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Pruning effect in *Eucalyptus grandis* x *Eucalyptus urophylla* clone growth

Efeito da desrama no crescimento de clone de *Eucalyptus grandis* x *Eucalyptus urophylla*

Antonio Carlos Ferraz Filho[1], Blas Mola-Yudego[2], José Ramón González-Olabarria[3] e José Roberto Soares Scolforo[1]

Resumo

O objetivo deste trabalho é avaliar o nível de desrama que não afeta o crescimento da árvore, aumentando a produção de madeira livre de nós com apenas uma aplicação de desrama na idade de 1,3 anos. O experimento foi desenvolvido no município de Aracruz, estado do Espírito Santo, Brasil. As intensidades de desrama testadas foram: 40%, 55%, 70% e 85% da altura total da árvore desramada, bem como uma testemunha não desramada. Os resultados obtidos três anos após a desrama mostraram que é possível atingir até 70% da altura da árvore desramada (altura desramada média de 7,3 m) em uma única operação sem afetar o tamanho das 700 árvores com maior diâmetro por hectare. Desramas de alta intensidade (85%) resultaram em efeitos negativos no crescimento. Desramas de baixa intensidade (40%) apresentaram efeito moderado no crescimento, possivelmente devido à exposição aos efeitos negativos da remoção de área foliar sem se beneficiar dos efeitos positivos nas características do dossel. Por fim, este trabalho discute diferentes regimes de desbaste e sua implicação no regime de desrama. Os resultados desta pesquisa podem contribuir para melhorar o manejo de plantios de espécies de rápido crescimento para produção de madeira sólida.

Palavras-chave: modelos de crescimento e produção; manejo florestal; plantios de rápido crescimento; madeira livre de nós; remoção de área foliar.

Abstract

The objective of this paper is to determine the pruning level that does not affect tree growth, increasing the amount of clear wood production in a single lift at age 1.3 years. The experiment was developed in the municipality of Aracruz, Espírito Santo state, Brazil. The pruning intensities considered were: 40%, 55%, 70% and 85% of the total tree height, as well as no pruning for control. The results obtained three years after pruning showed that it is possible to reach up to a 70% of total tree height pruned (mean pruned height of 7.3 m) in a single pruning lift without affecting the size of the 700 largest trees per hectare in diameter. High intensity pruning (85%) translated into negative effects on tree growth. Low intensity pruning (40%) also had moderate effects on growth, possibly due to exposure of negative effects of leaf area removal without benefiting from the positive effects on canopy characteristics. Finally, the paper discusses different thinning regimes and its implications on the pruning regime. The results of this research can contribute to improve the management of fast growing plantations for timber production.

Keywords: growth and yield models; forest management; fast growing plantations; clear wood; leaf area removal.

INTRODUCTION

The *Eucalyptus* plantation area in Brazil is among the largest in the world, covering about 7 million hectares (IBGE, 2014). The majority of these plantations are oriented to energetic and pulping purposes, being characterized by high planting densities, few silvicultural interventions after crown closure and short rotation lengths. However, the production of sawn wood derived from planted eucalypt is increasing (ABRAF, 2013), and the newly gained relevance of this type of product should translate in the implementation of innovative management alternatives.

[1]PhD Docent at Department of Forest Science. UFLA - Universidade Federal de Lavras. Postal Code 3037 – Centro - 37200000 - Lavras, MG, Brasil. E-mail: acferrazfilho@gmail.com; jscolforo@dcf.ufla.br.

[2]PhD Res Prof. Norwegian Institute of Bioeconomy Research (NIBIO), PO Box 115, 1431, Norway. / University of Eastern Finland, School of Forest Sciences. PO Box 111, FI-80101, Joensuu, Finland. E-mail: blas.mola@uef.fi.

[3]Researcher. Forest Sciences Centre of Catalonia (CTFC-CEMFOR), Ctra. de St. Llorenç de Morunys, km 2, 25280 Solsona, Spain. E-mail: jr.gonzalez@ctfc.es.

The quality of the wood is a key factor determining the price of the final product. Wood quality can be achieved through the production of clear wood, i.e. wood without the presence of knots. *Eucalyptus* species possess self-pruning behavior, and this process can be relied on to produce high--quality logs on Australian native forests, where rotations are long and densities high (KEARNEY et al., 2007). However, in planted forests, self-pruning does not always ensure clear wood production since often dead branches are not effectively shed from the stem due to the lower stocking and short rotation lengths.

Artificial pruning can thus be applied to ensure the production of quality products in plantation forests, being considered the most reliable management technique for restricting the knotty core (e.g. MONTAGU et al., 2003; FERRAZ FILHO et al., 2014) and subsequently for maximizing the production of clear wood within the log (e.g. SMITH et al., 2006). To ensure that the full benefits of pruning are attained, it is recommended that the pruning intervention occur when the branches are still alive, as early as 12-24 months for eucalypts species (MONTAGU et al., 2003, NUTTO et al. 2015). The pruning of live branches is also known as green pruning (MONTAGU et al. 2003, ALCORN et al. 2008). SMITH et al. (2006) showed that the occlusion rates of branches that were pruned after they had died were similar to those of unpruned dead branches. Green crown pruning ensures that the branches are small; facilitating pruning wound occlusion (POLLI et al., 2006).

According to ALCORN et al. (2008), understanding the impact of pruning intensity, in terms of the percentage of the vertical length of the live crown removed, on tree growth is critical to the development of appropriate pruning regimes that increase wood quality but minimize long-term growth reductions. Forrester et al. (2010) reviews many species that are capable to withstand as much as 40% of the green crown length removal without reducing stem diameter growth. Eucalypt species are generally more tolerant to pruning, tolerating up to 50% of lower live crown removal with little effect on tree growth (PINKARD; BEADLE, 1998a) if conducted at or after canopy closure.

While many studies have reported the effects of pruning *Eucalyptus* after canopy closure in Brazilian sites (e.g. FINGER et al., 2001; PULROLNIK et al., 2005; FONTAN et al., 2011), the treatments applied were not intense enough to induce growth loss from excessive crown removal. This leaves an information gap concerning exactly how much crown area can be removed in a single lift when applied to Brazilian fast growing sites.

The objective of this work is to identify the maximum pruning intensity for *E. grandis* x *E. urophylla* green crown removal that affects tree growth, permitting the elaboration of a single lift pruning regime that maximizes clear wood production without causing grown reduction.

MATERIAL AND METHODS

Study sites

Two experimental sites were established in Aracruz (Espírito Santo, Brazil). The study sites were located 13 kilometers from each other (19° 55′ S 40° 08′ W and 19° 48′ S 40° 12′ W), at altitudes of 34 and 59 m above sea level, respectively. The climate of the region is classified as tropical humid with a dry winter season (Aw according to the Köppen classification), with an average temperature of 23°C and average annual precipitation of 1.400 mm (MARTINS et al., 2011).

In order to avoid noise from surrounding environmental factors, both trial areas were established on lands previously used as eucalypt plantations, and similar soil conditions. The soils of both trials are formed by Yellow Argisol with medium to clayey texture. These soils are moderately deep and well drained, with the presence of a textural B horizon. Silvicultural operations conducted before planting consisted in weed control using a glyphosate product and a sub soil ripping operation 80 cm deep. Fertilization was similar for both trials, consisting in the application of about 100 kg/ha of NPK (06-30-06) plus the application of roughly 2 t/ha of dolomitic limestone prior to planting. Post planting fertilization was carried out 3 and 12 months after planting, using NPK+Boron (20-00-20+0.7) with doses varying according to the nutrient status of the stand, evaluated through soil analysis. When necessary, weed competition was controlled using glyphosate based products.

The seedlings used were of *Eucalyptus grandis* x *E. urophylla* clonal material, widely planted in the Southeast region of Brazil and the same in both experiments. The first experiment (trial 1) was planted in November 2000 with 3 x 3 m spacing. In the autumn of 2002 a single lift pruning was

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conducted (1 year and 4 months after planting) reaching five alternative intensities: 0, 40%, 55%, 70% and 85% of the total tree height. The second experiment (trial 2) was planted in May 2002 with the same spacing and was subject to the same treatments, but the single lift pruning was conducted during spring (also 1 year and 4 months after planting). Pruning was implemented using a pruning saw attached to a pole, where branch removal was flush with the stem.

The experiments where set up in a complete randomized block design, consisting of three replications. Since measurements were taken at the same plot at different dates, analysis of variance was performed using split plot in time arrangement. Each sample plot is comprised of eight measured trees, with a double buffer row in the exterior and single buffer row in the interior of the experiment. Thus, the total number of trees per plot ranged from 24 to 35, depending on the location of the plot inside the experiment. All the trees had their circumference and total height measured at the time of the experiment establishment. Afterwards, measurements were taken every three months until the stands completed approximately 3 years. Additional measurements were made at age 3.4 and 4.4, when the experiment ended.

At time of the pruning, the stands presented mean diameters at breast height (dbh, measured at a height of 1.3m) of 9.5 cm and 7.9 cm, and a mean height of 11.0 m and 9.5 m for trials 1 and 2, respectively. The height of the living crown was measured for all trees prior to pruning (only in trial 1). Mean live crown height before pruning, not considering isolated green branches, was 2.3 m for trial 1 (table 1).

Table 1. Mean pruning height (ph) values for trials 1 and 2 and amount of removed live crown (rc) for trial 1 (rc was not measured in trial 2, values in parenthesis are the standard deviation).
Tabela 1. Altura de desrama média (ph) para os experimentos 1 e 2 e quantidade de copa viva removida (rc) para o experimento 1 (rc não foi medida no experimento 2, valores entre parênteses são o desvio padrão).

	Trial 1		Trial 2
Treatment	**ph (m)**	**rc (%)**	**ph (m)**
0	0.0 (0.00)	0.0	0.0 (0.00)
40	4.5 (0.21)	22.6	3.8 (0.15)
55	6.1 (0.23)	43.3	5.2 (0.18)
70	7.9 (0.22)	62.1	6.7 (0.17)
85	8.9 (0.74)	81.1	8.2 (0.25)

Statistical analysis

Analysis of variance (ANOVA) using a split plot in time scheme (as presented in CASELLA, 2008) was used to assess the effect of pruning on tree and stand growth. The variables analyzed were: diameter at breast height (dbh, measured at 1.3 m from the ground), dbh mean monthly increment, total height (h), h mean monthly increment; stand basal area and slenderness index (expressed as h/dbh). The statistical software SISVAR (FERREIRA, 2011) was used to perform the ANOVA (table 2).

Table 2. Source of variation (S.V.) and degrees of freedom (D.F.) for the analysis of variance, where D.F.1 is relative to the variables dbh, total height, stand basal area and slenderness index and D.F.2 is relative to the variables dbh and mean height monthly increment.
Tabela 2. Fonte de variação (S.V.) e graus de liberdade (D.F.) para a análise de variância, aonde D.F.1 é relativo às variáveis dap, altura total, área basal do talhão e índice de esbeltez e D.F.2 é relativo às variáveis incremento médio mensal em dap e altura.

S.V.	D.F.1	D.F.2
Block	2	2
Pruning	4	4
Error 1	8	8
Time	8	7
Time x pruning	32	28
Error 2	80	70
Total	134	119

Considering that the studied stands should undergo a thinning operation after the termination of the pruning trial, the effect of pruning on dbh class was also analyzed. This was accomplished using a linear mixed model approach. The model formulation consisted in relating the dbh of different size classes (mean diameter of the 140, 280, 420, 560, 700 and 830 thickest trees per hectare, as well as the overall mean diameter) to the natural logarithm of age and pruning treatment as a factor [1]. To account for the different starting points of the trials, a random intercept was inserted in the model. The resulting mixed models were parameterized in the statistical software R, using the *nlme* package (PINHEIRO et al., 2012, R CORE TEAM, 2014).

$$dbh_{ij} = \beta_0 + b_{0i} + \beta_1 \cdot log(age) \cdot P.T. + \varepsilon_{ij} \quad (1)$$

Where: dbh_{ij} is either the mean diameter at breast height of plot i on trial j or the mean diameter of the 140, 280, 420, 560, 700 and 830 thickest trees per hectare; β_0 and β_1 are the fixed parameters of the model representing the intercept and inclination, respectively; b_{0i} is a random term added to the intercept to account for the different trials used in this study; *P.T.* is a categorical variable for the different pruning treatments; ε_{ij} is the residual error. b_{01} and ε_{ij} were assumed to be normally distributed and independent, with zero mean and constant variance.

RESULTS

The interaction between pruning and age significantly affected the mean dbh, dbh increment and slenderness for trial 1, whereas basal area was found to be significantly influenced by pruning alone. On trial 2 the interaction between pruning and age was observed to significantly influence dbh, dbh increment, and basal area, whereas pruning alone was found to affect slenderness. As expected, all variables (dbh, dbh increment, basal area and slenderness) were significantly influenced by age (table 3). The block factor was only significant (5% level) for the variables height increment in trial 1 and slenderness for trial 2.

Table 3. Summary of the analysis of variance using a split plot in time design to determine the effect of pruning treatment in different aspects of tree and stand *Eucalyptus grandis* x *E. urophylla* growth.
Tabela 3. Sumário da análise de variância utilizando o delineamento de parcelas subdivididas no tempo para determinar o efeito do tratamento de desrama no crescimento de aspectos da árvore e populacionais de *Eucalyptus grandis* x *E. urophylla*.

	Pruning			Age			Pruning x Age		
Variable	df	F statistic	P-value	df	F statistic	P-value	df	F statistic	P-value
Trial 1									
dbh (cm)	4	5.28	0.022	8	1549.82	<0.001	32	2.04	0.005
dbh increment (cm/month)	4	0.80	0.557	7	605.81	<0.001	28	21.18	<0.001
Height (m)	4	3.44	0.064	8	1670.29	<0.001	32	0.75	0.819
Height increment (m/month)	4	1.73	0.237	7	71.62	<0.001	28	0.73	0.819
Basal area (m^2/ha)	4	4.93	0.027	8	1182.08	<0.001	32	1.41	0.111
Slenderness (m/cm)	4	1.02	0.451	8	147.02	<0.001	32	1.64	0.040
Trial 2									
dbh (cm)	4	5.62	0.019	8	3622.65	<0.001	32	3.35	<0.001
dbh increment (cm/month)	4	7.14	0.010	7	926.67	<0.001	28	21.62	<0.001
Height (m)	4	3.23	0.074	8	2267.32	<0.001	32	0.75	0.817
Height increment (m/month)	4	6.09	0.015	7	297.67	<0.001	28	1.06	0.411
Basal area (m^2/ha)	4	5.06	0.025	8	1858.68	<0.001	32	2.54	<0.001
Slenderness (m/cm)	4	4.68	0.031	8	237.01	<0.001	32	0.92	0.590

Considering mean tree values, more intensive pruning operations resulted in smaller trees with larger slenderness values. An exception occurred when the pruning treatment compromised the removal of living branches of 40% of tree height, which resulted on smaller tree diameters than those obtained on pruning treatments of higher intensity (55% and 70% of the tree height) for trial 1 and 55% of tree height for trial 2 (table 4, figure 1). The higher slenderness values for more intensive pruning were a result of decreasing diameters values rather than variations on the tree heights. Height values tended to decrease slightly when more severe pruning was implemented, but the differences were not statistically significant.

The analyzed stand variable basal area followed the same behavior as dbh, with more intensive pruning presenting lower values and an inversion of the 40% treatment with treatments 55% and 70% for trial 1 and 55% for trial 2.

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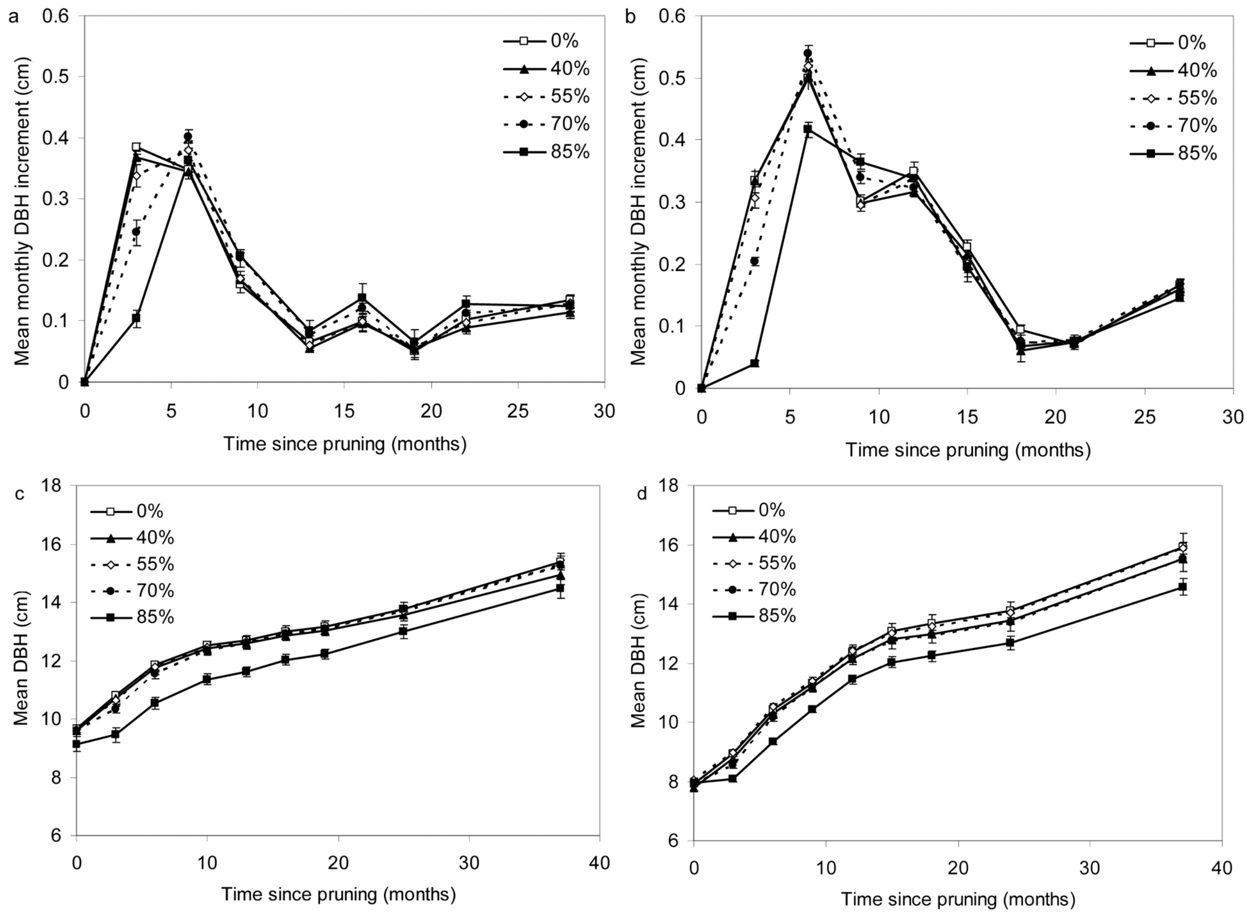

Figure 1. Mean diameter at breast height (dbh, 1.3 m) increments and mean dbh between successive measurements following pruning of 0%, 40%, 55%, 70% and 85% of total tree height in *Eucalyptus grandis* x *E. urophylla* trees at trial 1 (a, c) and 2 (b, d). Error bars represent the standard error of the means.

Figura 1. Incremento médio de diâmetro a altura do peito (dap, 1,3m) e dap médio nas diferentes medições após desrama de 0%, 40%, 55%, 70% e 85% da altura total de árvores de *Eucalyptus grandis* x *E. urophylla* no tratamento 1 (a, c) e 2 (b, d). Barras de erro representam o erro padrão da média.

Table 4. Mean tree and stand values differentiated using Tukey's least significant difference post-hoc analysis. Values correspond to age 4.4 years, numbers in columns followed by the same letter are not statistically different. s: slenderness ratio between dbh and height. G: basal area.

Tabela 4. Valores médios de árvores e populacionais diferenciados utilizando teste post-hoc de Tukey. Valores relativos aos 4,4 anos de idade, números nas colunas seguidos da mesma letra não são estatisticamente diferentes. s: índice de esbeltez entre dap e altura. G: área basal.

Pruning treatment	dbh (cm)	height (m)	s (m/cm)	G (m^2/ha)
Trial 1				
0 %	15.4 a	20.6	1.34 a	20.7 a
40 %	14.9 b	20.6	1.38 b	19.6 a
55 %	15.2 a	20.3	1.33 a	20.4 a
70 %	15.3 a	20.5	1.34 a	20.4 a
85 %	14.5 c	20.0	1.38 b	18.4 b
Trial 2				
0 %	15.9 a	23.0	1.44 a	22.4 a
40 %	15.5 b	22.9	1.48 a	21.2 b
55 %	15.9 a	22.9	1.44 a	22.2 a
70 %	15.5 b	23.1	1.49 a	21.2 b
85 %	14.6 c	22.1	1.51 b	18.7 c

The parameter estimates for the linear mixed models of different dbh size classes in relation to the intensity of the pruning treatment and the natural logarithmic of age are shown in table 5. The pruning treatments were treated as categorical variables within the models, thus the significance of the pruning related parameters indicates that the treatment is different than the un-pruned trees, since the un-pruned treatment was the reference level used in the model.

Table 5. Parameter estimates for the linear mixed model of different mean dbh dominant size classes in relation to the natural logarithmic of age and pruning treatment. Numbers between parentheses denote the standard error. (* indicate p-value < 0.001). σ_{trial}: Estimated standard deviation between trials. σ_{plot}: Estimated standard deviation between plots.

Tabela 5. Estimativa dos parâmetros para o modelo linear misto para diferentes classes de dominância de dap médio em relação ao logaritmo natural da idade e tratamento de desrama. Números entre parênteses são o desvio padrão. (* indica valor p < 0,001). σ_{trial}: Desvio padrão entre experimentos. σ_{plot}: Desvio padrão entre parcelas.

Parameter	Mean dbh	dbh^{140}	dbh^{280}	dbh^{420}	dbh^{560}	dbh^{700}	dbh^{830}
Intercept	7.675* (0.30)	7.948* (0.35)	7.853* (0.32)	7.828* (0.31)	7.796* (0.30)	7.766* (0.30)	7.750* (0.30)
log(Age)	5.318* (0.10)	6.010* (0.18)	5.917* (0.11)	5.826* (0.10)	5.742* (0.10)	5.652* (0.10)	5.544* (0.10)
40%	-0.203 (0.11)	-0.007 (0.13)	-0.022 (0.12)	-0.050 (0.12)	-0.056 (0.12)	-0.093 (0.11)	-0.124 (0.11)
55%	-0.037 (0.11)	0.049 (0.13)	0.054 (0.12)	0.039 (0.12)	0.034 (0.12)	0.032 (0.11)	0.027 (0.11)
70%	-0.224* (0.11)	-0.027 (0.13)	-0.047 (0.12)	-0.143 (0.12)	-0.188 (0.12)	-0.209 (0.11)	-0.229* (0.11)
85%	-0.969* (0.11)	-0.825* (0.13)	-0.803* (0.12)	-0.830* (0.12)	-0.882* (0.12)	-0.903* (0.11)	-0.927* (0.11)
σ_{trial}	0.386	0.453	0.416	0.397	0.386	0.391	0.393
σ_{plot}	0.561	0.681	0.625	0.607	0.599	0.589	0.575

DISCUSSION

Analysis of the results

This study focuses on the impact of pruning intensity on dense and fertilized planted forest, when pruning is implemented systematically on all trees of the stand. Since pruning was conducted in all trees of the stand, discussion and management implications are restricted to this type of pruning regime and those potential changes on the hierarchical position of trees, which often happen when selective pruning operations are implemented (ALCORN et al., 2008; PINKARD; BEADLE, 1998a), were not an issue to be considered in the present study.

Three years after pruning, trial 2 presented a higher dbh growth rate for un-pruned trees than trial 1. Trial 2 presented a larger dbh growth reduction between un-pruned trees and the highest pruning treatment (8.2%), compared to trial 1 (5.9%). In trial 1 the moderately intense pruning treatment (70%) presented mean diameters statistically equal to the un-pruned treatment, while a significant difference occurred in trial 2. The stronger effect of the pruning treatments in the most productive trial 2 is in conformity with other studies. For instance, Forrester et al. (2012a) reported that pruning reduced growth relatively more in fertilized treatments than in control treatments on an *E. nitens* plantation.

After 9 months of the pruning intervention, the trees treated with the most intense pruning (85%) were able to reach the same increments as the un-pruned trees (figure 1). The recovery time for trees under the 70% treatment was even shorter, reaching un-pruned increment growth 6 months after the pruning intervention. However, while the trees under the 70% pruning treatment were able to present mean dbh values similar to un-pruned trees three years after pruning, the mean dbh of the 85% treatment was still affected at this age. Longer diameter growth recovery periods post pruning for *Eucalyptus pilularis* and *E. cloeziana* were reported by ALCORN et al. (2008), 8 and 12 months for 50% and 70% green crown length removal, respectively.

It was found that tree height in both trials was less affected by pruning than the diameter growth response. This can be explained considering priority of carbon allocation for biomass accumulation in trees, where foliage growth (and thus height growth) can be ranked as being of greater importance than stem growth (DOBBERTIN, 2005). One of the main tree traits to be considered is the relation between tree height and diameter, as the slenderness of trees is regarded as an influential variable explaining the proneness of the trees to suffer wind damage. In this regard, even if trees under higher pruning treatments presented higher slenderness values, all trees regardless of the treatment had elevated slenderness values. Once thinning takes place in the stands, the risk of wind damage is expected to reduce gradually as the remaining trees increase the strength and size of their stem and root system (STOKES, 2006). However, during the immediate period after thinning, and for some time, the lack of contact between canopies will translate on higher risk of wind damage (MILNE, 1991; MARTÍN-ALCÓN et al., 2010). Low slenderness values (lower than 1) are associated with wind tolerant trees growing under low growth strains (BIECHELE et al., 2009; WOOD et al., 2008). Both characteristics are desirable for stands managed for solid wood products. This way, in

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areas directly exposed to wind it might be adequate to restrict intense pruning operations to avoid diameter reductions that consequently affect slenderness values, and to implement early thinning to ensure higher individual tree resistance.

This study showed that while there is a desired maximum pruning height that promotes clear wood production without negatively affecting tree growth, there might also be an undesired minimum pruning height that negatively affects tree growth in the long term. Approximately 3 years after the pruning intervention, those trees pruned at 40% of their total height presented lower mean diameter values than more intensely pruned trees (55% and 70% for trial 1 and 55% for trial 2). This behavior could occur due to the reason that in a light pruning operation (40% of total tree height or below), trees are exposed to the negative effects of leaf area removal without benefiting from the positive effects on canopy characteristics. Pruning causes changes in the canopy architecture, biomass partitioning and up-regulation of photosynthesis in the remaining leaves (FORRESTER; BAKER 2012). The negative effects of green crown removal in canopy dynamics include: decrease in leaf area resulting in reduced capacity of the tree to assimilate carbon and photosynthetically active radiation absorption (FORRESTER et al., 2013; PINKARD; BEADLE 1998b); loss of nutrients from the removed branches that would be remobilized in the crown (TAGLIAVINI et al., 1998). The positive effects of green crown removal in canopy dynamics include: increase in remaining foliage efficiency as determined by biomass increment per unit leaf area (BANDARA et al., 1999; FORRESTER et al., 2012b); increase in the photosynthetic rate of remaining foliage with the increase of CO_2 assimilation (FORRESTER et al., 2012b; PINKARD et al., 1998); reduced stand respiration (FORRESTER et al., 2012b); increased water used efficiency, light use efficiency and specific leaf area (FORRESTER et al., 2013; 2012b). This way, the interaction between the different positive and negative effects of pruning may have resulted on a reduced growth capacity when light pruning is implemented (40% of tree height), good growth recovery when moderately intense pruning is implemented (between 55 and 75% of tree height), and long standing negative impact on growth when a large portion of the canopy is removed (over 85% of tree height).

Management implications

Two different approaches for the management of eucalyptus for solid wood products are possible: intensive and multiproduct management. Intensive forest management can be defined as the manipulation of soil and stand conditions to ameliorate factors that limit tree growth (FOX, 2000). In the case of intensive forest management, this means controlling stand density in order to use the high diameter increment potential of *Eucalyptus* species during the first 3 years, which can be as high as 4 to 7 cm per year (NUTTO et al., 2006). In practical terms this is accomplished by initial planting at low densities (about 550 trees per hectare) or by an early thinning to waste operation (thin to about 550 trees per hectare prior to or just after canopy closure), focusing on the growth of a limited number of candidate trees. On the other hand, multiproduct forest is concerned with the growth of the stand as a whole, instead of focusing on final crop trees. A typical joint management system for the production of cellulose or biomass material from thinning harvests and solid products from final cuts was described by MAESTRI (2003). In this system, an initial planting density of 1111 trees per hectare is thinned to 450 trees per hectare at age 5 to 6 years, and a second thinning operation is carried out at age 8 to 9 years to 250 trees per hectare, with a clear cut after age 15 years.

The results of this study imply that 70% and 85% pruning treatments resulted in lower mean dbh values when compared to the un-pruned treatment. Considering that these stands are being managed under a multiproduct regime, they should be thinned down to about 450 trees per hectare, and the growth loss caused by this high pruning may be compensated by the higher amount of clear wood produced by the final crop trees. While the 85% treatment reduced mean dbh values even for the 140 thickest trees per hectare, the 70% treatment only presented lower growth than un-pruned for the 830 thickest trees per hectare. This implies that the residual stands of un-pruned or pruned to 70% total tree height will be equal after thinning for operations that leave at least 700 trees per hectare.

The results found in this study have important implications for the management of eucalypt for solid wood products considering a multiproduct management scheme. Considering a scenario that wood produced from a first thinning operation is not a priority, a pruning operation implemented after canopy closure can reach up to 70% of total tree height without affecting the growth of the trees that remain after the thinning operation (about 500 trees per hectare). When greater importance is given to the production of the first thinning operation, less intensive pruning operations must be carried out (55% of total tree height) to ensure productivity equal to an un-pruned stand. The possibility of this intensive pruning early in the life of the stand assures that mostly live branches are cut, facilitating the occlusion of the pruning wounds and consequently increasing the wood quality.

CONCLUSIONS

Three years after the pruning operation (stand age 4.3 years), intensive pruning (70% of pruned total tree height) did not significantly reduce mean diameter growth in the less productive site (trial 1) when compared to the un-pruned treatment. For more productive site (trial 2) this occurred in treatment 55%.

Pruning can be done up to 70% of total tree height without affecting the diameter growth of the dominant trees (up to the largest 700 trees per hectare, from a total of 1.111 trees/ha). This is desirable for growing large diameter trees (for solid wood product purposes), since these are the trees that will be left after thinning.

While there is a desired maximum pruning height that promotes clear wood production without negatively affecting mean tree growth (55% of pruned total tree height at age 1.3 years), there might also be an undesired minimum pruning height that negatively affects mean tree growth in the long term (40% of pruned total tree height at age 1.3 years).

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