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## TREE DIAMETER GROWTH FOLLOWING SILVICULTURAL TREATMENTS IN A SEMI-DECIDUOUS SECONDARY FOREST IN CENTRAL BRAZIL

Keywords:
Tropical dry forests
Forest management
Canopy gaps

**ABSTRACT:** In the Cerrado biome of Brazil, savannas and dry forests are intimately linked and form mosaics. These forests are composed of species of high commercial value, well accepted in the timber market, which causes intensive deforestation on the remaining vegetation. Thus, the management of these forests is an important alternative to reduce deforestation in the remaining vegetation. The objective of this study was to analyze the response of tree species in relation to silvicultural treatments of competition and liana cutting in a semi-deciduous forest in Central Brazil. The results showed that community basal area increased 24% over 4.8 years and the median periodic annual increment in diameter was about 20% higher in plots with silvicultural treatments: 2.9 $mm \cdot yr^{-1}$ in the control compared to 3.2 $mm \cdot yr^{-1}$ to 3.6 $mm \cdot yr^{-1}$ between treatments. This study demonstrated that it is possible to increase the rates of radial growth through silvicultural techniques.

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## CRESCIMENTO DIAMÉTRICO EM FUNÇÃO DE TRATAMENTOS SILVICULTURAIS EM UMA FLORESTA ESTACIONAL SEMIDECÍDUA NO BRASIL CENTRAL

Palavras chave:
Floresta Estacional Tropical
Manejo florestal
Abertura de dossel

**RESUMO:** No Bioma Cerrado, as florestas estacionais e o Cerrado *stricto sensu* estão intimamente ligados, fomando mosaicos. Essas florestas são compostas por espécies de alto valor comercial, bem aceitas no mercado madeireiro, o que provoca o desmatamento intensivo dessas matas. Assim, o manejo dessas florestas é uma alternativa importante para reduzir o desmatamento nos remanescentes, na medida em que proporciona o seu uso sustentável. Este estudo analisou o crescimento de espécies arbóreas em relação a tratamentos silviculturais de liberação de competição e corte de cipós, em uma floresta estacional semidecídua, no Brasil Central. Os resultados mostraram que a área basal da comunidade aumentou 24%, durante 4,8 anos e que a média do incremento periódico anual em diâmetro foi cerca de 20% maior nas parcelas onde ocorreram os tratamentos silviculturais: 2,9 $mm \cdot ano^{-1}$, na testemunha, comparado a 3,2 $mm \cdot ano^{-1}$ to 3,6 $mm \cdot ano^{-1}$ entre os tratamentos. O estudo demostrou que é possível aumentar o ritmo de crescimento das espécies com a aplicação dos tratamentos silviculturais testados.

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## INTRODUCTION

Forest management is based on the continuous production of forest resources over time and aims basically to find the balance between timber production and maintaining the ecological functions of forest ecosystems (WAKEEL et al., 2005). Practicing forest management requires decisions that consider a commitment between the maximization of timber production and minimization of the negative impacts on the biological integrity of the forest (PINARD et al., 1999). It is developed under a conservation perspective, helping natural regeneration and accelerating growth of existing trees (CHAZDON, 1998).

In implementing management plans, an understanding of forest dynamics and their responses to silvicultural interventions has emerged as an essential tool to improve the estimates of cutting cycles and timber production (SILVA et al., 2002). In this context, population studies are essential, particularly in tropical environments, where the number of species is high and their distribution uneven, with few species containing many individuals and a large number of species with a small number of individuals, being considered locally rare (ANDRADE; RODAL, 2004; SILVA et al., 2004). Moreover, the species have different ecological and silvicultural characteristics, which make predictions of production and management difficult especially in species-rich systems (SCOLFORO et al., 1996). Thus, detailed studies of forest dynamics, assessing the growth, mortality and recruitment of individual species, are essential to provide sustainable exploration and management of native forests in tropical regions.

Selective logging in tropical forests can also affect forest dynamics and forest succession by increasing the availability of resources for the remaining trees (WADSWORTH; ZWEEDE, 2006). It reduces competition for space, light and nutrients (SILVA et al., 1995), stimulating seedling regeneration and the growth of remaining trees until the productive capacity of the stand is again achieved, resulting in a need to intervene again. In this sense, several studies have been undertaken in tropical rain forests in order to investigate tree growth in response to increased availability of resources. These studies generally indicate higher diameter increment in areas where there was a release from competition.

However, changes in the environment caused by disturbance or silvicultural intervention can have the opposite effect, increasing the mortality of species that do not support the new environmental condition, which is generally accompanied by increased intensity in solar radiation and temperature and reductions in soil moisture (WADSWORTH; ZWEEDE, 2006). This is perhaps not as critical in deciduous forests, where species have greater plasticity with respect to solar radiation, because leaf fall in the dry season increases solar radiation in the interior of these forests.

Tropical forests in secondary succession are very productive (BROWN; LUGO, 1990) and usually contain fast-growing species, with wood of good quality, well accepted in the timber market and can provide non-timber products such as fruits, medicinal and ornamental plants, fodder and bee forage. The management of these forests is an important alternative to reduce deforestation pressure on the remaining forests, and play important ecological role by helping to fix carbon from the atmosphere, improving environmental conditions and restoring soil fertility, while offering hydrological benefits and maintenance of biodiversity (OLIVEIRA; SILVA, 2001). Additionally, they can increase or even guarantee animal and plant gene flow, function as ecological corridors and as a means for maintaining habitats.

Secondary forests are often located on farms near urban areas and can contain species of great commercial value, which may make them attractive and competitive with other land uses, encouraging conservation through forest management by providing income to landowners (BROWN; LUGO, 1990).

The objective of this study was to estimate the diameter growth of selected desirable tree species in an area of secondary semi-deciduous forest in Central Brazil. This was accomplished by studying the patterns in the vegetation dynamics, at the community level in relation to three low impact silvicultural treatments. Then, the efficiency of the treatments in maintaining the forest was valuated, comparing and verifying the effectiveness of these silvicultural interventions in relation to the growth rates of the species.

## MATERIALS AND METHODS

### Study site

The experiment was started in 2003 in the Santuário de Vida Silvestre Vagafogo, in Pirenópolis, Goiás, Brazil (15°49' S; 48°59' W), with an average altitude of 770 meters. The climate in the region falls within the type Aw, according to the Köppen classification (NIMER, 1989). The average annual

temperature is 22ºC, ranging from 16ºC to 34ºC and the average annual rainfall is 1.800 mm, with a dry season from May to august (INSTITUTO NACIONAL DE METEOROLOGIA - INMET, 2010).

The forest studied is characterized as semi-deciduous secondary forest (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE, 2004). This forest fragment of about 4 ha is located on a hill slope with the influence of a gallery forest in the lower portions of the land relief and a cerrado *stricto sensu* (savanna-type vegetation) in the highest parts. The study area comprised 1.2 ha of this fragment. The soils that predominate in the region are Entisols (BRADY; WEIL, 2001).

## Forest Inventory

In April 2003, sixteen adjacent 25 x 30 m plots were marked out on a hillside, maintaining a distance of 60 m from the more humid gallery forest. All individuals with diameter greater than three centimeters at breast height (± 1.3 m; DBH > 3 cm) were identified with the objective to compare the floristic composition in relation to environmental moisture gradients by Detrended Correspondence Analysis - DCA (KENT; COKER, 1992), prior to finalizing the experimental design.

The results of ordination by DCA allowed a randomized block design along a moisture gradient from the edge of the humid gallery forest to the vicinity of the cerrado *stricto sensu* (eigenvalue of axes 1 and 2: 0.32 and 0.15, respectively). With the DCA the quadrats was grouped by floristic similarity, which reflects the moisture gradient and, thus, the experimental blocks.

After that, all individuals were classified as desirable or undesirable trees, those qualifying as desirable having relatively straight stems, well-formed crown with few large branches, apparently healthy and not hollow or with signs of damage by wood-destroying insects.

The desirable trees that had DBH > 3 cm were identified to the species level and had their diameter at breast height measured. They were tagged with numbered aluminum strips, attached to the trees with smooth wire loosely twisted just above the point of measurement of DBH, totaling 2,670 trees of 147 species in 1.2 ha. These measurements were carried out again on December 2007.

## Experimental design and silvicultural treatments

Four blocks were established, each subjected to different humidity conditions (Figure 1). Block I - environment with a greater stream influence (distant 60 m from the stream); Block II - environment under intermediate influence from the stream (distant 90 m from the stream); Block III - lowest riparian influence (120 m from stream), and closer to the cerrado *stricto sensu*; Block IV - forest-cerrado *stricto sensu* (savanna) transition, the driest environment.

After the vegetation study and following the distribution of each block in the field, the experimental plots were randomly subjected to one of the following treatments: Control ("Treatment" 1 - T1); Treatment 2 (T2) - removal of all woody individuals within a radius of one meter (1 m) from the desirable trees; Treatment 3 (T3) – same as T2, plus the removal of all large lianas in the plot; and Treatment 4 (T4) – same as T3, plus the introduction of five seedlings of *Dipteryx alata* Vogel and five seedlings of *Myracrodruon urundeuva* Allemao, both about 30 cm high, with minimum distance of five meters between ea ch other, alternating the species.

The choice of the seedling species was based on their economic importance. *D. alata* is very much exploited in the region and has value both as timber and edible nuts. *M. urundeuva* is a highly valued timber species in Brazil, commonly used in rural areas, for poles and fence posts production

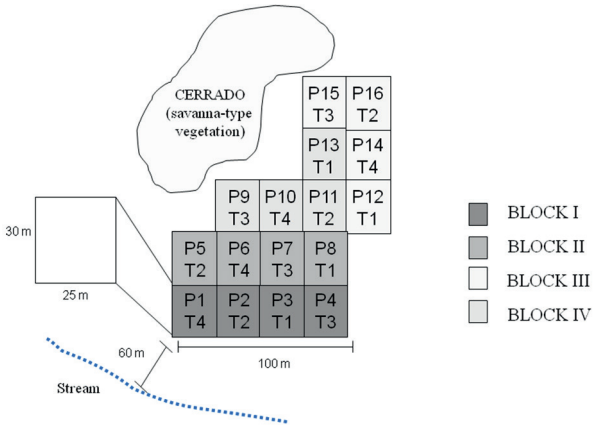


**FIGURE 1** Experimental design in the semi-deciduous secondary forest management study in Central Brazil (plots: P1 to P16; treatments: T1 to T4).

**FIGURA 1** Desenho experimental na floresta estacional semidecídua sob manejo no Brasil Central (parcelas: P1 a P6; tratamentos: T1 a T4).

### Data analysis

In order to detect differences between treatments and the control in the annual diameter increments, we calculated the periodic annual increments (PAI) in diameter (DBH) of the species by treatment, which were tested between each other and the control by the Mann-Whitney U test at a 5% probability (ZAR, 2010).

To better verify the diameter growth responses to the treatments, Box-plot diagrams of the ten most abundant species in the forest which commonly occurred in all four treatments were elaborated.

## RESULTS

The total basal area of the community (desirable trees) in 2003 was 12.58 $m^2 \cdot ha^{-1}$ and during the study period reached 15.60 $m^2 \cdot ha^{-1}$, an increase of 5,4%.$yr^{-1}$.

In 2003, before the treatments were applied, there was no statistical difference in basal area of the desirable trees between the plots [ANOVA, $p = 0.053$; normality (Shapiro-Wilk, $p = 0.53$), homogeneity of variances (Levene, $p = 0.68$)], as opposed to 2007, when there was a significant difference in basal area between treatments (ANOVA, $p = 0.02$; Shapiro-Wilk, $p = 0.57$; Levene, $p = 0.68$).

There was no difference in density of the desirable trees between the plots in 2003 ($\chi^2$, $p = 0.15$) [668 ± 27.8 individuals per plot (mean and standard deviation - SD)] nor in 2007 ($\chi^2$, $p = 0.11$) [639 ± 25.1 individuals per plot (mean ± SD)]. The desirable tree mortality in the period was 1.04%.$yr^{-1}$.

Since the periodic annual increment in diameter values of desirable trees did not present a normal distribution (Shapiro-Wilk test, $p < 0.001$), the medians were tested by the Mann-Whitney U test at 5% probability (ZAR, 2010). First the tests were made between treatments, at community level, and then between populations.

The periodic annual increments in diameter of the desirable trees increased under greater silvicultural interventions, and was about 20% higher in treatments 3 (clearing and removal of larger lianas) and treatment 4 (same as t3 plus enrichment planting) compared with the control (Figure 2).

In relation the ten most abundant species in the forest (within desirable trees), we observed that virtually all species had the lowest periodic annual increments in diameter in control plots, with the exception of *Astronium*

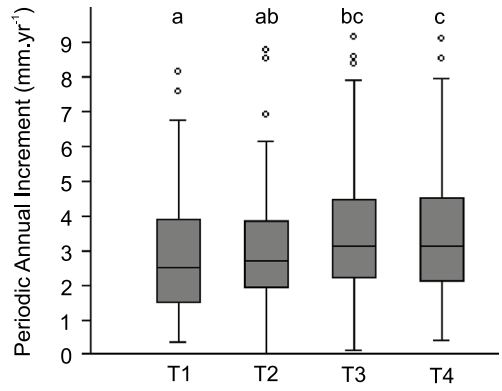


**FIGURE 2** Periodic Annual Increment in diameter of the community (desirable trees) in each silvicultural treatment in the semi-deciduous secondary forest under management in Central Brazil (T1 – control; T2 - clearing within a radius of 1 m; T3 - clearing and liana removal; T4 - treatment 3 plus seedling planting. Circles represent values up to 1.5 times the upper limit. [Medians were tested by Mann-Whitney U test ($p < 0,05$) and the differences are shown by the letters *a, b* and *c* in the graphic].

**FIGURA 2** Incremento Periódico Anual em diâmetro da comunidade (árvores desejáveis) em cada tratamento silvicultural na floresta estacional semidecídua sob manejo no Brasil Central (T1 – controle; T2 – liberação de 1 m de raio; T3 – liberação mais remoção de cipós; T4 – tratamento 3 mais plantio de enriquecimento). Círculos representam valores até 1,5 vezes o limite superior. [As medianas foram testadas pelo teste U de Mann-Whitney ($p < 0,05$) e as diferenças estão mostradas pelas letras *a, b* e *c* no gráfico].

*fraxinifolium* Schott ex Spreng, *Matayba guianensis* Aubl. and *Apuleia leiocarpa* (Vogel) J.F. Macbr. that showed the lowest periodic annual increments in diameter in treatment 2 (clearing), 3 (clearing and liana removal) and 4 (treatment 3 plus planting seedlings. Table 1).

For the community the median periodic annual increment in diameter was 2.9 mm·$yr^{-1}$ in the control compared to 3.2 mm·$yr^{-1}$ to 3.6 mm·$yr^{-1}$ between treatments.

## DISCUSSION

The periodic annual increment in diameter achieved with the studied silvicultural treatments indicated a good result. Similar results have also been found in secondary tropical rain forests: 3.0 mm.$yr^{-1}$ for cutting lianas in the Amazon (GERWING, 2001) and 4.0 mm·$yr^{-1}$ after selective thinning in the Amazon (SILVA et al., 1995). Another similar result was reported by Villegas et al. (2009) in a tropical dry forest in Bolivia,

also associated with silvicultural treatments. These results suggest higher growth rates in these disturbed environments in response to increased availability of resources, which can be confirmed by the low diameter increments found in preserved forests of 1.3 mm·yr$^{-1}$ (GERWING, 2001), 2.0 mm·yr$^{-1}$ (SILVA et al., 1995) and 1.6 mm·yr-$^{1}$ (SILVA et al., 2002), all in upland Brazilian Amazon forest, as well as in a preserved gallery forest (2.5 mm·yr$^{-1}$) reported by Felfili (1995).

**TABLE 1** Periodic Annual Increment (PAI) and Importance Value (IV %) of the ten most abundant species which were common in the four silvicultural treatments in the semi-deciduous forest under management in Central Brazil (T1 – control; T2 - clearing within a radius of 1 m; T3 - clearing and liana removal; T4 - treatment 3 plus planting seedlings).

**TABELA 1** Incremento Periódico Anual (PAI) e Valor de Importância (IV %) das dez espécies mais abundantes e comuns aos quatro tratamentos silviculturais na floresta estacional semidecídua sob manejo no Brasil Central (T1 – controle; T2 – liberação de 1 m de raio; T3 – liberação mais remoção de cipós; T4 – T3 mais plantio de enriquecimento).

| Species | PAI [median (mm·yr$^{-1}$)] | | | | IV (%) |
|---|---|---|---|---|---|
| | T1 | T2 | T3 | T4 | |
| *Protium heptaphyllum* (Aubl.) Marchand | 2.7 | 2.7 | 3.9 | 4.3 | 6.18 |
| *Myrcia rostrata* DC. | 0.7 | 1.7 | 1.6 | 1.6 | 3.96 |
| *Platypodium elegans* Vogel | 2.5 | 2.5 | 2.5 | 3.3 | 3.62 |
| *Aspidosperma subincanum* Mart. ex A. DC. | 3.1 | 4.2 | 3.0 | 3.3 | 3.4 |
| *Apuleia leiocarpa* (Vogel) J.F. Macbr. | 4.4 | 4.2 | 5.0 | 3.9 | 2.64 |
| *Astronium fraxinifolium* Schott ex Spreng. | 2.6 | 1.8 | 2.5 | 4.0 | 2.36 |
| *Myrcia sellowiana* O. Berg | 1.9 | 2.3 | 2.7 | 3.5 | 2.35 |
| *Copaifera langsdorffii* Desf. | 4.6 | 4.7 | 8.7 | 5.5 | 2.21 |
| *Matayba guianensis* Aubl. | 2.7 | 3.4 | 2.6 | 4.8 | 1.92 |
| *Myracrodruon urundeuva* Allemao | 1.4 | 2.1 | 1.9 | 3.3 | 1.72 |

The results found showed that the species responded favorably to silvicultural interventions, since the largest increases in diameter were found in plots under intervention, both in terms of individual species (for the ten most commons species) and for the whole community (147 species: all the desirable trees).

These results supported the classical theory of diameter growth being directly related to the spacing among trees in the fo feasibility rest (OEDEKOVEN, 1968). Although there was no statistical difference in tree density between treatments ( $\chi^2 < 0.05$), interventions also involved removing the larger lianas, very abundant in these secondary forests (BROWN; LUGO, 1990). Liana removal would free up the tree canopy of desirable trees, allowing for greater development capacity, which would be reflected in the diameter increases of the trees. This was also verified by Gerwing (2001) in the Amazon forest, where diameter growth was two times greater in areas with liana cutting compared to those without this treatment.

In nine secondary forests in Brazil, the annual change in basal area ranged between 0.53% and 4.1% (MEWS et al., 2011). These indices are lower than found in this forest, with silvicultural treatments, which confirms the effectiveness of this experiment.

It was expected that there would be little difference in diameter increment between treatments involving clearing a diameter radius to 1m and liana removal (treatment 3) and the same procedure plus enrichment planting of seedlings (treatment 4), because the seedlings planted were small and hence not very competitive in the first years. In a certain way this occurred, principally at the community level, confirming the effectiveness of the treatment 3 (additivity). Therefore, the reduction of competition within a 1 m radius coupled with the liana removal and with or without enrichment planting may represent a model that favors the growth of the species, reducing the time for them to achieve the minimum diameter for commercial exploitation.

However, one should consider that the growth rates in DBH vary significantly among and within populations, and also in relation to the season and microclimate conditions (SILVA et al., 2002). In the secondary forest under study, the median periodic annual increments in diameter indicated significant differences within species in response to the applied treatments. In the dense upland Amazonian forest, the variation within species was from 38% (*Goupia glabra*) to 431% (*Hevea guianensis*), while the variation in this semi-deciduous secondary forest was from 20% in *Apuleia leiocarpa* in control plots to 150% in *Protium heptaphyllum* in clearing plots (treatment 2). This large variation indicates that the efficiency of silvicultural treatments depends on the species, their ecological characteristics, and especially their response to the increased availability of light. Therefore, each selected species should be assessed individually to understand better the forest dynamics and estimate the efficiency of silvicultural treatments, aiming for shorter cutting cycles.

Another factor to be considered is the number of individuals in each diameter class. Felfili (1995) emphasized that the trends found in larger diameter classes are usually based on a small number of individuals because of the structure of tropical forests, and should be analyzed with care. The concentration of individuals in smaller diameter classes is characteristic of secondary forests. Furthermore, uneven-aged forests tend to have a higher frequency in the smaller diameter classes, due to natural forest succession under competition, when many individuals die and are recruited, and a few reach adulthood, maintaining the equilibrium of the forest. In the larger diameter classes, the response by a few individuals may not demonstrate the behavior of the forest, due to the small number of replicates.

It is suggested to follow up with periodic measurements of diameter increments of the species to determine the need for further interventions and to predict the future growth of the community and populations, as well as to infer the periodicity of cutting cycles that would help to plan a viable forest management regime of these seasonally deciduous forests in Central Brazil.

Additionally, it is considered that the main challenges for the biome Cerrado dry forest sustainable management include the small size of the forest fragments and of the trees; as well as the slope land, making the exploration difficult and costly. Thus, the technical and economic sustainable management viability will be based on wood supply for local or rural property uses, considering the most important products of the species: poles, fence posts and sawn timber.

## CONCLUSION

This study demonstrated that it is possible to increase the radial growth rates of some tree species through silvicultural techniques.

The treatments increased radial growth of trees as a function of the intensity of silvicultural interventions. Which is a good result, because tree growth was similar to values typically found in tropical rainforests under vine cutting, which may support the feasibility of such studies and help define cutting cycles aiming at sustainable timber production in Brazil Central.

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