = [(M/M_i)/\Delta t - 0.05]100$$

where M_f (final measurement), M_i (initial measurement) and Δt (difference in months between the two measurements).

The data were compared by variance analysis with a subsequent average comparison by using the Tukey test at 5% probability and when necessary, the transformation of the original data for variances homogeneity was performed.

Based on Zamith & Scarano (2006), two rates were used and obtained from the survival and growth data in order to perform comparisons among species and tillage methods according to the efficiency in the restoration process performance, which is the Growth Index (GI) and the Use Viability Index (UVI).

The GI was calculated according to the equation:

$$GI(i) = (Pa(i) + Pac(i)) / (Pa(max) + Pac(max))$$

Where $Pa(i)$ and $Pac(i)$ are awarded points (from the smallest to the largest growth) for each species according to the statistically significant differences in RGR in height and canopy area, respectively. The awarded points ranged from 1 to 5 in height and from 1 to 4 for the canopy area, and $Pa(max)$ and $Pac(max)$ the maximum possible values for each parameter.

The UVI was used to integrate the values of the growth rate and survival percentage in a single value, as idealized by Zamith & Scarano (2006), calculated by using the equation $UVI(i) = GI(i) \times PS(i)$, where: $PS(i)$ is the

percentage of each species survival, at the end of 25 months for the first three tillage methods and at the end of 21 months for the dry season tillage.

3. Results

3.1. Survival

At the end of the first year, there was low mortality for all the species in the four tillage forms, being registered 80% - 100% survival of planted seedlings. However, at the end of the second year, there was lower survival and it was observed that some values were much lower than these (Table 1), in which the overall average of the four methods was approximately 71%.

The small mound method and acclimated seedling in nursery method were the way that presented better survival results, in which half of the evaluated species had rates higher than 90% (Table 1).

Although the initial expectations were positive, the planting during the dry season was not successful, even with the decrease in soil water saturation. In this method, half of all evaluated species presented lower survival rates compared to all other tillage forms and no species reached higher values. This also occurred with the conventional method, although in this case it was already expected.

The species *C. brasiliense* and *C. urucurana* presented, after two years in conventional method on small mounds and acclimated seedlings in nursery, values between 90% and 100%.

C. odorata did not obtain good performance in any method. This result probably occurred mainly by the *Hypsipyla grandella* Zeller (Lepidoptera, Pyralidae) on seedlings, whose larvae feed on the apical meristem, causing stunted growth which generally culminates with death of plants.

3.2. Growth Index and Relative Growth Rate

Overall, the growth, expressed by GI, was lower under conventional and planting during the dry season method (Table 1).

The best results were obtained by small mound and acclimated seedling methods. The species with higher GI submitted to small mound method were *C. brasiliense*, *F. insipida* and *T. guianensis*. In acclimated seedling method *C. urucurana* and *C. myrianthum* presented higher GI (Table 1).

The highest height RGR occurred with *C. brasiliense* in conventional and small mound methods (Figure 1). However, there was no significant difference among *C. brasiliense*, *F. insipida*, *C. myrianthum* and *T. guianensis* in conventional method and among *C. brasiliense*, *F. insipida*, *T. guianensis* and *C. urucurana* in small mound method. *C. odorata* had the lowest rate of height growth in all conditions; however, it was not significantly different from *F. insipida* and *C. urucurana* in conventional method and *C. myrianthum* in small mound method. In acclimation method, growth rates were generally lower, and there was no significant difference among the species, except for *C. odorata*, which differed significantly from all others. In planting during the dry season, there was no significant difference among species (Figure 1).

The canopy growth rate was significantly higher for *C. urucurana* in comparison with other species in the four methods (Figure 2), presenting a high performance except when method was done during the dry season,

Table 1. Percent survival (%S), growth index (GI), and use viability index (UVI) of six tree species grown under four methods of tillage for restoring degraded Swamp areas. UVI bold > 50.

Species	Conventional tillage			Small mounds			Acclimated seedling tillage			Dry season tillage		
	%S	GI	UVI	%S	GI	UVI	%S	GI	UVI	%S	GI	UVI
<i>C. odorata</i>	17.8	0.33	5.87	65.9	0.28	18.45	22.7	0.40	9.08	31.8	0.50	15.90
<i>F. insipida</i>	62.5	0.44	27.50	95.2	0.71	67.59	67.5	0.60	40.50	65.5	0.50	32.75
<i>C. brasiliensis</i>	90.9	0.77	69.99	97.7	0.85	83.05	97.7	0.60	58.62	72.7	0.50	36.35
<i>C. myrianthum</i>	60.0	0.77	46.20	80.0	0.57	45.60	97.5	0.80	78.00	52.5	0.75	39.37
<i>T. guianensis</i>	56.8	0.66	37.49	79.5	0.71	56.45	65.9	0.60	39.54	61.4	0.50	30.70
<i>C. urucurana</i>	97.7	0.66	64.48	97.7	0.85	83.05	100.0	1.00	100.00	86.4	1.00	86.40

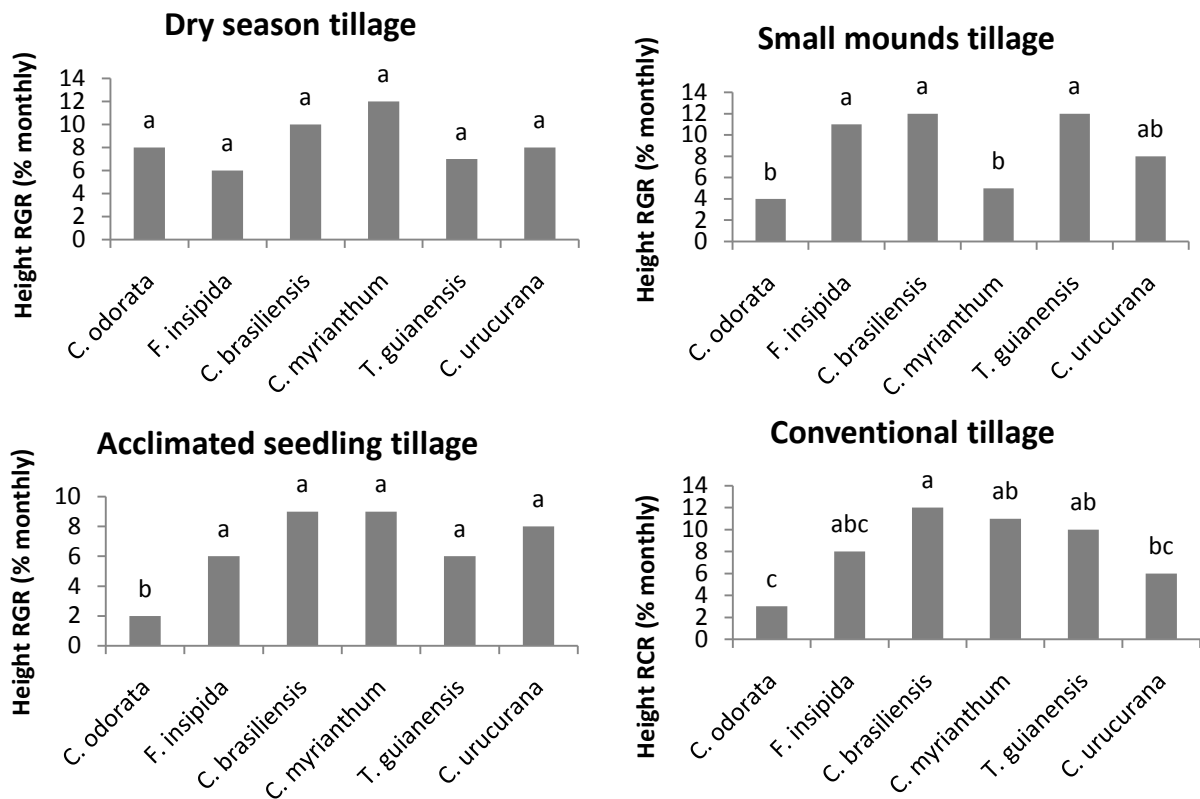


Figure 2. Average relative growth rate (RGR) for canopy area increment of six tree species grown under four methods of tillage in a Swamp restoration area.

which did not differ from *C. myrianthum* significantly.

During the dry season method, the RGR of the canopy area was much smaller for all species in comparison with the other tested methods.

3.3. Use Viability Index (UVI) in Restoration Initiatives

The UVI integrates the growth and survival index. The small mound method and acclimated seedling method were, in the present study, the most promising methods according to the UVI in restoration initiatives. These two methods also presented the highest survival values and the largest GI, for almost all species. So, they are recommended for restoration actions in Swamp Forests (**Table 1**).

The best results in UVI were obtained in descending order for *C. urucurana* in acclimated seedling and in planting during the dry season methods, followed by *C. brasiliense* for small mound method, *C. myrianthum* with acclimated seedlings and *F. insipida*, *T. guianensis* for small mound method (**Table 1**).

It was observed that *C. odorata* had a very low performance in all tested conditions, probably due to the *Hypsipyla grandella* Zeller. This is a species which often occupies the floristic lists compiled for Swamp Forest, so it can still be considered promising when restoring this vegetation.

4. Discussion

The results of the present study indicate that there is a promising potential for the restoration of degraded Swamp Forests through of methods developed specifically for this type of degraded area.

At the end of the second year, the survival rate of the four methods evaluated, had an overall average estimated at 71.7%. According to methods, the estimates of average survival were 86% for small mound method, 75.4% for acclimated seedling method, 61.7% for planting during the dry season method and 64.2% to conventional method.

Zamith & Scarano (2006) presented the results of a study on the restoration of salt marshes in which they

evaluated 17 species of typical trees and shrubs of this type of vegetation and monitored the survival and growth of 20 plants by species for 2 years. Despite the hardships imposed by nutrient-poor soil, 70% of the species had high survival percentage (greater than 80%) and considerable growth.

Among the methods evaluated in this study, the highest values of survival, GI and UVI were generally observed in small mound method (inverted pits).

The positive results of small mound method are probably related to the fact that in Swamp Forests, which occur in low and flat lands with irregular micro-relief, characterized by numerous small submerged elevations (“small mounds”) of dimensions ranging between approximately 0.20 and 0.50 cm-high and 0.5 to 2.0 m-diameter. Those are the “small mounds” where most individuals of this flora establish themselves naturally (Toninato et al., 1998).

In a study carried out by Marques & Joly (2000, 2002), the mortality of *Callophyllum brasiliense* Cambess. in flooded areas, was higher among seedlings and decreased in subsequent classes, mainly caused by the burial that smaller species suffered due to the entrainment of organic matter and soil by water from streams during the rainy season (Marques & Joly, 2002). In preserved swampy areas there have been observed plants growing on hillocks (accumulations of dirt or sand) or on bogs (accumulation of organic matter), or on natural small mounds, where the neck region of the plant, as well as part of its roots, are not in direct contact with water (Sztutman & Rodrigues, 2002).

Although small mound method has presented a really promising restoration action, it presents a lower yield in soil management, requiring greater financial investment in workforce especially during maintenance.

Galindo and colleagues (2012) have presented their results on a practical assessment of “*silvotermiteiros*” which are small mounds for planting tree species in wetlands, in intensive silvopasture systems, in Venezuela. According to the authors, the small mounds fulfilled the function of providing a well-drained micro-field for plants, favoring adaptation and accelerating the development in its early stages.

The acclimation in seedlings in the nursery proved to be very favorable for the beginning of the restoration of a Swamp Forest. Resistance and tolerance of a species in water saturated areas is not only conditioned by its survival, but also for its development and growth in anoxic conditions (Kozłowski, 1984). The soil saturation produces ecophysiological answers, morphological and anatomical changes, such as hypertrophy of lenticels, adventitious rooting and development of parenchyma at the base of stems and rhizomes. These changes were observed during the acclimation in seedlings and are generally associated with an increase in diffusion capacity of O₂ from aerial parts to roots. The O₂ deficiency occurs at the level of rhizosphere due to the water soil saturation (Joly & Crawford, 1982).

Studies must be carried out to determine the most suitable period of time for the water saturation of seedlings in the nursery, considering the adaptive particularities of each species, how this process must be conducted, which species best adapt to this procedure, which water saturation techniques are easy to be implemented and conducted at low cost to be developed on a large scale in nurseries. Such research could contribute with some interesting recommendations for nurserymen, both technically and financially.

As previously mentioned, small mound method raise the process costs. Thus, the development of a suitable acclimation method to be applied in nurseries would be very convenient considering the results obtained. This shows that such studies need to continue.

Regarding the growth, the performance was also promising, with the exception of *C. odorata*.

Within each method evaluated, the height Relative Growth Rate of species did not differ significantly in their majority. The same happened with the canopy area, with the exception of *C. urucurana*. Therefore, it is possible to say that the different species generally had a similar response when subjected to a method.

At Zamith & Scarano’s work (2006) nine out of the 17 species showed no significant increase in height and some species showed reduced canopy area due to deciduousness or broken branches.

In the present study, the dry season method, as an alternative of restoration action, was not very promising. The development of the seedlings until March 2010 showed that they did not reach the same levels of UVI compared to those obtained in small mound and acclimated seedling methods, probably because it had a shorter period of data collection.

Also, in the dry season of the year, the seedlings in the nurseries are not always in their proper development stage to be planted. In order to apply this method, the seedlings must be previously ordered, specifically for this season of the year.

Croton urucurana presented the highest UVI among the studied species, especially in acclimated seedling

method. The intensive growth of its canopy classifies this species as highly promising for situations when rapid shading of the soil is required, as a strategy to prevent grass invasion and other typically halophytic weeds. These results are in accordance with Gorenstein et al. (2006), who reports these species as the best developed in height and canopy projection in recovering experiment of riparian forest. Lorenzi (2008), describes this species as a pioneer; selective hygrophytes which characterizes wet and swampy lands, especially in riparian formations of the semi-deciduous broadleaf forest.

Calophyllum brasiliense presented the second best performance. The *C. brasiliense* tolerance to the soil water saturation, as well as its ability to survive and grow in flooded soil, have been pointed out and recommended by Marques & Joly (2000), for restoration programs in swampy areas. The results of the study by Teixeira et al. (2008) presented that *Calophyllum brasiliense* was one of the most abundant species in their floristic surveys in Swamp Forests.

The *Cytherexylum myrianthum* had the third best performance. It is a halophytic species, selective hygrophytes which characterizes gallery and Atlantic rain forests, it preferably occurs in very wet and swampy land, in dense ombrophilous forests and in the riparian areas of semi-deciduous seasonal forests (Carvalho, 1994; Lorenzi, 2008).

The species *T. insipida*, *Cedrela odorata*, and *Ficus insipida* have a slower development, however, they are necessary for the biodiversity formation of a mature Swamp Forest.

Zamith & Scarano (2006) have recommended the use of four species (*Senna australis*, *Pseudobombax grandiflorum*, *Chamaecrista ensiformis* and *Tapirira guianensis*) for restoring the open salt marsh on the west side of the Rio de Janeiro (Brazil), which had growth rates between 0.69 and 0.67 and UVI between 65.6 and 87.0. Furthermore, these species were more tolerant to high temperatures and wind.

Considering that species diversity is one of the important plant communities attributes which affects the ecosystems balance directly (Zamith & Scarano, 2006; Rodrigues et al., 2011), and that the differential performance of these species is essential in forest restoration, the results obtained here with these species are positive for the restoration of Swamp Forests and they are consistent with the initial hypothesis.

It is necessary to perform experiments which can clarify the benefits of alternative methods of wetland restoration (Zedler, 2003), and this study example with good initial results for restoring Swamp Forests in Brazil. Although a small number of species has been assessed, it indicates that there are promising prospects to restore the biodiversity and tropical ecosystem processes of Brazil and other countries.

5. Conclusions

In following researches on Swamp Forests restoration, studies which may present a list of recommended methods for different situations are important, depending on, for instance, the characteristics of the area to be restored, the structural and financial conditions of the rural producer and the region infrastructure.

It would be also interesting to evaluate other native species of Swamp Forests, considering the importance of maintaining and restoring this vital ecosystem, its biodiversity and its ecological processes.

It is suggested that further research, considered essential for the Swamp Forest restoration, should approach the seedling transplant as a restoring action, as well as cuttings, direct seeding and others. Studies on ecological succession and the adaptive mechanisms of typical species of this ecosystem would be equally important in order to enable the ecological processes recovering and the greatness of this forest type.

In addition, the long-term monitoring of the study area as well as the implementation of monitoring permanent plots for preserved Swamp Forests and restoration areas in this ecosystem will provide immensely valuable answers. That will enable practical actions for their protection and restoration as well as the basis for long term related research.

It is important to remember that these studies may support public policies for the protection and restoration of typical wetland forests.

Implications for Practice

Based on practical experience and the results of this research, the authors of this article recommend the following to those who have the difficult task of restoring Swamp Forests or wetlands:

- Instead of making use of soil pits for tillage, plant the seedlings of Swamp Forest typical species on small mounds of soil approximately 30 cm high and 70 cm wide, so that their roots will be raised from the water-

logged soil surface. Thus, the seedlings will present best results for survival and development. This method can also be used to restore other wetland forests.

- To the nurserymen who produce seedlings of Swamp Forest typical species, it would be better to leave them acclimating in tanks whose water level rises gradually and it is kept in the border of the plant bag or tube for at least 50 days.
- To those restorers who intend to plant in the dry season of the year, it would be better to order the nursery seedlings beforehand, to guarantee the properly tillage size in this period, which it is not so common.
- In the rainy seasons, do not perform the conventional tillage which is the opening of pits at the soil level. This procedure does not produce good results on seedling tillage for the restoring of wet areas.

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