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Pruning height in *Eucalyptus* clones established in an agrosilvopastoral system

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ABSTRACT: The aim of the current study is to evaluate the effect of pruning intensity on the diameter and height of three *Eucalyptus* clones established in an agrosilvopastoral system. The study followed a completely randomized block design in a split-plot arrangement, with repeated measures in time. Plots were represented by three *Eucalyptus* clones (VE01, VE07 and VE06) and sub-plots were represented by three pruning heights (0%, 25% and 50% of total tree height), and the repeated measures were months. Trees were pruned at 18 and 24 months after planting, by keeping the same proportion of pruning Heights. Diameter at Breast Height (DBH) and total Tree Height (Ht) were measured every six months since the first pruning; periodic increase in both variables was calculated. Clone VE01 recorded DBH and Ht values lower than the ones recorded for VE07 and VE06. Pruning treatments did not show significant effects on tree growth.
Keywords: silviculture; agroforestry; diameter at breast height; total tree height.

Altura de desrama em clones de eucalipto estabelecidos em um sistema agrossilvipastoril

RESUMO: O presente trabalho teve como objetivo avaliar o efeito da intensidade de desrama no crescimento em diâmetro e altura total de três clones de eucalipto estabelecidos em um sistema agrossilvipastoril. Foi utilizado delineamento em blocos casualizados em esquema de parcelas subdivididas com três repetições, sendo a parcela representada por três clones de eucalipto (VE01, VE07 e VE06) e a sub-parcela por três alturas de desrama (0%, 25% e 50% da altura total da árvore). Foram aplicadas duas desramas sequenciais, aos 18 e 24 meses, mantendo-se as proporções de altura. Foram medidos o diâmetro a altura do peito (DAP) e altura total das árvores (Ht) a cada seis meses após a primeira desrama e calculados os incrementos periódicos para ambas as variáveis. O fator clone afetou as variáveis estudadas, com diferenças significativas entre o clone VE01 e os clones VE07 e VE06, sendo o primeiro o que apresentou os menores valores para ambas as variáveis. A altura de desrama não apresentou efeito significativo no crescimento das árvores dos três clones, de forma que se deve indicar a desrama de 50% da altura das árvores em duas intervenções sequenciais.
Palavras-chave: tratos silviculturais; agrossilvicultura; diâmetro a altura do peito; altura total.

1. INTRODUCTION

Agrosilvopastoral systems have been reported as important alternative for sustainable agricultural production, since it integrates pastures, crops, tree and animal species in the same area in order to optimize and diversify production, as well as to mitigate environmental impacts caused by livestock production (BOSI et al., 2020). These systems reduce erosion, improve water conservation, capture and fix carbon, reduce the need of applying mineral fertilizers, as well as improve soil microfauna and animal comfort.

In addition to environmental aspects, these systems enable diversifying farms' income through the obtainment of forest products (MÜLLER et al., 2011). In order to enable a more profitable use of this component, it is necessary applying specific silvicultural techniques capable of producing high-quality solid wood for noble use (WANG; ZENG, 2016).

Thus, thinning and pruning are the main tools used to achieve these goals. Early thinning is not often used in agrosilvopastoral systems; thus, pruning emerges as the main practice to obtain quality wood (FERRAZ FILHO et al., 2016a). Artificial pruning consists in removing the lower part of tree canopy by cutting branches close to the trunk. Based on this technique, scars left by removed branches are restricted to the most central parts of the tree. In addition, it improves wood quality, mainly for sawmill using, because it reduces live and dead knots (VALE et al., 2002) and increases the extent of clean wood, larger and straighter boles, (POLLI et al., 2006; SPIECKER, 2021). Pruning is also an important management practice to regulate the competition for resources among the system's components (ORTEGA-VARGAS et al., 2019). According to Machado (2014), if this procedure is carried out early in systems integrating pastures and annual crops, it can still prevent likely injuries to trees caused by herbicide drift, as well as favors its application.

Planting arrangements in agrosilvopastoral systems are designed to optimize solar radiation distribution among different strata, through the adoption of broader spacing between trees to enable crops and pastures to receive the

necessary amount of this resource in order to maintain their photosynthetic activity and sustainable yield. Consequently, there is increased development of branches with thicker diameters in the basal portions of trees (VALE et al., 2002; FONTAN et al., 2011).

The practice of pruning changes the architecture of trees, and it can compromise their growth, mainly when the leaf area is significantly reduced (PULROLNIK et al., 2005; CEZANA et al., 2012). Thus, it is essential understanding the impact of pruning intensity on tree growth in order to develop a pruning regime to enable quality wood production without affecting tree growth and production (ALCORN et al., 2008b).

Pruning management must adjust its frequency and intensity to plants' age to enable injuries to heal faster (POLLI et al, 2006). These factors can change depending on the genetic material and quality of the site, as well as on plants' vigor and age (PULROLNIK et al., 2005; FORRESTER, 2013).

Thus, it is important emphasizing that the scientific literature about pruning application in eucalyptus monocultures presents controversial results, and it makes it hard to establish a clear line of action, as pointed out by Tonini et al. (2016). Studies about integrated systems are even more scarce; the most current references comprise studies conducted by Vale et al., (2002), Fontan et al. (2011), Machado (2014), Tonini et al. (2016) and Ferraz Filho et al. (2016b).

Thus, the aim of the current study was to evaluate the effect of artificial pruning height on the growth (in diameter) and height of three eucalyptus clones established in agrosilvopastoral system in Coronel Xavier Chaves County / MG.

2. MATERIALS AND METHODS

2.1. Study Location

The study was carried out at Sítio das Gabirobas, which is a family-based dairy farm in Coronel Xavier Chaves/MG, (21°00'44.75" S; 44°12'28.42" W). According to the Köppen-Geiger classification, the climate in the region is classified as Subtropical highland type (Cwb). Monthly rainfall rate reaches 217 mm in Spring/Summer and 15.6 mm in Winter; mean daily air temperature reaches 21.9°C in Spring/Summer and 17.3°C in Winter (Figure 1).

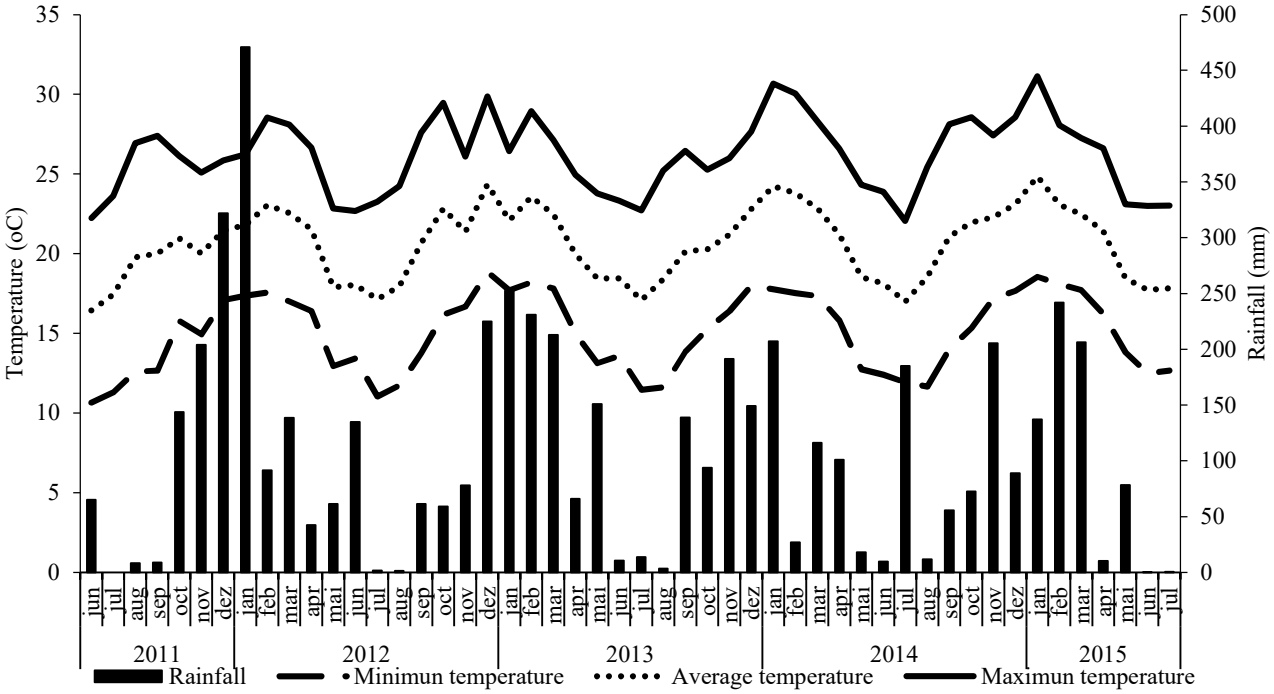

Figure 1. Mean temperatures and Rainfall during the experiment period (Agritempo, 2021).
Figura 1. Temperaturas médias e precipitação durante o período do experimento (Agritempo, 2021)

2.2. Agrosilvopastoral System

The experiment was installed in November 2009 within a 4.5-ha area with dystrophic Red-Yellow Latosol, slightly wavy relief and maximum slope angle of 10°. Average soil chemical properties in the area were: pH (water), 5.5; organic matter (OM), 2.1 dag/kg; $P_{(Mehlich-1)}$, 0.9 mg/dm^3; $K_{(Mehlich-1)}$, 51.0 mg/dm^3; Ca, 0.9 cmolc/dm^3; Mg, 0.2 cmolc/dm^3; Al, 0.1 cmolc/dm^3; H + Al, 3.6 cmolc/dm^3.

Trees were established at spatial arrangements (with double rows) spaced 28 meters from each other. Tree rows within these spatial arrangements were spaced 3 meters from each other, whereas plants in the rows were spaced 2 meters from each other; total density was 323 plants ha^{-1}.

In the first year, *Urochloa brizantha* cv. Marandu intercropped with maize hybrid (AG 1051) was sowed at spacing between rows of 0.8 and population density of 50,000 plants ha^{-1}. The silvopastoral system was maintained from the second year onwards, using lactating Holstein x Zebu cows, under rotational stocking regime, with resting periods ranging between 24-28 days and paddock occupation ranging of 3-5 days, depending on the time of the year.

The experiment implementation process used 400 kg ha^{-1} of 08-30-16+zn formula, which was applied with the aid of spreader at the bottom of the maize sowing furrow, in association with 200 kg ha^{-1} of simple superphosphate, before brachiaria seeding. In addition, 150 g pit^{-1} of 08-30-

16+zn formula was applied at the bottom of the pit, at tree planting time. Cover fertilization with 350 kg ha^{-1} of 20-05-20 formula was applied to maize, distributed in two equal portions, at 25 and 35 days after sowing. Cover fertilization with 150 g pit^{-1} of 20-05-20 formula was applied to eucalyptus, distributed over the soil around the treetop, in two portions: the first one was applied at 60 days and the second one, at 90 days after planting. Cover fertilization based on the very same aforementioned amounts was reapplied in the second year.

2.3. Experimental design

The factors were distributed according to a randomized block design with subdivided plot scheme (Table 1), with repeated measures in time. The clones were allocated in the plots, while pruning it in the subplots, and measurement times (months) considered as repeated measures.

Table 1. Treatments applied to three *Eucalyptus* clones established in an agrosilvopastoral system in Coronel Xavier Chaves County/MG.
Tabela 1. Tratamentos aplicados a três clones de Eucalyptus estabelecidos em um sistema agrossilvipastoril no Município de Coronel Xavier Chaves/MG

Treatments		Ht before pruning		Pruning Ht	
Clone	Height	1st	2nd	1st	2nd
VE01	0%	6.11	7.49	-	-
	25%	6.07	7.56	1.5	1.9
	50%	6.32	8.07	3.0	4
VE07	0%	7.00	8.64	-	-
	25%	6.76	8.26	1.7	2
	50%	7.08	8.76	3.5	4.4
VE06	0%	7.62	8.90	-	-
	25%	7.63	8.88	1.7	2.2
	50%	7.52	9.04	3.7	4.5

1st = first pruning at 18 months; 2nd = second pruning at 24 months

Three clones of a hybrid deriving from *Eucalyptus urophylla* S. T. Blake x *Eucalyptus grandis* W. Hill ex Maiden (VE01 – Copebrás 69, VE07 – Cenibra 57 and VE06 - GG 100), collected at Esteio Nursery in São João Del Rey County / MG were used; three pruning heights in comparison to total tree height (0%, 25% and 50%), in six times (18, 24, 30, 36, 42 and 52 months). The first pruning was performed in 18-month-old plants and the second pruning was performed in 24-month-old plants, by maintaining these percentages. Pruning saw equipped with extension cable (2.0m to 6.0m) was used to cut the branches perpendicularly to their insertion and close to the trunk.

Each plot comprised six trees; thus, 18 trees were measured in each of the nine treatments - 162 trees, in total.

2.4. Data collection and analysis

Circumference at breast height (CBH) was measured with measuring tape at 1.30 m from the ground and total tree height (Ht) was measured with Abney level at 18 (before the first pruning application), 24 (before the second pruning application), 30, 36, 42 and 52 months of age. CBH values were converted into diameter at breast height (DBH).

The data were analysed in a randomized complete block design in a subdivided plot scheme with repeated measures in time. The systems were allocated in the whole plot and the seasons of the year in the smallest parcel. Mixed models were used with the PROC MIXED of SAS® (SAS, 2001), considering the clone, the pruning, the month and their interactions as fixed effects and the blocks and the error as random effects. The choice of the covariance matrix was based on the Akaike information criterion (WOLFINGER, 1993), adopting the following sources of variation: block, clone, pruning, months and their interactions. The averages were compared by Tukey test, using the LSMEANS command. For all analyses, was considered a significant effect was considered when $P \leq 0.05$, and a tendency when $0.05 < P \leq 0.10$.

3. RESULTS

3.1. Growth in DBH

There was no effect of pruning treatments ($P = 0.29$) or interaction of the factors ($P > 0.05$) on the DBHb. Diameter at breast height (DBH) was influenced by clone ($P = 0.03$) (Table 2) and time ($P < 0.01$) (Figure 2).

Table 2. Mean diameter at breast height (DBH) of three Eucalyptus clones (at different ages) established in an agrosilvopastoral system, subjected to three pruning intensities, in Coronel Xavier Chaves /MG, Brazil.
Tabela 2. Diâmetro médio à altura do peito (DAP) de três clones de Eucalyptus (em diferentes idades) estabelecidos em um sistema agrossilvipastoril, submetido a três intensidades de poda, em Coronel Xavier Chaves/MG, Brasil.

Clone			SE
VE01	VE06	VE07	
12.64b	13.74a	13.19ab	0.3923

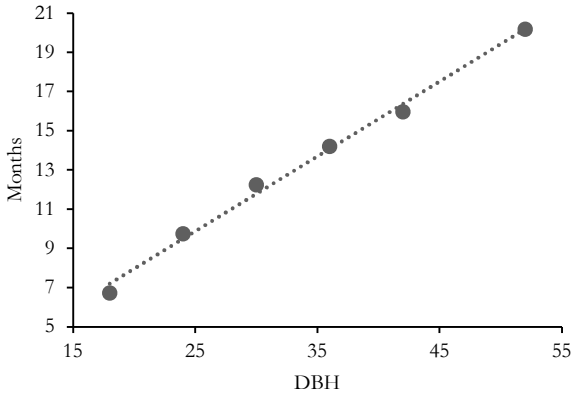

Figure 2. Diameter at breast height (DBH) of Eucalyptus clones at different ages established in an agrosilvopastoral system, subjected to three pruning intensities, in Coronel Xavier Chaves/MG, Brazil.
Figura 2. Diâmetro à altura do peito (DAP) de clones de Eucalyptus em diferentes idades estabelecidos em um sistema agrossilvopastoril, submetidos a três intensidades de poda, em Coronel Xavier Chaves/MG, Brasil.

The VE06 clone recorded the highest DBH values at all three pruning throughout the experimental period; it was followed by the VE07 clone, although there were not statistically significant differences between them. The VE01 clone recorded the lowest DBH values ($p < 0.05$) in comparison to the other clones, after 30 months of age.

The VE06 clone stood out with the highest DBH values at 52 months of age (34 months after the first pruning), in comparison to the other two clones.

Factors 'clone' and 'pruning height' did not affect periodic increase in DBH. Thus, clear trend in this parameter was not observed in the applied treatments. However, as shown in Figure 3, periodic DBH increments recorded for all three clones have decreased among evaluated periods up to 42 months of age, in all treatments (means: 3.01 cm, from 18

to 24 months; 2.49 cm, from 24 to 30 months; 1.90 cm, from 30 to 36 months; and 1.84 cm, from 36 to 42 months).

The highest DBH increase was observed in the last evaluation period (4.21 cm, from 42 to 52 months); it happened because this 12-month period was the one encompassing the entire annual growth cycle of plants.

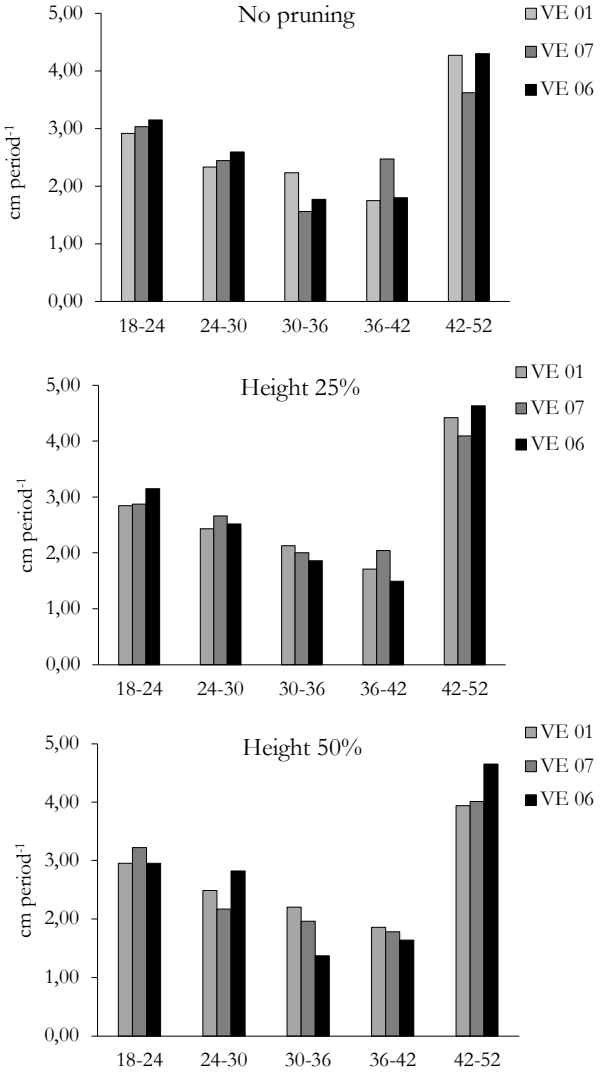

Figure 3. Diameter at breast height increment (centimeters period^{-1}) of three Eucalyptus clones (at different ages) established in an agrosilvopastoral system, subjected to three pruning heights, in Coronel Xavier Chaves/MG, Brazil.
Figura 3. Incremento do diâmetro à altura do peito (centímetros período-1) de três clones de Eucalyptus (em diferentes idades) estabelecidos em um sistema agrossilvipastoril, submetido a três alturas de poda, em Coronel Xavier Chaves/MG, Brasil.

3.1. Growth in Ht

As observed for the DBH, the Ht was not affected by pruning treatments ($P = 0.48$), as well as other interactions ($P > 0.05$). Total tree height was influenced by 'clone' ($P < 0.01$) and time ($P < 0.01$), with interaction of this factors ($P < 0.01$).

Unfolding the interaction 'clone x months', studying clones in each month, it is observed that the clone V01 presented the lower values in all months, compared to the others. The clones V06 and V07 were different only at the months 30 and 52 (Table 3).

Table 3. Total height (Ht) of three Eucalyptus clones (at different ages) established in an agrosilvopastoral system in function of age (months).
Tabela 3. Altura total (Ht) de três clones de Eucalyptus (em diferentes idades) estabelecidos em um sistema agrossilvipastoril em função da idade (meses).

Months	Clone			SE
	V01	V06	V07	
18	6.17^{fB}	7.59^{fA}	6.95^{fA}	0.42
24	7.71^{eB}	8.94^{eA}	8.55^{eA}	
30	11.28^{dC}	12.93^{dA}	12.15^{dB}	
36	12.79^{cB}	14.27^{cA}	13.64^{cA}	
42	15.16^{bB}	16.72^{bA}	16.60^{bA}	
52	21.96^{aC}	27.23^{aA}	23.72^{aB}	

Means followed by same letters, uppercase in line and lowercase in columns, are not different by Tukey test ($P > 0.05$).

The VE06 clone at 52 months of age (34 months after the first pruning) recorded significant increase in total tree height, which resulted in the highest values observed for this variable in comparison to the other two clones (Figure 4).

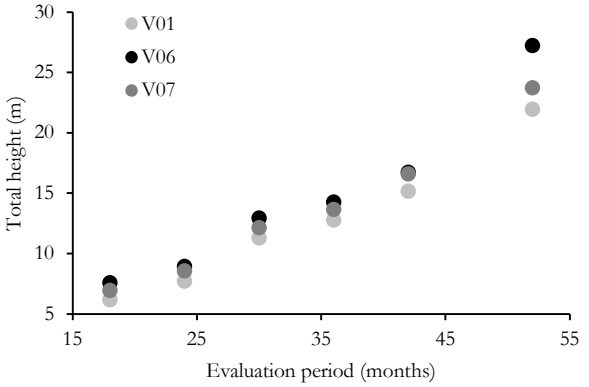

Figure 4. Total height (Ht) of Eucalyptus clones at different ages established in an agrosilvopastoral system, subjected to three pruning intensities, in Coronel Xavier Chaves/MG, Brazil.
Figura 4. Altura total (Ht) de clones de Eucalyptus em diferentes idades estabelecidos em um sistema agrossilvopastoril, submetidos a três intensidades de poda, em Coronel Xavier Chaves/MG, Brasil.

Growth in height (1.5 meter in all treatments, on average) within six months (18-24 months), after the first pruning applied at 18 months was lower than that observed in the six months period after the second pruning at 24 (3.72 meters, on average). Than, lower growth (1.45 meter, on average) was observed in the following period (30-36 months); values increased from this point onwards, as seen in Figure 5 (2.74 meters from 36 to 42 months and of 8.0 meters from 42 to 52 months, on average).

4. DISCUSSION

According to Zhang; Liu (2021), nonstructural carbohidrates levels in Poplar trees, fluctuate during the growing season regardless of the pruning intensities, which could explain the lack of significant diferences among pruning height treatments on tree height and diameter grwoth of *Eucalyptus* clones.

These parameters were affected only by clone treatments, as expected (PULROLNIK et al., 2005). Ramirez et al. (2018) also confirm this theory. These authors suggested that the better development of *Acer platanoides* when compared to *Acer saccharinum*, after pruning, may be due to its better capacity to

maintain higher levels of carbohydrates on aboveground organs.

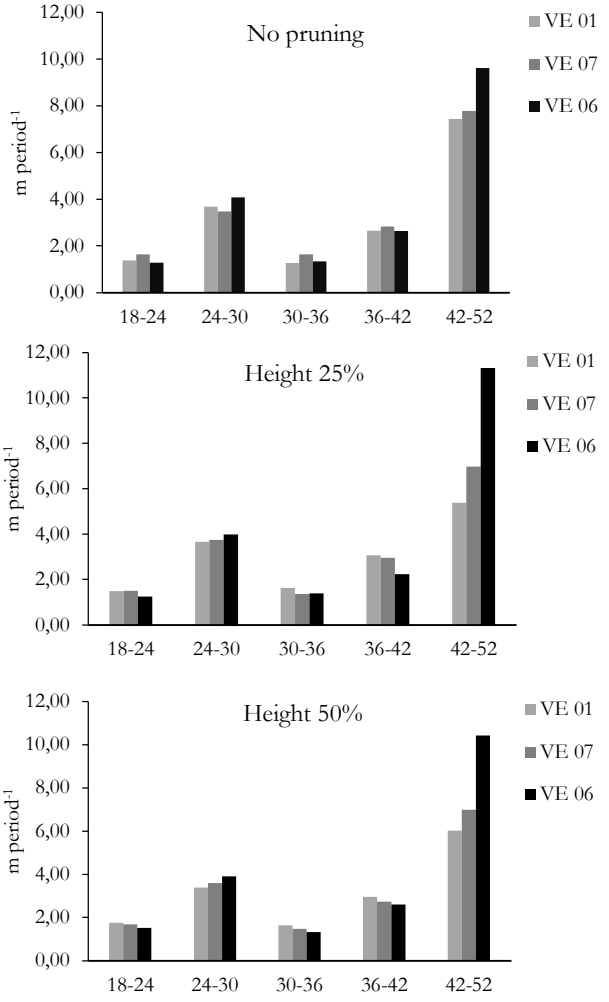

Figure 5. Periodic increase in total height (meters period-1) of three Eucalyptus clones (at different ages) established in an agrosilvopastoral system, subjected to three pruning heights, in Coronel Xavier Chaves/MG, Brazil.

Figura 5. Aumento periódico da altura total (metros período-1) de três clones de Eucalyptus (em diferentes idades) estabelecidos em um sistema agrossilvopastoril, submetido a três alturas de poda, em Coronel Xavier Chaves / MG, Brasil.

DBH increments decreased up to 42 months (24 months after the first prunning and 18 months after the second). According to Alcorn et al. (2008a), highly intense pruning (over 50%) leads to reduced growth in DBH and Ht for longer periods-of-time (up to 12 months). They have investigated the effect of pruning intensities on *Eucalyptus pilularis* and *Eucalyptus cloeziana* planted in monoculture system. Results have shown that the removal of up to 20% of the treetop did not affect tree growth, whereas the removal of up to 50% of it delayed diametric increase for up to 8 months.

This outcome can be explained by trees' ability to recover moderate losses in the photosynthetic area without permanent damage to growth rates (ALCORN et al, 2008a; LANDHÄUSSER; LIEFFERS, 2012). Zhang; Liu (2021), observed that moderate pruning (1/3 of tree height) did not affect the hability of 12 years old Poplar trees recover compensatory growth. Maurin; Desrochers (2013) also confirmed that moderate pruning during summer season is the best option for hybrid poplar trees.

According to Júnior; Seitz (2015), the maintenance of up to 50% of the treetop did not significantly affect growth in DBH of *Eucalytpus dunnii* plants grown in monoculture system. In this sense, the results obtained in this study suggest that removing 50% of the crown will not compromise tree growth. In addition, more cylindrical shafts and consequently better quality wood will be produced.

On the other hand, Ferraz Filho et al. (2016b) observed negative effect of pruning applied at 12 months of age on clones of *E. grandis* × *E. urophylla* hybrid established in a silvopastoral system and subjected to removal of 40% and 60% of treetop in comparison to lower pruning intensities (0% to 20 %). According to the aforementioned authors, dead branches were not observed at the base of the treetop at treatments' application time. This finding indicates that this portion of the treetop remained capable of significantly contributing to tree growth.

Spacing in single rows enables treetops to have wide access to incident light, so they receive solar radiation from all sides. The planting arrangement adopted in the present study was installed in double rows, and it often results in the early shading of leaves at the base of the treetop, within the space between tree rows (Figure 6). Lisboa et al (2014) observed that in the basal sections of unpruned *Eucalyptus regnans* trees the photosynthetic rates were lower than in the upper sections wich was assigned to crown closure.

Paula et al. (2013), observed greater diameter growth in single rows arrangement (9 x 3 m) when compared with double rows arrangement (9 m x (3 x 3 m)).

Results in the current study also contradict those presented by Pulrolnik et al. (2005), who observed that eucalyptus plants established in conventional planting spacing, with higher proportion of treetop remaining after pruning at 20 months of age, presented greater periodic DBH increase, whereas the other plants made greater investment in treetop recovery at the expense of DBH in the months following the pruning. This outcome was corroborated by Alcorn et al. (2008a).

The behavior observed for periodic increase in total tree height may be associated with periods of higher and lower rainfall rates. Pruning applied at 18 months took place at the peak of the least rainy season, whereas pruning applied at 24 months was carried out exactly at the peak of the rainiest season. These results are corroborated by those observed by Lisboa et al (2014), for *E. regnans* trees.

The wider spacing used in agrosilvopastoral systems leads to reduced competition for light and, consequently, to better use of this resource by treetops, for longer periods-of-time. This, according to Silva et al. (2016), would also explain the grater variation among measured data. The greater photosynthetically active radiation availability resulting from pruning can lead to increased carbon assimilation by the remaining treetop. Consequently, it enables faster leaf area recovery at the same levels as before pruning and, accordingly, it enables faster treetop recovery (FONTAN et al., 2011; LISBOA et al., 2014). This outcome is associated with higher photosynthetic activity observed in leaves grown in the upper parts of the treetop (ALCORN et al., 2008b; LANDHÄUSSER; LIEFFERS, 2012).

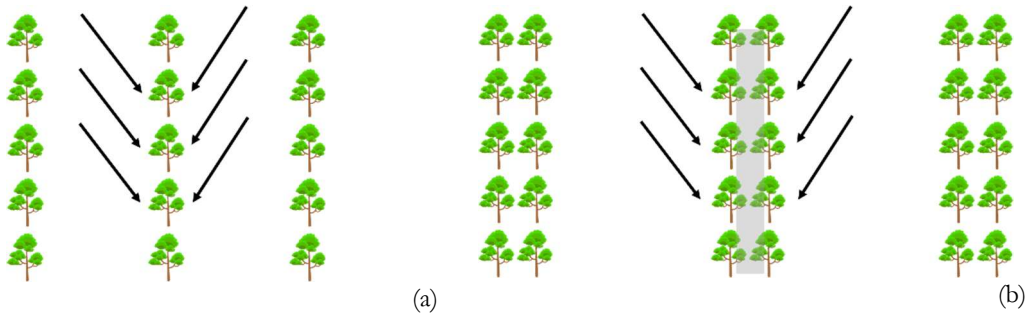

Figure 6. Light incidence on the top of trees arranged in single (a) and double rows (b).
Figura 6. Incidência luminosa no topo das árvores dispostas em fileiras simples (a) e duplas (b).

5. CONCLUSIONS

VE06 and VE07 clones performed better than VE01 in diameter at breast height and total height, at all pruning levels.

The pruning heights evaluated did not influenced the growth in diameter at breast height and total plant height of three eucalyptus clones established in agrosilvopastoral system.

Thus, treetop pruning up to 50% of total tree height, at 18 and 24 months of age, can be recommended to enable quality wood production with lower operating costs, without prejudice to the system yield.

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