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The Simulated Effect of Defoliation in the Growth of the *Eucalyptus grandis*

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In recent decades, Brazil has been standing out as one of the major world producers of pulp and paper. The industrial sector defined as pulp and paper currently consists of approximately 222 companies with activities in 539 municipalities, which are distributed throughout the national territory. The pulp and paper industry is divided in the forest and industrial sectors. In the forest sector a major problem in the production process is the control of pests that occur in the culture, reducing the productive capacity of the forest which directly affects the industrial sector. Noteworthy are the defoliating insects such as leaf-cutter ants, Lepidoptera and beetles, which cause great damage. Studies assessing defoliation caused by these insects are important tools that can aid programs of integrated pest management to increase productivity and reduce production costs. This work aimed to evaluate the effect of different levels of simulated defoliation on the growth of *Eucalyptus grandis* trees, with six months of age. The experiment was conducted in a randomized block design with five replications and six treatments, totaling 3,000 trees. Defoliation levels of 100 %; 50 % and 75 % of the upper canopy were analysed, as well as 50 % and 75 % of the basal part of the crown, and the top 25 % of the trees. The control was 0 % defoliation. The results showed that only total defoliation can cause a reduction in diameter and height growth. These trees lost 10.88 mm and 0.72 m in their diameter and height, respectively. At 240 days after injury, in spite of total defoliation, the trees already, presented height identical to those of trees which had undergone 50 to 75 % defoliation. The volume loss in this period, for the totally defoliated trees was 35 %. This loss will be reduced to 13 % when extrapolated for a rotation of 7 years. The results may be used in the monitoring program of leaf-cutting ants to reduce to the cost of chemical control of these insects on *Eucalyptus* in Brazil, and consequently improve the environmental quality of planted forests, raising their productivity and quality.

1. Introduction

Brazil stands out as one of the major world producers of pulp and paper and to meet this demand large areas planted with *Eucalyptus* spp. are needed. One of the major problems in the production process is the control of pests and diseases in the culture, which decreases the production capacity of the areas directly affecting the industrial sector. The use of information that can minimize the damage caused by forest pests in the production process (Zanetti et al., 2000) and also planning models in industry (Müller et al., 2012) has shown that these losses can be addressed.

Leaf-cutting ants of the genera *Atta* and *Acromyrmex* are considered a major pest of cultivated forests in Brazil, with high financial resources necessary for the control of these insects (Della Lucia, 2011). Chemical control is the most efficient method at the time though other methods are discussed in the literature (Mendes, 1979; Oliveira et al., 2011). The main product used in the Brazilian market for the

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control of leaf-cutting ants is a granular bait containing the molecule sulfluramid ($C_{10}H_6F_{17}NO_2S$). International pressure through the Stockholm Convention on Persistent Organic Pollutants (COP.6, 2013) has discussed the removal of the same, however there is no known product on the market that can control the ants with the desired efficiency, without harming the productivity sector and the pulp and paper industry.

The search for alternatives to chemical control is a reality within the forestry companies as well as investigation on the maintenance of leaf-cutting ants population below economic threshold during the growth and maturation of the forest (Zanetti et al., 2000; Zanetti et al., 2003; Souza et al.,2011; Zanetti, 2011). Losses due to defoliation caused by the leaf-cutting ants in plantations vary depending on the age of the plant and the intensity with which they were attacked; if they are constant, this may lead to loss of 100 % production losses (Hernandez and Jaffe, 1995). The projections of damage by leaf-cutting ants based on old data from the literature can achieve a cost of US$ 8.26 per destroyed eucalyptus tree. The losses may reach 1.2 billion trees per year when average the mean of four adults nests per hectare occurs. If these trees are used for pulp this injury may be three times (Della Lucia and Souza, 2011).

Several studies have sought to understand and assess the losses caused by these insects when the plants are damaged or when simulated artificial defoliation simulates damage by these insects (Oda and Berti-Filho, 1978; Freitas and Berti filho, 1994a; Ribeiro and Woessner, 1980; Matrangolo et al., 2010; Reis Filho et al., 2011; Nickele et al., 2012). Losses in diameter and height of trees defoliated by leaf-cutting ants have been evaluated in different regions and environmental conditions and the results have helped to quantify losses, the definition of acceptable levels of defoliation and understanding of the direct and indirect effects on the forest plantations.

This work aimed at evaluating the losses in the diameter increment and height, caused by simulating the attack of leaf-cutting ants, on *Eucalyptus grandis*, with 6 months of age.

2. Material and Methods

The experiment was conducted in the municipality of Mucuri, Bahia - Brazil, with a 6 months- old *Eucalyptus grandis*, at a spacing of 3.0 x 2.5 m in an area of rainforest. The experiment was performed in a complete block randomized design with five replications and six treatments , namely: - Treatment 1 (T1) : Total defoliation of plants ; - Treatment 2 (T2) : Defoliation of 75 % of the upper canopy part of the trees; - Treatment 3 (T3) : Defoliation of 50 % of the upper canopy part of the trees; - Treatment 4 (T4) : Defoliation of 25 % of the upper canopy part of the trees ; - Treatment 5 (T5) : Defoliation of 50 % of the lower canopy part of the trees ; and Treatment 6 (T6) is the trees with no defoliation (control).

We used a total of 3,000 trees, 500 trees for each treatment; spacing between trees was 3.0 x 2.5 m. The plots were separated by 15 m, and the trees of each plot (100 plants) were numbered for individual control of loss or gain by tree growth. The injuries were simulated in each tree by hand or with the aid of scissors, a visual scale being used depending on the height of treetops and the amount of leaf to be removed in each treatment. The first measurement of the diameter and height of each of the 3,000 marked trees was performed before the injuries and then every two months until the eighth month after injury. The diameter was measured using calipers, about 20 cm from the soil and in the same direction in all measurements. Height was taken with the aid of a ruler docking with 10 m long.

The analysis of variance between the mean values of diameter and height increment every 60 days was performed, and the averages compared by Tukey test at 95 % probability. For each treatment set a sigmoidal model (Eq(1)), which describes the height and diameter growth during 240 days of the experiment was defined as follows:

$$I = a_0 + \frac{a_1}{1 + EXP\left(\frac{X - a_2}{a_3}\right)} \qquad (1)$$

where: *I* is increment; a_0, a_1, a_2 and a_3 are the regression coefficients independent and X variable is the age or the days after defoliation.

The average values of diameter and height obtained during this experiment were used to calculate the volume of injured and non-injured trees, to estimate the volume loss (%) due to the simulated defoliation. The same tree form factor was considered in this calculation.

3. Results and Discussion

Only the increase in average diameter of trees subjected to total defoliation every interval of 60 days and until the end of the experiment was significantly lower than those of the other treatments (Table 1). Thus, only the total defoliation of trees slowed the increase in diameter up to 60 days; at that time the trees had already remade their foliage.

Table 1: Average increase in diameter (D in mm) and height (H in m) of 6 months-old Eucalyptus grandis subjected to different defoliation levels. Bahia/Brazil.

Level of defoliation	Average Increments by days of study			
	60 d	120 d	180 d	240 d
	Diameter (mm)			
T1	2.05a*	15.03a	27.24a	32.45a
T2	9.58b	25.44b	36.92b	41.85b
T3	9.84b	25.36b	36.66b	41.95b
T4	11.64b	27.60b	39.50b	44.48b
T5	11.09b	27.09b	38.12b	43.50b
T6	11.57b	26.89b	36.75b	43.25b
	Height (m)			
T1	0.16*a	1.29a	2.99a	3.46a
T2	0.49b	1.81b	3.63b	3.83b
T3	0.49b	1.84b	3.65b	3.87ab
T4	0.57b	1.96b	3.82b	4.07b
T5	0.65b	1.80b	3.55b	3.93ab
T6	0.66b	1.84b	3.66b	4.17b

* Means in the same column followed by the same letter do not differ statistically ($p < 0.05$). Where the treatment: T1 is the complete defoliation (100 %); T2 is the defoliation of 75 % of the upper canopy part of the trees; T3 is the defoliation of 50 % of the upper canopy part of the trees; T4 is the defoliation of 25 % of the upper canopy part of the trees; T5 is the defoliation of 50 % of the lower canopy part of the trees and T6 is the trees with no defoliation (control).

The curve of the estimated values of such treatment was different from the others in the beginning of the treatment. On average, at the end of the first 60 days, these trees had added only about 2 mm to their diameter, while trees from the other five treatments had increased from 9.57 to 11.64 mm. Thereafter, the growth in diameter of totally defoliated trees was similar to that of the other treatments. However, at the end of 240 days, the diameter of these trees was significantly lower than the others, similar to the amount initially lost. Therefore, once the foliage was recomposed, no harmful effect on subsequent growth was observed, and the trees have grown as much as the others. The values were obtained by subtracting the value of the increase in non-defoliated trees from those obtained from the leafless trees, as values estimated by the equation in each period evaluated (60,120,180 and 240 days). A reduction in the potential growth of defoliated trees would be visible by the steady increase of this difference, but in this work it was observed that growth only fluctuated around a mean difference.

Analogous behavior was observed in the height increment of trees subjected to total defoliation, which was significantly lower up to 180 days. During this period, the trees subjected to the treatments showed statistically identical increments in height. Between 180 and 240 days, however, the overall effect of defoliation at the time began to dissolve, because the increase was equal to that which had been observed in three other more severe treatments. Thus, these results indicate that young trees, when fully defoliated, will be able, in time, to match up, at least in height, to the trees subjected or not to partial defoliation.

Matrangolo et al. (2010) found that the greater the number of defoliation in *Eucalyptus grandis*, the greater the loss of height and diameter growth. And in the case of successive defoliation this loss was more damaging because it can stop the growth of trees or cause death, a fact already discussed by Speight and Wylie (2001). In general, studies that have assessed the losses caused by defoliation of different plants when damaged by various insects or by the simulation of damage, has demonstrated how the subject is complex and difficult to obtain real values of losses in growth (Zanetti et al., 2003; Matrangolo et al., 2010; Reis Filho et al., 2011; Nickele et al., 2012). Losses from the attacked plants depend also on environmental factors such as the degree and persistence of defoliation, on plant vigour before peeling, site, soil moisture, climate, among others, to recover (Grahan, 1963).

The totally defoliated trees grew less in diameter and height than those subjected to partial defoliation. The non – defoliated trees grew on average 43.01 mm (from 41.1 to 44.84 mm) in diameter and 4.17 m in height (between 3.93 and 4.40 m), while completely defoliated trees grew 32.13 mm in height (between 29.55 and 34.71 mm) and 3.45 m (3.21 and 3.70 m) in diameter . There is a difference of less than 10.88 mm in diameter and 0.72 m in height, considering a confidence interval of 95 % for the maximum and minimum values 240 days after defoliation, the non-injured trees showed an average diameter of 73.5 mm and an average height of 5.92 m. Considering the average loss in diameter growth caused by defoliation to be 10.88 mm and 0.72 m in height, we can estimate the diameter and height of the injured plants as 73.5 - 10.88 = 62.62 mm and 5.92 - 0.72 = 5.27 m, respectively. In this case, using the standard formula for the calculation of wood volume to obtain the volume of injured tree this value is 64.6 % of that of non-injured, a loss which is approximately 35.4 % in the volume of timber due to total plant defoliation.

In this work we observed that the loss in diameter increment were higher than in height. This parameter was also observed by Reis Filho et al. (2011) in *Eucalyptus grandis* with 100 % of defoliation: in this case, the losses were 13.2 % in height and 20 % in diameter. Freitas and Berti Filho (1994[b]) also observed an increase in loss of DAP 78.9 and 37.8 % and height of 60.7 and 35.65 %, for levels of 100 and 75 % defoliation, respectively, after one year period. This occurs probably because trees use mainly the products of photosynthesis for diameter growth, and only secondarily current reserves of carbohydrates, whereas for height growth trees use the reserves present and stored during the previous year (Kozlowski ,1963).

Table 2: Coefficients and statistical of the sigmoidal models that describe the increase in diameter and height of Eucalyptus grandis trees, when subjected to simulated different levels of defoliation at six months of age. Bahia/Brazil.

Level of defoliation*	Coefficients and Parameters Statistics					
	a_0	a_1	a_2	a_3	R^2	F
	Diameter (mm)					
T1	-1.104	34.15	125.5	31.89	0.95	170.0
T2	-4.884	48.58	97.9	44.50	0.99	1540.8
T3	-5.711	49.86	96.9	47.20	0.97	230.5
T4	-7.454	54.48	90.6	49.30	0.97	226.3
T5	-7.343	53.21	90.8	49.40	0.98	407.7
T6	-11.390	58.27	84.0	59.00	0.98	502.5
	Height (m)					
T1	-0.0285	3.54	133.8	26.05	0.97	235.1
T2	0.0427	3.90	123.1	26.50	0.98	472.3
T3	0.0351	3.94	122.9	26.95	0.98	330.8
T4	0.0204	4.18	122.1	28.61	0.98	317.7
T5	-0.0287	4.15	124.6	34.23	0.99	670.9
T6	-0.0373	4.37	126.5	34.92	0.97	311.9

*where the treatment: T1 is the complete defoliation (100%); T2 is the defoliation of 75 % of the upper canopy part of the trees; T3 is the defoliation of 50 % of the upper canopy part of the trees; T4 is the defoliation of 25 % of the upper canopy part of the trees; T5 is the defoliation of 50 % of the lower canopy part of the trees and T6 is the trees with no defoliation (control).

The regression curves obtained in this work and adjusted to the sigmoidal model were very close and almost perfectly parallel, except for the treatment of 100 % defoliation. The R^2 values obtained on the chosen model indicate that the age variable was able to explain the increase in both diameter and height during the 240 days of the experiment. The coefficients and statistical parameters of the models are shown in Table 2.

The mortality of plants due to defoliation was 2 %, only for the treatment with complete defoliation, reinforcing that plants when subjected to a single defoliation can recover without major losses, provided that other environmental factors contribute to this process. The highest mortality rates has observed in 1-3 years-old plants or when this defoliation is constantly being repeated, causing stress and therefore plant death (Freitas and Berti Filho, 1994a; Freitas and Berti Filho, 1994b; Reis Filho, 2011).

4. Conclusion

We conclude in this working that the values emphasize the need for regionalized studies to evaluate the losses as well as the monitoring of damaged plants throughout the entire production cycle of forest. Therefore, understand the relationships between plants, leaf-cutter ants and environmental factors are paramount to minimize losses throughout the production process and to implement programs of integrated management of leaf-cutting ants, by forestry companies, thus reducing environmental impacts on timber production for the industrial sector.

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