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Article

Weed Control Strategies for Restoration of the Atlantic Forest in the State of Rio de Janeiro - Brazil

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ABSTRACT

The objective was to evaluate the best weed control strategy, for the formation of forest stands in Atlantic Forest, Brazil, aiming at restoration in an area dominated by *Urochloa decumbes*, evaluating the biological indicators and costs. It also sought to verify the magnitude of response of mechanical control compared to treatment without intervention, for similar sites where the experiment was installed and conducted. The treatments were: T1 - mechanical (mowing and crowning); T2 - chemical (application of glyphosate syrup); T3 - mechanical cultural (weeding, seeding and cultivation of *Cajanus cajan* and *Canavalia ensiformes*); T4 - chemical cultural (application of glyphosate, seeding and cultivation of legumes); T5 - absolute control (no intervention after planting). Activities and evaluations were carried out up to 30 months after planting the seedlings of the five species used. It was observed that in all treatments the survival of the plants reached values higher than 80%, at 6 and 18 months after planting. It was found that, on average, the tree plants in T2, T3, and T4 showed significantly higher growth than those in T1 and T5, which did not differ. The control with glyphosate is indicated for areas with predominance of *Urochloa* sp. Strategy control with glyphosate and cultivation of herbaceous legumes has potential use and needs adjustments to reduce costs. Also, that the control with mowing and crowning is not indicated due to the high cost and not favoring the growth of the planted trees, because it did not show significant differences in relation to the controls.
Keywords: environmental recovery; planting of seedlings; herbicides.

RESUMO

O objetivo foi avaliar a melhor estratégia de controle de plantas daninhas, para a formação de povoamentos florestais na Mata Atlântica, Brasil, visando a restauração em área dominada por *Urochloa decumbes*, avaliando os indicadores biológicos e custos. Também buscou verificar a magnitude da resposta do controle mecânico em relação ao tratamento sem intervenção, para locais semelhantes onde o experimento foi instalado e conduzido. Os tratamentos foram: T1 - mecânico (roçada e coroamento); T2 - químico (aplicação de xarope de glifosato); T3 - cultura mecanizada (capina, semeadura e cultivo de *Cajanus cajan* e *Canavalia ensiformes*); T4 - cultura química (aplicação de glifosato, semeadura e cultivo de leguminosas); T5 - controle absoluto (sem intervenção após o plantio). As atividades e avaliações foram realizadas até 30 meses após o plantio das mudas das cinco espécies utilizadas. Observou-se que em todos os tratamentos a sobrevivência das plantas atingiu valores superiores a 80%, aos 6 e 18 meses após o plantio. Verificou-se que, em média, as plantas arbóreas em T2, T3 e T4 apresentaram crescimento significativamente maior do que as de T1 e T5, que não diferiram. O controle com glifosato é indicado para áreas com predominância de *Urochloa* sp. Estratégia de controle com glifosato e cultivo de leguminosas herbáceas tem potencial de uso e necessita de ajustes para redução de custos. Também, que o controle com

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roçada e copa não é indicado devido ao alto custo e não favorecer o crescimento das árvores plantadas, pois não apresentou diferenças significativas em relação às testemunhas.
Palavras-chave: recuperação ambiental; plantio de mudas; herbicidas.

Introduction

Given the current degradation scenario and the difficult task of increasing forest cover and safeguarding ecosystem services essential for the well-being of populations, initiatives and research are needed to form forest stands aimed at contributing to the restoration of the Atlantic Forest (Trentin et al., 2018; Santana, 2019; Martins, 2020; Turchetto et al., 2020), Brazil. Considering the commitments towards forest restoration made in the United Nations Environment Programme and the Food and Agriculture Organization of the United Nations, as the United Nations Decade of Ecosystem Restoration 2021-2030 (UN, 2021), it is necessary to overcome several forest restoration challenges faced in tropical regions in order to achieve satisfactory results. One of the ways to carry out restoration is with the implementation and formation of mixed forest stands, through the planting of seedlings. In the region of occurrence of the Atlantic Forest biome, the main difficulty and that which most burdens the costs, according to Leles *et al.* (2015) and Santana (2019), is the control of weeds.

One of the important steps for reforestations to achieve the main objective, which is to serve as a "catalyst" of forest restoration is the control of weeds, especially areas dominated by *Urochloa* sp. and *Panicum maximum* (Leles et al., 2017; Santana et al., 2020b, 2020a; Santos et al., 2020). Thus, methods and their combination for weed control have been studied (Leles et al., 2015, 2017; Santos et al., 2020; Ribeiro, 2020; Santana et al., 2020; Turchetto et al., 2020) .. A widespread approach to the control and management of these plants has been the application of herbicide grout. Studies by Scoriza *et al.* (2015), Santos et *al.* (2018), Ribeiro (2020), Santana *et al.* (2020) and Santos et *al. (*2020) indicate potential use of glyphosate-based herbicide as a tool for area preparation and during stand formation (weed control). Among the main factors indicating the use of glyphosate in the control of areas dominated by *Urochloa* sp. is the increased plant growth of tree species (Campoe et al., 2014; Santana et al., 2020; Santos et al., 2020, 2018) and costs, when compared to the mechanical method - crowning and mowing (Santos et al., 2018; Santana, 2019). Also, the dynamics of herbaceous plants, with a decrease of *Urochloa* sp. in the understory and arrival of other herbaceous and more tree species (Ribeiro, 2020).

Studies show that the magnitude of response of stand formation according to the method(s), also known as strategies, of weed control vary with the predominant herbaceous species, the tree species used, spacing and with the edaphoclimatic conditions of the region. The region of this study area, according to the summary of the Executive Management Plan of the Ecological State Station of Guaxindiba - EEEG (INEA 2013), has a hot and humid climate, without pronounced winter, with marine influence and rainy season in summer, being poorly distributed, quite different from other regions of the Atlantic Forest. This document mentions that the EEEG is in the phytophysiognomy of Semideciduous Seasonal Forest, in the so-called tableland forests, distinguished from other Atlantic Forest formations by occupying an extensive area of coastal plain or tableland, of Tertiary origin, with its species distributed along a climatic gradient (coastal-interior direction), and is one of the most devastated regions of the state of Rio de Janeiro.

There are also a variety of other forms of interventions, which aim to minimize competition within restoration sites, such as use of herbaceous legumes (Ribeiro, 2020; Santana et al., 2020; Santos et al., 2020)agroforestry systems, and the use of physical barriers such as cardboard, for example (Brancalion et al., 2014; Gonçalves et al., 2021; Martins et al., 2019; Turchetto et al., 2020). The choice of the most suitable forest

restoration model will depend on the best combination of the available techniques considering the lowest cost, with the best results.

This work aims to evaluate the best weed control strategy for the formation of forest stands for restoration in the Norte Fluminense region, Brazil, evaluating the biological indicators and costs involved in the implementation of activities up to 30 months after planting. It also sought to verify the magnitude of response of mechanical control compared to the treatment without intervention, for similar sites where the experiment was installed and conducted.

2. Material and Methods

The experiment was implanted and conducted in an area for stand formation aiming forest restoration, located in the Ecological State Station of Guaxindiba, Municipality of São Francisco de Itabapoana, Rio de Janeiro State, Brazil - geographical coordinates Zone 24K 284415m E and 7631627m S. It is inserted in an area whose main objective is the formation of more than 500 hectares of forest. The experiment site is approximately 10 km (as the crow flies) from the northern coast of Rio de Janeiro.

According to Köppen's climatic classification, the climate of the study region is Aw, with greater precipitation occurring in summer, and cold and dry winter. During the period of the experiment, daily rainfall was recorded, obtained by a rain gauge installed in the study area. Temperature data were obtained from the historical database of INMET (2019/2020), recorded at a meteorological station in Campos dos Goytacazes, RJ, located 43 km away from the experiment. In 2019, precipitation was 954 mm, with November having 290 mm (30%). In 2020 it was 1,163 mm, with March being the rainiest month, with 175 mm (15%). The average temperature during the analyzed period was approximately 24 ºC.

The relief of the study area is flat, well drained and the previous land use was pasture, with a predominance of *Urochloa decumbes* (Stapf.) R. D. Webster and previously, the area was used for beef cattle breeding. The soil of the experimental area has a loamy-clayey texture and is classified according to the Brazilian Soil System as Quartz Neosol (Embrapa, 2018). The results of the chemical analysis of the 0-40 cm soil layer, before the implementation of the experiment shows pH = 5.0; P and K = 1.5 and 43 mg dm^{-3}; Ca^{2+}; Mg^{2+}; Al^{3+}; H+Al and SB = 0.6; 0.4; 0.3; 2.3 and 2.4 $cmol_c$ dm^{-3}; V and m = 51 and 9.0 %, respectively.

The monthly soil water balance during the experiment period, considering a soil available water capacity of 100 mm, indicates that most of the year there is water deficiency, which usually hinders the process of formation of forest restoration stands. Of the 30 months of the experiment, only in 6 months there was surplus water in the soil.

2.1 Characterization of the Experiment

After selecting the area for the experiment, mowing was performed with a mechanized brush cutter (driven by an agricultural tractor). After a few days and after rains (late October 2018), subsoiling was performed with a subsoiler and in the same passage harrowing with 4 disc harrow, distance between "lines" of 3 meters, at a depth of approximately 60 cm and surface laterality of 30 cm. Then made to 150 grams of N-P-K (06-30-06) + 7% Ca and 6% S, per cradle, at the time of planting, which occurred on 31/10/2018, with a distance of 2 meters between them.

The species used were *Anadenanthera macrocarpa* (Benth.) Brenan (angico-vermelho), *Joannesia princeps* Vell. LC. (boleira), *Inga vera* Wild. (ingá), *Paubrasilia echinata* (Lam.) Gagnon, H.C. Lima & G.P. Lewis (pau-brasil) and *Dictyoloma* vandellanum Adr. Juss. The planting spacing was 3 x 2 m. These species were chosen because they are naturally occurring in the Norte Fluminense region and are part of the list of species found in Mata do

Carvão (area near EEEG) in a survey published by Silva and Nascimento (2001). Another factor that contributed to the use of the species was having seedlings with standardized heights and satisfactory quality, according to the authors' experience and standards described by Souza Junior and Brancalion (2016).

The experiment was set up with four weed control treatments, plus a witness treatment (no intervention - planted and left). The treatments consisted of: T1 - Mechanical: (crowning and mowing), crowning of the planted seedlings was performed, with the help of a hoe with a diameter of approximately 70 cm and mowing in between rows and lines, with the help of a side-shooter, whenever *Urochloa decumbes* (Stapf.) R. D. Webster reached a height greater than 35 cm; T2 - Chemical: application of glyphosate-based herbicide (Roundup original), at a dose of 1.44 kg ha^{-1} active ingredient - isopropylamine salt formulation of glyphosate 570 g L^{-1} and 480 g L^{-1} of acid equivalent), with a dose of 4 liters per hectare of the herbicide; T3 - Mechanical and Cultural: weeding in the whole area and removal of plant material, soon after planting the tree seedlings and during the cultivation of herbaceous legumes - *Canavalia ensiformis* (L.) DC (pork bean) and *Cajanus cajan* (L.) Mill sp. (cowpea); T4 - Chemical and Cultural: application of grout based on N-(phosphonomethyl) glycine and glyphosate di-ammonium salt concentration 577.0 g/L. After desiccation, sowing and cultivation of *Canavalia ensiformis* (L.) DC (pork bean) and *Cajanus cajan* (L.) Mill sp. (cowpea). In every glyphosate application activity, a 20 liter capacity manual knapsack sprayer was used, with an average pressure of 3.0 bar and *Teejet Turbo induction* (TTI) air *induction* spray nozzle, with a flow rate of 0.8 liter/minute. There were moments, from the second intervention on, when herbicide was applied, in a smaller dose than the initial one, and others when the brachiaria bushes were weeded. T5 - No intervention: absolute witness, after planting the forest seedlings there were no anthropic interventions in the four experimental units of the treatment. In all applications of glyphosate-based syrup (T2 and T4), care was taken to apply early in the morning and on a day with wind speed below 8km/h, with the aim of avoiding drift of the product to the plants of tree species and less possibility of herbicide volatilization.

The design used was entirely randomized, with five treatments and four blocks, totaling 20 sampling units. Each sampling unit was formed by five "rows" of 10 planting cradles (2 seedlings of each species per row). Thus, each experimental unit was 300 m² and the experiment occupied an area of approximately 0.6 hectare.

The seedlings were produced in polypropylene tubes with a capacity of 280 cm³, with a production period varying from 4 to 6 months, according to the production characteristic of each species. At planting time, for each species, seedlings with the closest possible height of the aerial part were selected. The average height of the aerial part of the species varies from 35 to 50 cm, depending on the species.

In treatments T3 and T4, the seeding of the cowpea was done in a continuous furrow, 5 cm deep, in the middle of the inter-row of tree species (1.5 m distance "line" of tree species), with 8 to 10 seeds per linear meter. The sowing of the pork bean was done between the line of Guandu bean and the tree species, opening holes with a hoe, 40 cm apart.

The control of leaf-cutting ants was done with visits to the experimental site, and when necessary, placement of granulated baits. The replanting of the tree species was done 30 and 60 days after planting, replacing the dead seedlings in all experimental units, using the same batch produced for the experiment. To control the yield and costs of the interventions, a field spreadsheet was prepared with the number of men, time per activity, inputs, and materials used in each intervention.

2.2 Evaluations of Tree Species

Evaluations were made of tree plant survival at 6 and 18 months after planting the seedlings and height growth, with the help of a graduated ruler, of the five tree species at 6, 12, 18, 24, and 30 months after planting.

In this last evaluation, the diameter at ground level was also measured with a digital pachymeter. At 18 and 30 months after planting, in order to determine the crown area and concomitant ground coverage by the plants, the length of the crown was measured longitudinally and transversally to the planting line, using a tape measure.

To calculate canopy cover of tree species, the methods chosen were Degree of Cover (GC), which consists of the relationship between the area of canopy of tree individuals and the total area of the sample unit (Mueller-Dombois and Ellenberg, 1974) and the method of line intercession (IL), which relates the length of the crowns of planted trees to the length of the planting line (Melo et al., 2007)as used by Santana et al. (2020a) and Santos et al. (2020). These indices, whose formulas are presented below, have been frequently used in the evaluation of forest restoration projects by the environmental agency of the State of Rio de Janeiro, Brazil (INEA, 2017).

Cup area $CA_i = \frac{\pi \times D_1 \times D_2}{4}$

Degree of coverage: $DC = \left(\frac{\sum AC_i}{S}\right) \times 100$

Intersection of lines: $IL = \left(\frac{\sum D_1}{C}\right) \times 100$

Where: CA_i = canopy area of each tree individual (m^2); D_1 and D_2 = canopy length, respectively, longitudinal and transversal to the planting line (m); S: sample unit area (m^2); C= planting line length.

2.3 Cost Analysis of Weed Control Strategies

In order to evaluate the costs that were employed in the interventions for weed control, the activities carried out by the field collaborators were timed, with the beginning and end of the activities being recorded, disregarding the moment of rest of the collaborator and the machine. All materials and inputs used in the performance of each activity were also recorded. From each treatment and repetition (experimental unit) information was obtained separately.

The prices were considered the values of May 2023. Considered the price of man $hour^{-1}$ was R$ 14.70 including salary, fees, social and labor charges, food, insurance, uniforms and individual protection equipment. The price of the liter of glyphosate was R$ 65.00 commercial product, of gasoline R$ 5.49 and of time oil R$ 28.00, kilogram of guandu bean R$ 25.00 and of pork bean R$ 12.50. In preparing the area and planting, where the treatments had not yet been implemented, the values updated for May 2023 are R$ 180.00 tractor $hour^{-1}$, R$ 170.00 bag of 50 kg of N-P-K (06-30-06) and R$ 3.30 seedlings of the tree species, produced in 280 cm^3 tubes.

The data obtained were for the sample unit area (1,200m^2) of each treatment, and were transformed to hectare (ha), the standard unit employed in forest restoration projects.

2.4 Statistical Analysis

To meet the assumptions of the analysis of variance, the variances of data on growth in height, diameter and canopy area of the tree species at 30 months and soil cover of each treatment at 18 and 30 months were subjected to Bartlett's test for homogeneity of variance and the residuals had their normality tested by the Shapiro-wilk test. Assumptions being met, analysis of variance was performed and in case of significance ($p \geq 0.05$) Tukey's test for comparison of means was applied at the 95% significance level.

3. Results and Discussion

3.1 Survival and Growth of Tree Species

The survival rate of the five tree species in all treatments reached values higher than 90% (Figure 1) at six months after planting. For *Joannesia princeps* and *Inga vera* there was no plant death in the treatments evaluated, showing the hardiness of the two species, as mentioned by (Carvalho, 2008, 2003)indicating that it can coexist in an area dominated by brachiaria. A similar result was found by Santana *et al.* (2020) when evaluated *Inga edulis* under different control strategies in an area of *Urochloa brizantha* dominance, where they observed that 100% survival was achieved, even in the mechanical method. The results also indicate that herbicide application in two treatments, and the cultivation of leguminous plants did not affect the survival of the tree species plants, at six months after planting the tree seedlings, in an environment with 80% of the months of the year with water deficiency in the soil. In the evaluation performed 6 months after planting - after 4 months of water deficiency in the soil, there were no differences in the survival of tree species between the mechanical control and control treatments, showing that sites similar to the experiment, it is apparently preferable not to control with mowing and crowning.

At 18 months after planting, it is observed that on average in the witness treatment the survival rate was 85% and in the mechanic 94%, requiring no new replanting actions, according to indications by Belloto *et al.* (2009) and Inea (2017). This difference found between the experimental units of the control treatment and the mechanical method is relative, because it is observed on a daily basis, that in the formation of stands aiming restoration can be performed replanting with seedlings of tree species diversity up to ages greater than 2 years. The survival averages at 18 months, involving the five species are within the established by the "State System of Monitoring and Evaluation of Forest Restoration" (Inea, 2017), not requiring replanting.

Testing control strategies for coexistence of *Urochloa* spp. with eight tree species, Santana *et al.* (2020) found 82% survival in the treatment with dominance of glyphosate application at 18 months after planting, in Cachoeiras de Macacu, RJ. Similar result was found by Santos et al. (2020), when evaluating the behavior ten tree species with this control strategy of *Urochloa decumbens*, *at* 18 months after planting, obtained 86% survival of tree species plants. In this study, the survival rate, on average, was 90%, and in three species, the rate was approximately 100%, highlighting the potential of glyphosate use and the importance of its correct application for the formation of stands aiming forest restoration.

The average plant height of the five species evaluated, in the treatments with mechanical control and in the control treatment (no intervention) showed significantly lower growth than in the other treatments evaluated, and these did not differ (Figure 1). This result, along with survival, indicates that, for this site with most of the year with soil water deficit, when the brachiaria is cut, it normally sprouts as occurs when grazed by animals and with this occurs competition for water, hindering the growth of tree species, i.e. it is preferable to plant and not cut.

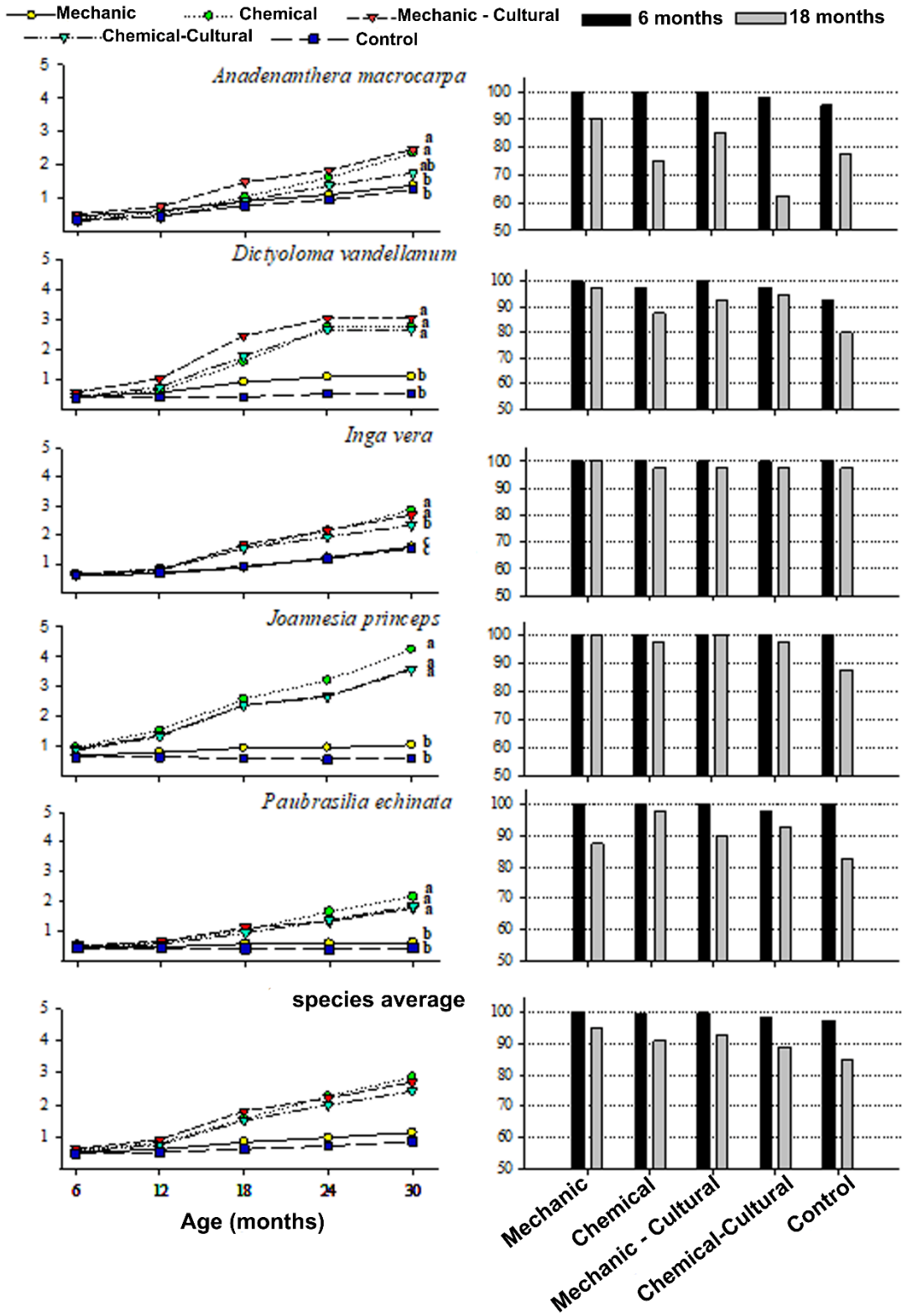

Figure 1. Height of the aerial part (left column) and Survival (right column) at times after planting, of five tree species, under four methods of weed control and witness in a forest restoration area, municipality of São Francisco de Itabapoana, RJ. For each species, different letters mean that in the last evaluation, the average plant height of the treatments differed from each other (P ≥ 0.95), by Tukey's test. Source: Elaborated by the authors.

The results of this study, along with others conducted in the state of Rio de Janeiro (Ribeiro, 2020; Santana et al., 2020; Santos et al., 2020) suggest that mowing and crowning are not efficient practices to control *Urochloa* spp. plants, aiming to form stands for restoration of the Atlantic Forest. Figure 1 also shows that for the five

species evaluated, the average height of the aerial part of the plants in the chemical, mechanical cultural and chemical cultural treatments at 18 months was significantly higher than the average of the plants in the mechanical treatment at 30 months, with greater emphasis on *Dictyoloma vandellanum* and *Joannesia princeps*. Similar results were found by Santana *et al.* (2020) studying control strategies of *Urochloa brizantha* up to 18 months to form a stand for restoration, in a site without water deficiency in the soil. In mechanical and control treatments, the brachiaria not only competed for water and nutrients, which are relatively scarce in the region of the experiment, according to Silva *et al.* (2009)can have an allelopathic effect on most crops, inhibiting the growth of tree species.

Regarding the growth of crown area, in the two evaluations and the diameter at ground level at 30 months after planting, it is also observed that in general, the plants in the chemical, mechanical cultural and chemical cultural treatments showed significantly greater differences than those in the mechanical and control treatments (Figure 2), and these did not differ among themselves. This result is similar to the height of the aerial part at 30 months after planting (Figure 1).

Absence of significant differences in growth between the tree plants of mechanical control - grazing and crowning and witness, at 30 months after planting was not expected, as evidenced by the works of Santos *et al.* (2019), Santana *et al.* (2020b) and Santana et *al.* (2020a) who found that coexistence with brachiaria impaired the growth of tree plants in the initial stage of formation of stands. Also addressing the problem of weeds in forest restoration, Leles *et al.* (2017) indicate that the coexistence of species of the genus *Urochloa* has impaired the growth of tree species in the formation of forest stands. What probably occurred in this work is that the soil in most of the year has water deficit and when the brachiaria (mechanical control) is cut, it sprouts and consumes the little water in the soil, hindering the growth of tree species that were planted.

On average, the degree of canopy cover and inter-row intercession maintained the behavior of the other biometric indicators (Figures 1 and 2), as shown in Table 1. Numerically, the chemical treatment showed the highest percentage of canopy cover, followed by the mechanical cultural and chemical cultural treatments at 18 and 30 months after planting, being corroborated by the height of the part area and reducing the emergence of weeds. At 30 months after planting, the values of the degree of canopy cover and the intercession in the rows were higher than 100% in the chemical treatment, i.e., the canopies were already intertwining, indicating canopy formation, exceeding the minimum values of the legislation of monitoring biological indicators of area with forest restoration in the state of Rio de Janeiro (INEA, 2017). Similar value was observed only in the intercession of the lines in the mechanical cultural treatment, where the projection of the canopy perpendicular to the planting line, may have suffered interference by the permanence of leguminous herbaceous plants (cowpea).

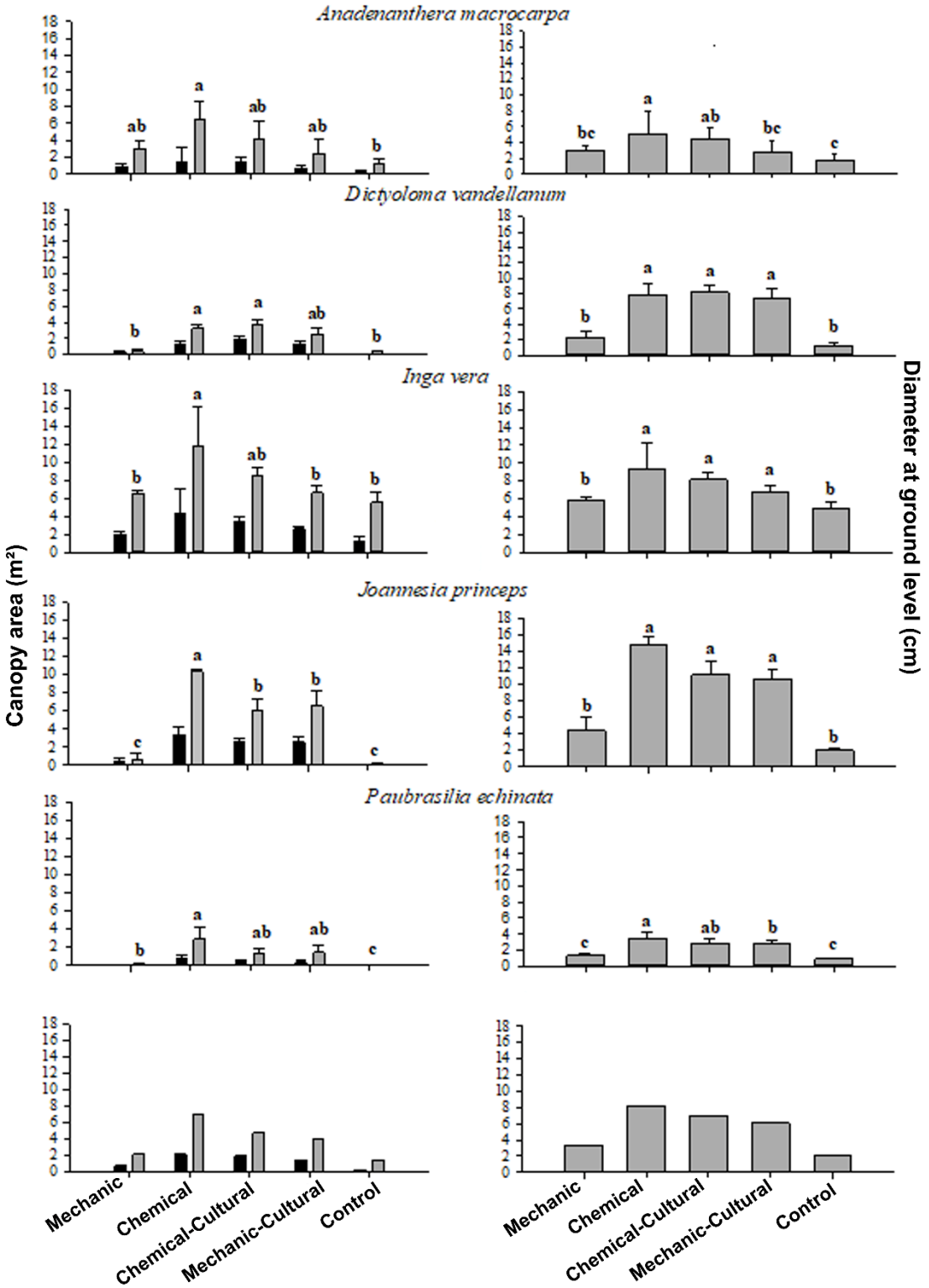

Figure 2. Crown area (left) at 18 and 30 months after planting and diameter at ground level (right at 30 months) of five tree species, under four methods of weed control and control in a forest restoration area, municipality of São Francisco de Itabapoana, RJ. For each species and age of evaluation, different letters mean that, mean of the plants of the treatments differ from each other (P ≥ 0.95), by Tukey's test. Source: Elaborated by the authors.

Table 1. Mean values and (coefficient of variation) of canopy cover (%), of the five tree species deployed, in four weed control strategies and witness, using two methods, at two ages after planting in a reforestation area, municipality of São Francisco de Itabapoana, state of Rio de Janeiro, Brazil.

Age	Method	Chemist	Mec_cultural	Quim_cultural	Mechanic	Witness
18 months	Degree of Coverage	34.9 (57.1)	30.9 (5.9)	22.9 (13.7)	11.7 (22.9)	4.6 (49.6)
	Intersection of lines	64.3 (37.9)	69.2 (3.4)	56.0 (7.1)	36.3 (12.2)	16.9 (23.6)
30 months	Degree of Coverage	103.8 (33.0)	74.1 (6.1)	60.0 (11.5)	32.8 (12.2)	21.5 (27.6)
	Intersection of lines	119.6 (24.4)	105.1 (2.9)	94.1 (5.4)	54.8 (12.2)	36.5 (26.5)

Source: Elaborated by the authors.

The canopy cover of the sample units of the chemical and mechanical cultural treatments indicates that the maintenance activities for both methods can be interrupted at 30 months after planting, because the weed infestation is already reduced by shading the area. Using similar planting spacing of the working seedlings, Santos *et al.* (2020) found similar results of canopy cover by both methods, at 30 months after planting, in the municipality of Bom Jardim, RJ, which has higher average annual precipitation and better distributed rainfall than in São Francisco de Itabapoana. Santana *et al.* (2020), working in a site that does not present soil water deficit throughout the year, and a group of eight species found that at 18 months after planting the seedlings, soil cover in the chemical treatment units was around 120%, in the chemical cultural 55% and in the mechanical 30%. These studies show that using glyphosate mixture as a control, 100% canopy cover is achieved at a much younger age than the mechanical treatment, contributing to the discharge of the compensatory measure with the environmental agency, which in the case of the state of Rio de Janeiro is the State Environmental Institute (INEA). The magnitude of this response in the three studies varies according to the quality of the site, the tree species used, the predominant herbaceous species, and the frequency and dose of glyphosate used.

The results of this study indicate that in the mechanical treatment units, weed control should not be interrupted 30 months after planting. This recommendation is due to the biological indicators of plants (height and canopy cover) are not yet suitable for brachiaria shading, as presented in Table 1 and Figures 1 and 2, because they do not meet the criteria of Article 5, which refers to the parameters used for certification, monitoring and discharge of the fulfillment of restoration commitments that are based on meeting the ecological indicators set out in Resolution No. 143 / 2017 (Inea, 2017).

3.2 Interventions and Costs

It is observed that up to 30 months after planting the seedlings in the experimental units of the mechanical treatment there were seven grazings, and on five occasions, due to the height and proximity of the brachiaria to the arboreal plants, crowning occurred (Table 2) and was the treatment with the greatest number of interventions and highest cost of weed control, and is among the lowest growth of arboreal plants (Figures 1 and 2 and Table 1). This method according to Silva (2009), is usually the most expensive due to the low yield of its operation and with technological advances, according to Santos et al. (2020) and Turchetto et. al. (2020) and this method with manual labor has been avoided by the relatively high costs compared to other methods. Using this treatment, the last mowing was in April 2021 (30 months after planting) and thus, the average period between interventions was 4.3 months, similar to the work of Santos et al. (2020) that also occurred seven mowings and five strip weeding in an experiment in the mountainous region of Rio de Janeiro. The work of

Santana et. al. (2020), also using the mechanical method, the average interval of interventions was 2.8 months, up to 18 months after the planting of seedlings for the formation of stands aiming forest restoration, in Cachoeiras de Macacu - RJ. These differences occur due to edapho-climatic conditions of the environment, especially rainfall distribution throughout the year and the predominant species of *Urochloa in* the area, considering that the three works are in an area of predominance of this genus.

Table 2. Number of interventions under four weed control strategies up to 30 months after planting of tree seedlings, municipality of São Francisco de Itabapoana, RJ.

Activity	Mechanic	Chemist	Mec and cultural	Thu and cultural
Mowing	7		1***	
Crowning	5	2		1
Glyphosate in total area		3		3****
Glyphosate in brachiaria bushes		2		
Manual weeding in total area			1	
Sowing the legumes			1*	1**
Brachiaria weeding in legume cultivation.			3	1
Manual weeding of brachiaria bushes				1*****
Costs (R$ / hectare)	7.053,00	892,00	13.655,00	5.098,00

* performed in November 2018 (20 days after planting the seedlings), right after manual weeding;
** performed in February 2019 (3.5 months after planting the seedlings); 45 days after 1st glyphosate-based grout application and 5 days after 2nd glyphosate application;
*** held in November 2020;
**** held in December 2018, February 2019 and February 2020;
***** held in May 2019.
Source: Elaborated by the authors.

In the experimental units of the chemical treatment, seven interventions occurred in the 30-month period of stand formation, all relatively quickly, so the cost was almost 8 times lower than the units of mechanical treatment (Table 2). Differences in cost of weed control and plant growth of tree species for stand formation aiming restoration, of great magnitude between these two methods has been observed by other works. Santos et al. (2018) observed that up to 30 months after planting, the cost using mechanical method was almost three times higher than chemical; Santana (2019) found that up to 18 months after planting, this difference was 4.5 times. The two hoeing crownings performed in the chemical treatment occurred because the planting beds of some tree plants had brachiaria plants, which the technical team judged to be harming the growth of the trees, and if glyphosate were applied it could affect the plants of interest. These interventions were localized, occurred in August and December 2019 (10 and 14 months after planting) and took relatively little time.

The applications of glyphosate grout in total area, except in the locations of projection of the crown of the plants of tree species, occur in December 2018 (45 days after planting the seedlings), June 2019 and April 2020 (18 months after planting). In November 2019 (1 year after planting) herbicide application occurred in brachiaria bushes and again in December 2020 and aimed to control only the species that is potentially weedy and allow other herbaceous species to complete their cycle in the environment, as noted by Ribeiro (2020), with the production of flowers, pollen and nectar, which are important for pollinators and with that for forest restoration, in addition to decreasing the amount of herbicide syrup spent and thus, control costs. Using the chemical method, the last intervention was at 18 months, decreasing weed control costs and allowing at 30 months after planting, soil coverage by the tree plant canopies to be greater than 100% (Table 1), evidencing, along with other works (Santos et al, 2018; 2020; Ribeiro, 2020; Santana et al., 2020a) the potential of using

glyphosate to control Poaceae in a stand formation area for forest restoration of the Atlantic forest, provided it is used in correct doses and with adequate technology and application care.

The mechanical treatment with weeding in total area and then sowing and cultivation of *Cajanus cajan* and *Canavalia ensiformes* showed very high cost, compared to the other methods, as also observed by Santos et al. (2020). This occurred due to the low performance of the weeding operation as preparation of the area for sowing (35% of the costs), as mentioned by Silva et al. (2009) and Santos (2016). Another activity that demanded high cost (41% of total cost) were the three weeding operations during legume cultivation. Silva et al. (2009) mention that weeding usually leaves the soil exposed, increasing the possibility of soil erosion processes, especially in areas of sloping soil, which is not the case in this work. In addition, the latter authors call attention to the fact that if weeding occurs on rainy days, new weeding may be necessary due to regrowth of the weeded clumps, which is common in areas dominated by *Urochloa* or *Panicum*. The costs of acquisition of legume seeds and sowing were estimated at R$1,726.00/ha and R$1,285.00/ha, respectively. These can be reduced by the production of legume seeds, which are relatively easy to be produced and processed on the property or enterprise itself. Based on this work and other experiences, this strategy is not recommended for weed control in areas with a predominance of Poaceae, because of the high cost and possible problems of soil erosion.

Table 2 shows that the strategy of control of brachiaria plants using glyphosate-based herbicide spray and sowing and cultivation of *Cajanus cajan* and *Canavalia ensiformes*, called chemical - cultural, six weed control interventions were performed at an estimated cost of R$ 5,696.00 / hectare, or 4.7 times less than the mechanical cultural, due to the absence of weeding in the total area and weeding in the legume cultivation. The largest cost item in this treatment was with legume seeding (35%) - slightly higher than in the previous method due to the need to manage the desiccated straw from herbicide application, followed by weeding in brachiaria bushes (22%). The cost of this last activity will probably decrease if post-emergent graminicide is used, which used at the correct dose only controls plants of the Poaceae family. The cost of acquisition of glyphosate, transportation of water, equipment and people, use of personal protective equipment, mixing and application of the syrup, in this treatment corresponded to R$ 1,095.00 / ha (90.8%). As shown in Table 2, in this treatment a crowning of some plants was performed (18 months after planting), before the last application of glyphosate grout in total area, a fast operation that demanded less than 10% of the cost of control.

4. Conclusions

The best weed control strategy on sites similar to this study and with a predominance of *Urochloa decumbes*, for the formation of forest stands aimed at restoration is the use of glyphosate-based herbicide, because it provides greater growth of the plants of tree species, fewer interventions and lower costs.

The cultural chemical method has potential for use, requiring adjustments in its methodology.

The use of the mechanical - cultural strategy is not recommended due to the cost and possibility of soil erosion.

For similar sites where the experiment was installed and conducted, it was identified that when comparing the mechanical method and no intervention, it is preferable to plant and do no weed control intervention, because there were no marked differences in survival and significant differences in growth of tree species, besides the relatively high cost of the set of activities of the mechanical method.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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