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Growth response of two genetic materials of *Eucalyptus* to different height and time of pruning

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ABSTRACT

We conducted four experiments to evaluate the effects of different heights and times of pruning on the growth of *Eucalyptus grandis* and *E. grandis x E. camaldulensis* GC INTA 8 in Concordia (Entre Ríos, Argentina). During winter, two experiments were carried out on 20 months old stands and, during spring, two more experiments were carried out on 24 months old stands. Each experiment consisted of two treatments assigned under a completely randomized design with four replicates of 300 m^2 plots: T1= pruning to 2.5 m; T2= pruning to 4.5 m. Diameter at breast height (DBH) and total height were measured before pruning and after 12 months to calculate height and DBH growth in the first year following pruning. We used GLM and GLMM to modeling growth. Then, we compared the mean values of height and DBH growth ofT1 with T2 using Fisher's LSD test. Finally, we calculated the resulting remaining crown (RC) after pruning treatments. After winter pruning, we found no significant differences in the growth of the two genetic materials. On the contrary, after spring pruning, the DBH growth of *E. grandis* was significantly lower (p=0.001) in T2 (3.4 cm) than in T1 (3.9 cm), while the height growth of GC INTA 8 was significantly lower (p=0.011) in T2 (3.2 m) than in T1 (3.5 m). According to the results, winter pruning of *Eucalyptus* genetic materials does not affect their growth in the first year, regardless of the height of pruning. However, spring pruning can affect DBH or height growth, depending on the variety. The extremely dry conditions during the development of these experiments may have affected growth responses differently. Further studies should focus on growth responses to pruning under normal climate conditions and other factors that may also affect growth.

Keywords: eucalyptus, hybrid clone, silvicultural practice.

RESUMEN

Se establecieron cuatro experimentos para evaluar el efecto de la época y la altura de poda sobre el crecimiento de Eucalyptus grandis y E. grandis x E. camaldulensis GC INTA 8 en Concordia (Entre Ríos, Argentina). En invierno se instalaron dos experimentos en rodales de 20 meses de edad, y en primavera se instalaron dos experimentos más en rodales de 24 meses. Con diseño completamente aleatorizado con 4 repeticiones se aplicaron dos tratamientos en parcelas de 300 m^2: T1= poda a 2,5 m; T2= poda a 4,5 m. Se midió diámetro a la altura del pecho (DAP) y altura total antes de la poda y 12 meses después de su aplicación, y se calculó el crecimiento en DAP y altura y la copa remanente. Mediante MLG y MLGM y test LSD de Fisher se comparó el crecimiento en DAP y altura de T1 y T2 en cada experimento. No se encontraron diferencias significativas entre T1 y T2 después de la poda en invierno en ninguno de los dos materiales genéticos. En cambio, luego de la poda de primavera el crecimiento en DAP de E. grandis resultó significativamente menor (p=0,001) en T2 (3,4 cm) que en T1 (3,9 cm) y el crecimiento en altura de GC INTA 8 fue significativamente menor (p=0,011) en T2 (3,2 m) que en T1 (3,5 m). En conclusión, la poda en invierno no afecta el crecimiento de estos Eucalyptus, mientras que la poda en primavera puede afectar el crecimiento en DAP o altura según el material genético. Las condiciones de extrema sequía ocurridas durante el desarrollo de estos experimentos pudieron

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haber afectado las respuestas de estos materiales genéticos. Se requieren nuevos estudios para evaluar el efecto de las podas en condiciones climáticas normales y considerar otros factores que pueden también afectar el crecimiento.

Palabras clave: *eucalipto, clon híbrido, práctica silvícola*.

INTRODUCTION

Pruning plantation forests is a silvicultural practice used to obtain knot-free wood (Kurtz and Ferruchi, 2000; Aparicio and Caniza, 2009), which is valuable to industries that manufacture wood parts with specific visual and structural requirements. However, in the northeast of the province of Entre Ríos (Argentina), log price depends on the thinnest end diameter, and there is still little price difference between pruned and unpruned logs (García, 2019).

Pruning when branches begin to dry and fall will enlarge the defect core, thereby decreasing clear wood production (García and Ramos, 2021). Although eucalyptus trees naturally lose their branches, achieving acceptable defect cores requires pruning to be done early (Reid, 2002; Nolan *et al.*, 2005). Frequent and progressive pruning will result in uniform knot-free cores through the stem (Aparicio and Caniza, 2009; Resquín *et al.*, 2007). However, this practice is expensive and it will increase log price (García and Ramos, 2021). Intensive pruning in young trees with green branches can lower costs, promote wound closure, and increase clear wood production (Ferraz *et al.*, 2016). Ren *et al.* (2015) reported that pruning 50% of the whole crown of *E. grandis x E. urophylla* improved veneer quality and increased green knots per unit area.

Intensive pruning can reduce tree growth (Pinkard 2002; Larocca *et al.*, 2005) and promote epicormic sprouting (Seitz, 1995; Methol *et al.*, 2005). However, pruning and thinning applied together can minimize these effects on tree growth (Pinkard y Beadle, 1998). Alcorn *et al.* (2008) indicate there may be up-regulation of photosynthesis in the remaining foliage after pruning, resulting in physiological mechanisms for compensatory growth.

The effect of pruning on growth reduction depends on species and site conditions at the time of pruning (Forrester *et al.*, 2010). To adequately plan pruning, each genetic material's growth characteristics and branch persistence should be considered (Couto, 1995; Methol *et al.*, 2005; Resquín *et al.*, 2007; García and Ramos, 2021; Ramos and García, 2022; García *et al.*, 2023) to achieve a balance between temporary growth reduction and knot-free wood production (Kurtz and Ferruchi, 2000; Reid, 2002).

There is evidence of differences in productivity between *Eucalyptus grandis* and *Eucalyptus* clones growing in Entre Ríos (Harrand *et al.*, 2022). Differences in branch longevity among various genetic materials of *Eucalyptus* are also observed (García *et al.*, 2023). Under similar environmental conditions, different *Eucalyptus* varieties have different growth patterns and responses to disturbing events (Chauke, 2009; Eksteen, 2012). Then, applying pruning treatments to different *Eucalyptus* varieties is likely to result in different growth responses.

When referring to the height of pruning, some authors suggest following a schedule where interventions do not remove more than 50 % of the green crown in order not to reduce growth (Larocca *et al.*, 2005; Nolan *et al.*, 2005). Aparicio and Caniza (2009) propose pruning *Eucalyptus* to 2-2.5 m when they are 1-2 years old and lifting to 5.5 m when they are 2-3 years old, while Kurtz and Ferruchi (2000) recommend pruning to 3 m when trees reach a full height of 7-8 m. Results of pruning intensity trials show that severe pruning can reduce the growth of DBH and can have an effect on height growth. However, the effects of severe pruning can disappear after a few years or persist (Pinkard and Beadle, 1998; Resquín, 2007; Lisboa, 2012; Ferraz *et al.*, 2016).

A convenient alternative when there are homogeneous stands is to prune only once to a height that will allow for a basal-pruned log to be obtained from each tree (García and Ramos, 2021). However, it is important to note that for a fixed pruning height, the growth of the trees within a stand may be affected differently even if they are all pruned to the same height.

Pruning guides suggest that the best seasons to prune are fall and winter before the onset of vegetative activity (Kurtz and Ferruchi, 2000; Aparicio and Caniza, 2009). In contrast, García and Ramos (2021) mention that wounds heal faster after spring pruning.

This study aimed to evaluate the growth response of two different *Eucalyptus* genetic materials to two pruning heights applied in winter and spring after twelve months of the application of the treatments.

MATERIALS AND METHODS

We conducted this study in Campo El Alambrado (Concordia, Entre Ríos, Argentina 31°16'8.86" S, 57°58'51.86"O) of the Instituto Nacional de Tecnología Agropecuaria (INTA), where soil belongs to Oxic Udifluvents, characterized by sandy over sandy-clay materials at 65-85 cm depth, with rolling stones, well to excessively drained, with reduced fertility and low water retention capacity (Plan Mapa de Suelos de la Provincia de Entre Ríos, 1993). Forest plantations in Entre Ríos stretch for 20 km parallel to the riverbank. *Eucalyptus grandis* is the commonly planted species in commercial plantations, with an average yield of 25-30 m^3 ha^{-1} in sandy soils (Bedendo, 2020) and clear-cut at about ages 8-13 (Larocca *et al.*, 2005). The climate is warm temperate (subtropical) without a dry season, mean annual temperature of 18.7 °C, mean annual precipitation of 1372.9 mm, and a frost-free period of ten months (Ramos *et al.*, 2018). The study took place through a period strongly influenced by the ENSO phenomenon (El Niño-Southern Oscillation), with a prolonged drought where the water deficit concerning normal annual precipitation ranged from -409.2mm in 2021 to -217mm in 2022 (Ramos, 2021; Ramos and Garín, 2022).

We studied two genetic materials of *Eucalyptus* that were planted in October 2019: *Eucalyptus grandis* Hill ex Maiden from the commercial seed orchard of INTA Concordia, and *E.*

grandis x *E. camaldulensis* GC INTA 8 commercial clone (hereafter GC INTA 8). We conducted four experiments as follows: 1) *E. grandis* stand, aged 20 months, pruned in June 2021, during winter season; 2) *E. grandis* stand, aged 24 months, pruned in November 2021, during spring season; 3) GC INTA 8 stand, aged 20 months, pruned in June 2021, during winter season, and 4) GC INTA 8 stand, aged 24 months, pruned in November 2021, during spring season. Each experiment involved two pruning heights: T1) 2.5 m, called low pruning and widely implemented in *Eucalyptus* plantations in Entre Ríos, and T2) 4.5 m, the usually second pruning, that permits to obtain a basal pruned log of commercial length. In each experiment, pruning treatments, T1 and T2, were conducted in 300 square meters plots with four replicates, using a completely randomized design.

On average, the density of the stands after an early thinning to waste operation -which occurred just before pruning- was 565 trees per hectare. For experiment 1, the average number of trees per plot was 14, for experiments 2 and 3 it was 17, and for experiment 4 it was 20. At the time of the experiments establishment and after 12 months of each pruning application, we measured the diameter at breast height (DBH) and the total height of all trees within each plot using a measuring tape (accuracy 0.1 cm) and a telescopic pole (accuracy 0.05 m). We observed differences in average DBH and height values of the stands before pruning treatments application, as shown in table 1.

After applying pruning treatments, we measured the percentage of the remaining crown (RC) for each tree, which was calculated by subtracting the height of pruning from the initial total height of the tree. Our study involved recording the growth in DBH and height of 250 *Eucalyptus grandis* trees as well as 296 GC INTA 8 trees.

With InfoSTAT statistical software (Di Rienzo *et al.*, 2020) we analyzed the growth in DBH and height in each experiment using GLM (for modeling data sets with homogeneous variance) and GLMM (for modeling data sets with heterogeneous variance). We included initial DBH and initial height as covariables in the analysis of DBH growth and height growth, respectively. For each experiment and variable of interest, we selected the best model based on the Akaike criterion (AIC): smallest AIC values indicate better adjustment. We used a one-way GLM model with height of pruning as the fixed effect for the DBH growth in experiments 1 and 2, and for the height growth in experiments 1, 3, and 4. For the DBH growth in experiments 3 and 4, and for the height growth in experiment 2, we opted for GLMM: we selected the height of pruning as the fixed effect, and the function of variance g(d) = d with plot as the grouping factor to indicate that the residual variance is distinct for each plot. We compared DBH and height growth mean values using Fisher's LSD test.

RESULTS

Twelve months after winter pruning -applied in experiments 1 and 3- we found no significant differences in either DBH (figure 1) or height growth (figure 2) between the two pruning heights. The p-values were higher than 0.05. DBH growth of *E. grandis* was 4.0 cm in T1 and 3.9 cm in T2, while DBH growth of GC INTA 8 was 3.9 cm in both T1 and T2 treatments. Height growth of *E. grandis* was 4.1 m in T1 and 4.0 m in T2, while height growth of GC INTA 8 was 3.9 m in T1 and 3.8 m in T2. In contrast, twelve months after spring pruning -applied in experiments 2 and 4- the results were different depending on the *Eucalyptus* variety. The growth in DBH of *E. grandis* (figure 1) was 13 % lower in T2 (3.4 cm) than in T1 (3.9 cm), with a p-value of 0.001, while DBH growth of GC INTA 8 presented no significant differences (p-value=0.263) between T1 (3.6 cm) and T2 (3.6 cm). Height growth of GC INTA 8 (figure 2) was 9% lower in T2 (3.2 m) than in T1 (3.5 m), with a p-value of 0.011. In comparison, height growth of *E. grandis* showed no significant differences (p-value=0.938) between T1 (4.1 m) and T2 (4.0 m) twelve months after spring pruning.

Although treatments consisted of fixed pruning heights, in experiments 1 and 2, which involved *E. grandis*, we observed remarkable differences in remaining crown (RC) ranges after pruning application (table 2). In experiment 1, only 5% of the trees in T1 had less than 50% of RC, while in T2, 90% of the trees had less than 50% of RC. Similarly, in experiment 2, only 2% of the trees in T1 had an RC lower than 50%, whereas in T2, 46% of the trees had an RC lower than 50%. On the contrary, in experiments 3 and 4, which involved GC INTA 8, only T2 caused some trees to have RC values lower than 50%: in experiment 3, 4 % of the trees, and in experiment 4, only 1 %. In both experiments, all the trees pruned to 2.5 m (T1) had an RC equal to or higher than 50%.

DISCUSSION

Pruning trials mainly consider the species and the age and size of the trees, rather than the season. Lund *et al.* (2023) highlight that there is a significant gap in knowledge regarding the optimal pruning times for specific species. Our results indicate that pruning to fixed heights had different effects regarding the season and the variety of *Eucalyptus*. After 12 months of the pruning intervention in winter, the trees of both genetic materials pruned to 4.5 m were able to reach the same growths as the trees pruned to 2.5 m, although the ranges of the remaining crown after pruning differed for *E. grandis* in comparison to GC INTA 8. The compensatory response to pruning may explain our results. This response involves an increase in the photosynthetic rate of the remaining crown, which allows the removal of

Experiment	Time of pruning	Stand age	Genetic material	DBH (cm)	height (m)
1	winter	20 months	*E. grandis*	8.1 ±1.6	7.7 ±1.3
3	winter	20 months	GC INTA 8	8.8 ±0.9	10.3 ±0.7
2	spring	24 months	*E. grandis*	9.1 ±1.7	8.9 ±1.4
4	spring	24 months	GC INTA 8	8.9 ±1.2	11.1 ±0.8

Table 1. Average and standard deviation of diameter at breast height (DBH) and height of the stands before the implementation of pruning trials.

Experiment	T1 (pruning to 2.5 m)	T2 (pruning to 4.5 m)	Trees with an RC lower than 50%	
			T1	T2
1	40-78%	22-55%	5%	90%
2	49-79%	23-62%	2%	46%
3	69-78%	43-61%	0%	4%
4	62-81%	48-64%	0%	1%

Table 2. Range of remaining crown (RC) and percentage of trees having an RC lower than 50 % after the implementation of pruning treatments.

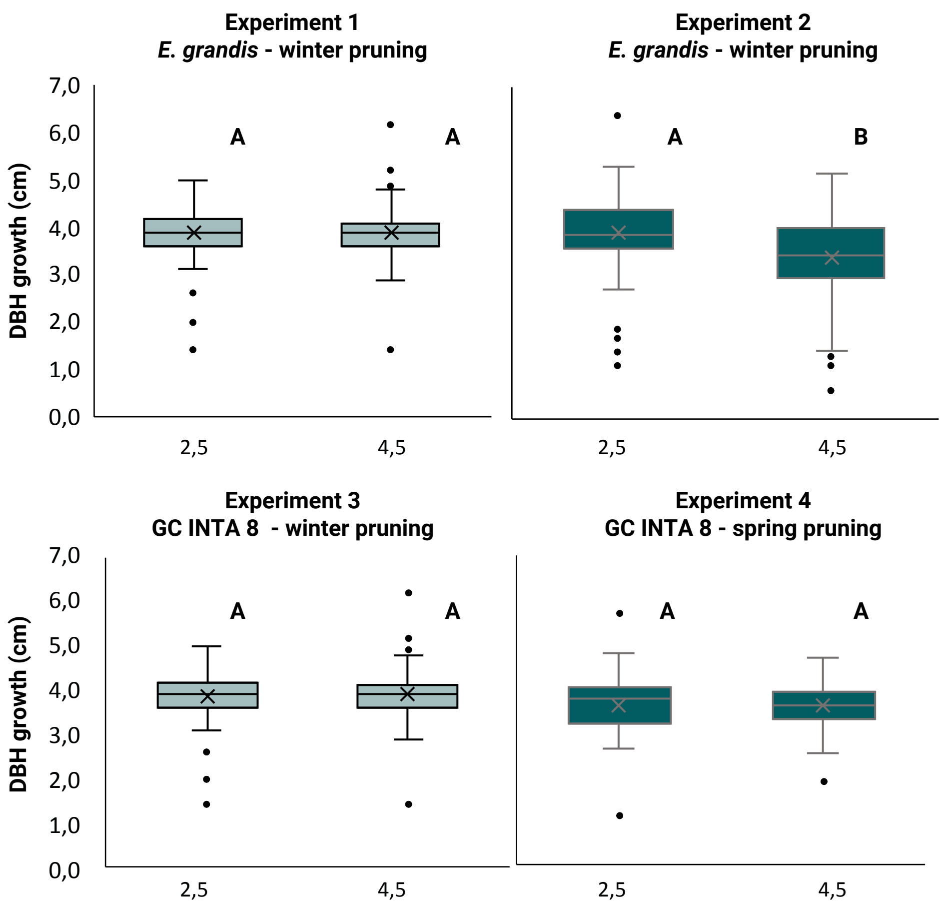

Figure 1. DBH growth twelve months after pruning treatments application. Different letters indicate significant differences between pruning treatments within each experiment (Fisher's LSD test, p<0.05).

some foliage without negatively affecting tree growth (Lisboa *et al.*, 2014). In coincidence, Ferraz *et al.* (2008) report that pruning in fall 16 months old *E. grandis* to 4.5 m or below when trees were 11 m tall presented similar DBH and height growth after nine months of the intervention. Other study concludes that pruning *Eucalyptus* to 2.4 m at 18, 21 and 24 months old does not affect the growth in volume (Larocca *et al.*, 2005).

Pruning experiments applied in spring caused different responses of trees. While *E. grandis* presented lower DBH growth after 12 months, smaller height increments were observed in GC INTA 8, when pruning to 4.5 m in comparison to the less intensive treatment. In contrast, Maurin and DesRochers (2013) observed that pruning had no effect on DBH growth for trees pruned in fall or spring, while pruning to 2/3 of the crown length decreased DBH of trees pruned during summer compared to unpruned trees. Additionally, when referring to growth patterns, Ferraz *et al.* (2016) point out that tree height was less affected by pruning than the diameter growth response.

According to Harrand *et al.* (2022), during their early stages, *E. grandis* x *E. camaldulensis* clones tend to exhibit higher

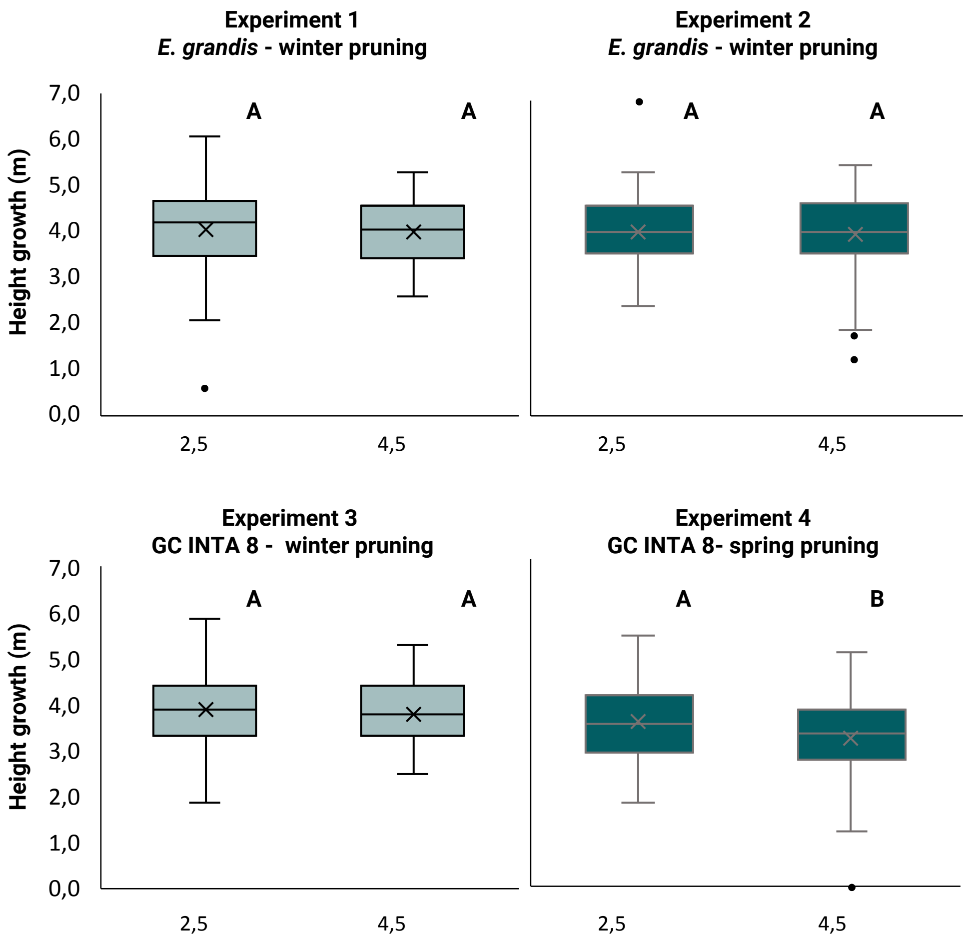

Figure 2. Height growth twelve months after pruning treatments application. Different letters indicate significant differences between pruning treatments within each experiment (Fisher's LSD test, p<0.05).

mean height and equal or greater DBH values than *E. grandis*. The authors also note that these initial differences can persist for a longer time under site conditions that limit growth. In this study, *E. grandis* trees were shorter and more heterogeneous than the hybrid clone trees. As a result, the RC percentages after pruning had a wider range in *E. grandis* than in the hybrid clone. While some research papers refer to the importance of leaving at least 50 % of the green crown when pruning *Eucalyptus* in order not to reduce tree growth (Larocca *et al.*, 2005; Nolan *et al.*, 2005; Forrester *et al.*, 2010), others indicate variable recovery times when trees are treated with intensive pruning (Ferraz *et al.*, 2016; Alcorn *et al.*, 2008).

A physiological approach to pruning may help interpreting growth responses after pruning interventions. On one hand, during winter, respiration costs are much lower for intensively pruned trees than for other treatments (Pinkard *et al.*, 1999). Additionally, as a result of a loss of leaf area, a compensation in growth occurs (Alcorn *et al.*, 2008; Ramos and Licata, 2013; Lisboa *et al.*, 2014). Under the same environmental conditions, different *Eucalyptus* varieties show different growth patterns and responses to disturbing events (Chauke, 2009; Eksteen, 2012). Although hybrid *Eucalyptus* clones have shown better behavior than *E. grandis* trees in sites with limiting growth conditions (Harrand *et al.*, 2022), prolonged drought periods seem to affect both *Eucalyptus* genetic materials. According to Beadle's research in 1997, responses to pruning depend, among other factors, on water availability. Therefore, the differences in growth responses recorded in this study could be attributed to the extremely dry period during the establishment and evaluation of the experiments. Under such unfavorable conditions, a greater stomatal conductance in pruned trees suggests greater drought stress resistance (Maurin and DesRochers, 2013) of trees when pruned in winter, whereas a higher water demand for transpiration in spring may have caused growth reduction.

CONCLUSIONS

Winter pruning to two different heights has no impact on the growth of *Eucalyptus* trees. *E. grandis* and the hybrid clone GC INTA 8 show similar responses. It means it is possible to prune 20 months old stands to 4.5 m in a one-time operation without significant growth reduction. Therefore, a pruned basal log of commercial length of 4.15 m can be obtained from each individual tree.

Spring pruning effects on growth depend on the genetic material. DBH growth of *E. grandis* and height growth of GC INTA 8 are lower when pruned to 4.5 m during spring. However, further studies should investigate other factors that could also impact growth and knot-free wood formation.

Although statistically significant, differences of 0.5 cm in DBH growth and 0.3 m in height growth may eventually disappear and have no economic impact or influence on management decisions. Forest managers can maximize the amount of clear wood obtained from each basal log by developing pruning plans based on the benefits of a one-time pruning approach. To make these plans effective, it is important to consider factors such as species' branch longevity, resource availability, acceptable growth loss, and the expected recovery rate of growth.

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