PRODUCTIVITY AND QUALITY IN THE PROCESSING WOOD OPERATION FOR ENERGY

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ABSTRACT – Optimizing resources is essential for the excellence and competitiveness of a forestry company. In this context, this study evaluated the productivity and quality of eucalyptus wood processing for energy purposes. The study was conducted in a forestry company in Paraná State in stands of *Eucalyptus urophylla* × *Eucalyptus grandis* and *Eucalyptus saligna* clones named stands 1 and 2, respectively, with an age of 7 years old. The trees were processed with a harvester and included the following four stem diameter limits for pulp production and co-products for energy purposes: 8, 10, 12, and 14 cm; and pulp logs with a length of 7.20 m. The technical analysis of the operation determined the average operating cycle times, utilization rate and machine productivity. In addition, a quality analysis determined the stem diameter limits for production of the co-products and the lengths of the pulp logs; the limit diameters were compared by the Tukey's test, and the stands by the Student's t-test ($\alpha \leq 0.05$). The results showed that the processing time decreased with increasing limit diameter, with the highest values being in stand 1 due to the higher number of branches and forked trees. The processing logs at 10 cm limit diameter provided higher harvester productivity, with 59.5 m^3 PMH^{-1} and 62.2 m^3 PMH^{-1} in stands 1 and 2, respectively. Furthermore, the best quality in the limit diameter measurement was obtained at 10 cm. Thus, the effects of forest stand and limit diameters on processing and operation quality were evident.

Keywords: Forest processor; Bioenergy; Wood harvesting.

PRODUTIVIDADE E QUALIDADE NO PROCESSAMENTO DE MADEIRA PARA ENERGIA

RESUMO – A otimização dos recursos é essencial para a excelência e competitividade de uma empresa florestal. Neste contexto, o estudo avaliou a produtividade e a qualidade do processamento da madeira de eucalipto para fins energéticos. Para isso, o estudo foi conduzido em uma empresa florestal no estado do Paraná, em povoamentos de clones de ***Eucalyptus urophylla*** *×* ***Eucalyptus grandis*** *e* ***Eucalyptus saligna*** *denominados povoamentos 1 e 2, respectivamente, com idade de 7 anos. O processamento das árvores com o harvester incluiu quatro limites de diâmetros do fuste para a produção de celulose e coprodutos para fins energéticos, sendo: 8, 10, 12, e 14 cm; e, toras para celulose com um comprimento de 7,20 m. A análise técnica da operação determinou os tempos médios do ciclo operacional, a taxa de utilização e a produtividade da máquina. Ao passo que, a análise de qualidade determinou os diâmetros limite do fuste para a produção dos coprodutos e os comprimentos das toras para celulose, sendo que, os diâmetros limite foram comparados pelo teste de Tukey e os povoamentos pelo teste t de Student ($\alpha \leq 0,05$). Os resultados mostraram que o tempo de processamento diminuiu com o aumento do diâmetro limite, com os valores mais elevados no povoamento 1, devido ao maior número de galhos e de árvores bifurcadas. As toras processadas no diâmetro limite de 10 cm*

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proporcionaram uma maior produtividade do harvester, com 59,5 m³ PMH⁻¹ e 62,2 m³ PMH⁻¹ nos povoamentos 1 e 2, respectivamente. Adicionalmente, a melhor qualidade na medição do diâmetro da ponta foi obtida a 10 cm. Portanto, os efeitos dos povoamentos florestais e dos diâmetros limite na qualidade de processamento e operação eram evidentes.

Palavras-Chave: Processador florestal; Bionergia; Colheita de madeira.

1. INTRODUCTION

The energy biomass obtained from wood harvesting operations is important for energy generation in large forestry sector companies in Brazil due to its renewable characteristics. This forest biomass comes from wood harvesting residues, and is composed of the final portion of the stem (tips), branches and bark, which is an organic material generated by photosynthesis (Pena-Vergara et al., 2022). Its use mitigates greenhouse gas emissions into the atmosphere through the release of neutral carbon during the combustion process (Moreira, 2011).

The use of biomass, also called co-products, is generally associated with multiple-use stands, in which logs of various assortments are obtained for industrial processes, and the residual biomass can be used for energy production (Oro et al., 2018). The full tree harvesting system is normally used in this situation, characterized by cutting the trees, followed by dragging them to the edges of the stands for final processing of the wood, and enabling a concentration of biomass for subsequent chipping (Spinelli et al., 2018). In addition, forestry processors are used to obtain logs with different assortments according to the needs of the consumer market (Malinovski et al., 2014).

However, errors in the harvester wood processing may occur in log measurement control (Nadolny et al., 2019; Mederski et al., 2018; Bembenek et al., 2015). These errors are due to the characteristics of the tools used to measure the tree stem at the head, of may cause loss of contact of the rollers and knives with the head with the tree due to the roughness of the bark, species, branch resistance and deformities in the stem shape (Silva et al., 2022).

Another variable which influences wood processing is the diameter limit for obtaining co-products. Many forest companies define 8 cm as the stem diameter limit in order to provide a larger volume of logs for the industrial process. However, the co-product quality can be compromised by providing a higher bark to wood ratio. This relationship can hinder the efficiency in the chipping process in the field and the energy parameters at the time of combustion, as well as the mass flow and drive torque of a biomass feeding system (Rackl and Günthner, 2016). Therefore, the variation in the diameter limit between pulp and co-products in the stem with the establishment of larger diameters can provide significant gains in the energy parameters at the time of combustion in the industry.

Changing the diameter limit to larger values reduces the number of logs destined for pulp production, and consequently can influence the productivity of wood processing machines. Therefore, performance studies and determination of quality tools are needed to help control and make decisions in operational planning. Several quality tools for forestry activities can be used, including histograms (Trindade et al., 2007). Histograms can be used in mechanized logging operations to arrange the data in graphical form and their distribution. Another efficient quality tool, but little known and applied in forest operations is the six sigma, which aims to improve production performance through analyzing process variability, emphasizing the concept of continuous improvement (Henderson and Evans, 2000).

Thus, due to the complexity of forest operations and the need to search for new alternatives to improve productivity and quality in processing eucalyptus wood for energy purposes, this study hypothesizes that increasing the diameter limit reduces the harvester productivity in processing due to the smaller volume of wood processed for pulp; in addition, it increases the quality of products and co-products due to the greater contact of the stem with the measuring tool. Therefore, this study aims to evaluate the effect of four stem diameter limits and two eucalyptus clonal stands on the operational cycle time, productivity and wood processing quality.

2. MATERIAL AND METHODS

2.1 *Characteristics of the study area*

This study was conducted in a wood harvesting operation belonging to a forestry company which has forest stands located in Paraná State, Brazil. The relief of the evaluated stands was classified as flat to gently undulating, with an average slope of 8%. The studied region presents an average annual temperature between 19 and 20 ºC, average annual precipitation between 1,400 and 1,600 mm, and a predominate climate between Cfa and Cfb according to the Köppen climate classification (Alvares et al., 2013).

The forest stands were composed of interspecific hybrid *Eucalyptus urophylla* S. T. Blake × *Eucalyptus grandis* W. Hill ex Maiden clones and *Eucalyptus saligna* Smith clones, both 7 years old, and a density of 1,111 trees per hectare (spacing 3.75 m × 2.40 m). The diameter at breast height (DBH) in the *E. urophylla* × *E. grandis* stand was 19.0 cm; the average tree height was 32.0 m; the dominant height was 34.2 m; and the average individual volume was 0.39 m. The DBH in the *E. Saligna* stand was 18.6 cm; the average tree height was 31.3 m; the dominant height was 34.2 m; and the average individual volume was 0.38 m.

2.2. *Harvester processor description*

Mechanized forest processing was performed by a harvester forest tractor equipped with a processing head. The harvester was a Doosan brand, model DX300, with 147 kW of power; machine operating weight of 29,300 kg; maximum crane reach at ground level of 10 m; and tracked wheels. The head was Waratah, model 622B, operating weight of 2,280 kg; maximum hydraulic pressure of 32 MPa; maximum delimbing opening of 650 mm; maximum feed roller opening of 730 mm; and maximum sawing capacity of 750 mm.

2.3. *Sampling procedure*

The minimum number of samples required for technical and quality analysis of the processor and wood quality was determined according to the methodology proposed by Murphy (2005) (Equation 1).

$$n = \frac{t^2 \times \mathrm{Var}\,(\mathrm{WCT})}{\left(E \times \frac{\overline{\mathrm{WCT}}}{100}\right)^2} \quad \text{(Eq. 1)}$$

In which: n is the number of work cycles, t is the t value, Var (WCT) is the variance of the work cycle time, E is the required level of accuracy (5%), and ($\overline{\mathrm{WCT}}$) is the average work cycle time (minutes).

2.4. *Technical processing analysis*

The processing of trees was evaluated with four stem diameter limits for pulpwood and co-product production for energy purposes, being: 8, 10, 12, and 14 cm, and the pulp logs were 7.20 m long. The harvester operating cycle in wood processing was divided into partial activities, and the times consumed in each phase were determined: Search and Picks (SP), time consumed by the machine to search and close the head by picking up a tree; Processing (PR), time consumed by the machine in processing the trees; Displacement (DI), time consumed by the machine in moving along the processing stack; and Interruptions (IN), time pertaining to machine stops for operational and non-operational reasons.

Utilization rate was calculated by the percentage of productive machine hours in relation to the total time scheduled for the operation (Ackerman et al., 2014). This calculation was performed with the grouping of data from the evaluated treatments because the observed times did not allow necessary observations of delays to verify the effect of treatments on utilization rate. Moreover, the productivity of the machine was determined in cubic meters of wood processed into logs with bark per productive machine hour from the average commercial volume obtained in the on-board computer of the machine.

2.5. *Processing quality analysis*

The quality was evaluated by determining the actual diameter limits of the co-products for energy use and the length of the processed logs for use in pulp production. To do so, a tree caliper was used after processing the trees to obtain the diameter limits of the co-product tips, and the treatments: 8 cm; 10 cm; 12 cm; and 14 cm were measured.

The length of the logs for pulp production was 7.20 m. However, with the application of the evaluated treatments, the length of the last log of the stem was affected, and could not reach the expected length. Therefore, for better use of the processed trees, it was accepted that the last log would be destined for pulp production when longer than 2.50 m, and otherwise it would be destined for energy purposes (co-products) due to the restrictions of the wood transportation vehicles. Therefore, a log length analysis was performed after tree processing to evaluate the influence of the length measuring error made by the harvester processor, as well as the influence of the utilization logs. The log length intended for pulp was obtained using a measuring tape.

2.6. *Quality tools used*

The quality of the diameter limit of the co-products and the lengths of the logs intended for pulp and co-product production were determined by the variation in the obtained measurements according to the non-compliant values. To do so, a comparison was made with the scheduled values and the error was calculated, in percent (Equation 2):

$$\text{Error }(\%)=\frac{Ns-Nn}{Ns}\times 100 \qquad \text{(Eq. 2)}$$

In which: Error is the error obtained (%); Ns is the number of samples that got the scheduled value; and Nn is the number of samples that did not get the scheduled value.

2.6.1. Six *Sigma*

The Six *Sigma* analysis refers to the evaluation of the hit and/or miss rate, and the values considered acceptable are those expected as a desirable standard with a variability of ± standard deviation from the mean of the data obtained. The values outside this range were considered non-compliant and determined the error rate, as previously presented. These rates were compared with the scale proposed by Trad and Maximiano (2009).

2.6.2. Histogram

The histogram is a tool which enables ordering the values of the co-product tips in graphic form, determining their distribution and being able to visualize their distribution. Thus, it was possible to infer the type of distribution of the evaluated population through the histogram shape. First, the range (R) of the co-products' diameter limits and the number of classes (K) were calculated using the Sturges equation to construct the histograms (Equation 3). Then, the size of the classes (h) was determined, obtained by dividing the amplitude (R) by the number of classes (K); next, the distribution of the classes was obtained and the frequency table was built, marking all the data. The histogram was subsequently constructed by placing the class intervals on the horizontal (x) axis and the relative frequencies of the data on the vertical (y) axis.

$$k= 1+3.3\log N \qquad \text{(Eq. 3)}$$

In which: K is the number of classes; and, logN is the logarithm of the amount of data.

The normal distribution curve of the histograms was plotted on the histograms, which was calculated using a mass density function made by the values of the ratio between the average of the values sampled for each treatment, the number of values collected, and the calculated increment (Equation 4):

$$\text{Value}=\text{Vmin}+n.\text{I} \qquad \text{(Eq. 4)}$$

In which: Vmin is the minimum value of the data; n is the sample number; and "I" is the increment.

2.7. *Statistical analysis*

The statistical analysis followed a Completely Randomized Design considering two forest stands in four diameter limit situations for the production of co-products. The limit diameters in the production of co-products were considered as treatments for the machine time study and the operational cycles as repetitions. The data were analyzed for normality by the Kolmogorov-Smirnov test and homogeneity of variance by the Bartlett's test, followed by ANOVA, and Tukey's test was applied at 5% significance level when necessary.

The means of machine productivity, diameter limit quality, and log length among species were evaluated by the Student's t-test, comparing them for each diameter limit treatment, considering each effective operational cycle of the machine, tips, and logs measured as repetitions, respectively.

3. RESULTS

3.1. *Technical analysis of the wood processing operation*

The wood processing with harvester was evaluated by 790 and 993 operating cycles in the eight situations evaluated (two stands and four diameter limits), with 356 and 644 meeting the minimum number required by the pilot study. It was verified in the time study that there was a reduction in the times consumed in the processing and in the total time of the operational cycle with the increase of the co-product diameter limit (Table 1).

Table 1 – Average values, in seconds, of the times consumed by the partial and total elements of the *harvester* processor operating cycle.
Tabela 1 *– Valores médios, em segundos, dos tempos consumidos pelos elementos parciais e totais do ciclo operacional do processador* ***harvester****.*

D Lim(cm)	*E. urophylla × E. grandis*				*E. saligna*			
	Effective times (s)							
	SP	PR	DI	TC	SP	PR	DI	TC
8	6 a	18 a	9 a	24 a	5 a	16 a	7 a	22 a
10	5 b	16 b	6 a	22 b	5 a	14 b	7 a	20 b
12	6ab	16bc	6 a	22bc	5 a	14bc	5 a	19bc
14	5 b	13 d	7 a	19 d	5 a	12 d	6 a	18 d
Average	**6**	**16**	**7**	**22**	**5**	**14**	**6**	**20**

In which: DLim is diameter limit; s is seconds; SP is search and pick; PR is processing; DI is displacement; TC is total cycle time; and means followed by the same letters in the column do not differ statistically by Tukey's test (p-value ≤ 0.05).
Em que: DLim é limite de diâmetro; s é segundos; SP é busca e pega; PR é processamento; DI é deslocamento; TC é tempo total do ciclo; e médias seguidas pelas mesmas letras na coluna não se diferem estatisticamente pelo teste de Tukey (p-valor ≤ 0,05).

The highest machine productivity was obtained at the diameter limit of 10 cm, being 59.5 and 66.2 m^3 PMH^{-1} in the *E. urophylla × E. grandis* and *E. saligna* stands, respectively (Table 2).

3.2.*Quality analysis of the wood processing operation*

For the quality analysis of the wood processing operation, it was found that the treatment whose co-product diameter limit came closest to the scheduled diameter was 10 cm in both species, reaching *Sigma* 3 (Table 3).

Table 2 – *Harvester* productivity in processing eucalyptus stands at the different diameter limits evaluated.
Tabela 2 *– Produtividade do* **harvester** *no processamento de povoamentos de eucaliptos nos diferentes diâmetros limites avaliados.*

DLim (cm)	*E. urophylla × E. grandis*		*E. saligna*		UR (%)
	Productivity (m^3 PMH^{-1})	ACV(m^3)	Productivity (m^3 PMH^{-1})	ACV(m^3)	
8	57.4*	0.38	65.2*	0.39	81.7
10	59.5*	0.36	66.2*	0.36	
12	57.9*	0.35	63.3*	0.34	
14	57.3*	0.30	54.7*	0.27	
Average	58.0	0.35	62.3	0.34	81.7

In which: DLim is the diameter limit; UR is the utilization rate; ACV is the average commercial volume per tree; and * significant at the 5% level by the Student's t-test (p-value ≤ 0.05).
*Em que: DLim é o limite de diâmetro; UR é a taxa de utilização; ACV é o volume comercial médio por árvore; e * significativo ao nível de 5% pelo teste t de Student (p-valor ≤ 0,05).*

The distributions of the diameter limit values of 8 and 10 cm were satisfactory, because they were close to the programmed values in both stands (Figures 1a and 1d). The distributions in the diameter limits of 12 and 14 cm showed higher frequency at values below the programmed ones (Figure 1e to 1h).

In relation to quality of log lengths, it is possible to observe the average values for the length of the processed logs by treatment in both stands evaluated (Table 4). The average values for the lengths of logs processed in the studied stands show that the overall average for *E. urophylla × E. grandis* was 6.50 m, with an error of 8.4%, while the average log length for *E. saligna* was 6.92 m with an error of 2.6%, with a statistically significant difference at the 5% level by the Student's t-test.

Table 3 – Average values of the diameter limits of the co-products.
Tabela 3 *– Valores médios dos diâmetros limite dos co-produtos.*

D Lim (cm)	*E. urophylla × E. grandis*			*E. saligna*		
	$\bar{D}$ (cm)	Error (%)	*Sigma*	$\bar{D}$ (cm)	Error (%)	*Sigma*
8	7.9^{ns} (±1,2)	1.0	3	7.9^{ns} (±1,1)	1.5	3
10	9.9^{*} (±1,0)	0.4	3	9.7* (±0,1)	2.8	3
12	11.3^{ns} (±0,9)	5.9	2	11.3^{ns} (±1,2)	5.9	2
14	13.7^{ns} (±1,1)	2.0	2	13.7^{ns} (±1,5)	2.5	3

In which: DLim is the diameter limit; $\bar{D}$ is the average diameter; * significant at the 5% level by the Student's t-test (p-value ≤ 0.05); and ns not significant (p-value > 0.05) between stands.
*Em que: DLim é o limite do diâmetro; é o diâmetro médio; * significativo ao nível de 5% pelo teste t de Student (valor p ≤ 0,05); e ns não significativo (valor p > 0,05) entre os povoamentos.*

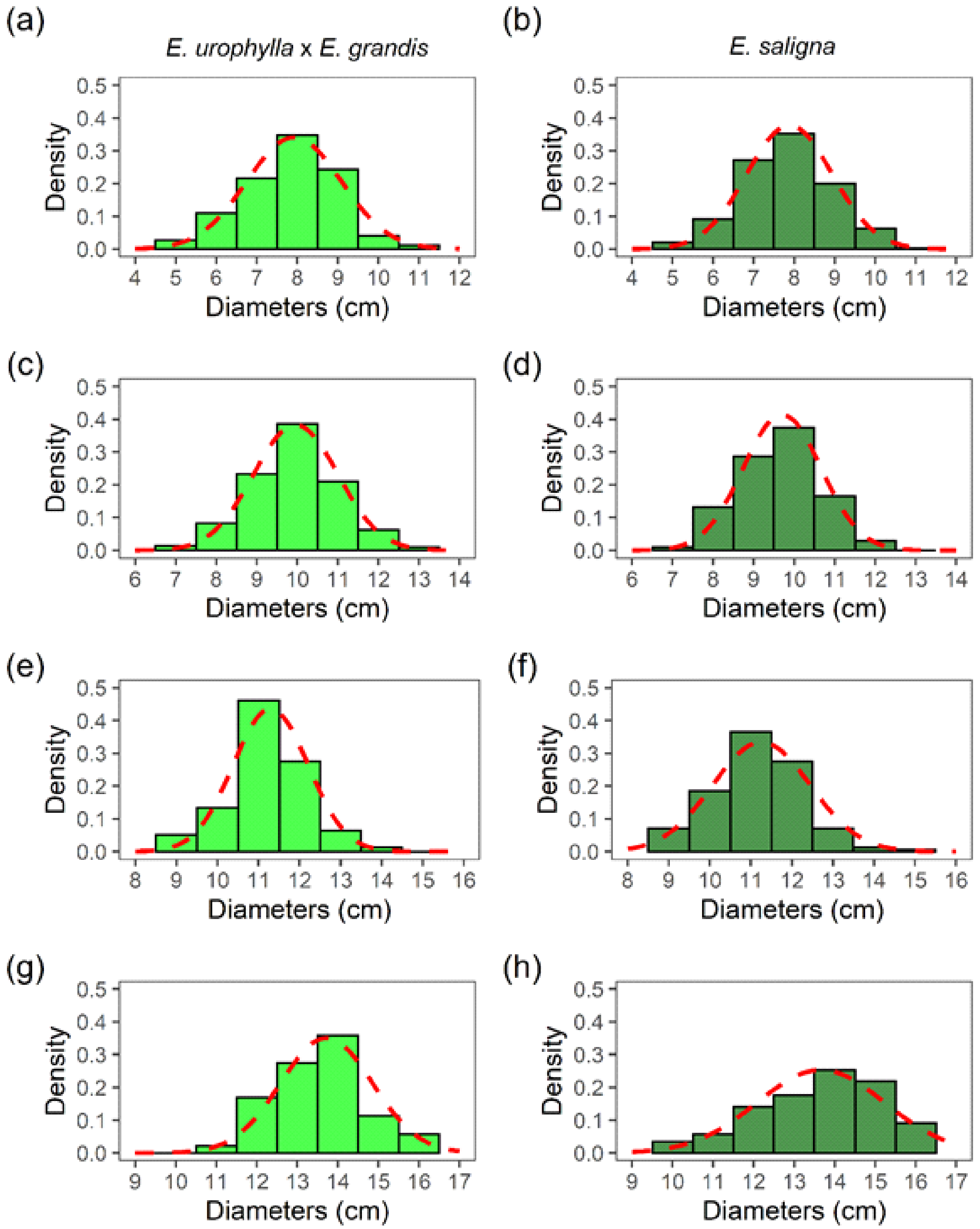

Figure 1 – Distribution of co-product diameter limit classes; a and b) 8 cm; c and d) 10 cm; e and f) 12 cm; g and h) 14 cm; and dashed red line refers to the normal distribution curve.

Figura 1 *– Distribuição das classes de diâmetro limite de co-produtos; a e b) 8 cm; c e d) 10 cm; e e f) 12 cm; e g e h) 14 cm; e linha vermelha tracejada refere-se a curva de distribuição normal.*

Table 4 – Average values for processed log lengths.
Tabela 4 *– Valores médios dos comprimentos das toras processadas.*

Scheduled length (m)	DLim (cm)	*E. urophylla* × *E. grandis*		*E. saligna*	
		Length (m)	Error (%)	Length (m)	Error (%)
	8	6.27* (±0.31)	11.7	7.06* (±0.12)	0.6
7.20	10	6.40* (±0.59)	9.8	6.92* (±0.24)	2.6
	12	6.62ns (±0.47)	6.8	6.79ns (±0.55)	4.3
	14	6.72* (±0.40)	5.4	6.91* (±0.27)	2.7
Average		**6.50 (±0.44)**	**8.4**	**6.92 (±0.30)**	**2.6**

In which: DLim is the diameter limit; ± is the standard deviation; * significant at the 5% level by the Student's t-test (p-value ≤ 0.05); and ns not significant (p-value > 0.05).

*Em que: DLim é o limite do diâmetro; ± é o desvio padrão; * significativo no nível de 5% pelo teste t de Student (valor p ≤ 0,05); e ns não significativo (valor p > 0.05).*

4. DISCUSSION

The total time consumed in the processing activity decreased with the increase in the diameter limit and the only treatments which did not present a statistically significant difference between them were the 10 and 12 cm diameter limits in both studied stands (Table 1). The partial activity that influenced the total time was wood processing; this was expected due to the reduction of wood destined for pulp, as this was the element which consumed the longest time of the operational cycle since it involved simultaneous execution of delimbing and timber tracing activities, and was also influenced by the wood volume processed, the presence of branches in the stem, and length of the processed logs, as already verified by other studies (Diniz et al., 2018; Drinko et al., 2015).

Regarding the effect of the forest stand in treatments with the same diameter limit, the harvester showed higher productivity in processing *E. saligna* trees, justified by the lower presence of branches and forks when compared to the *E. urophylla* × *E. grandis* trees; this situation compromises the performance of the machine in performing the operation. Therefore, it was evident that the greater the presence of branches and forks in the trees, as visually observed during data collection, the greater the effort demanded from the harvesting head when delimbing the stem. This influence of forked trees is due to the need for individual processing of the trees, consuming more time, and consequently reducing the productive capacity of the machine (Diniz et al., 2020).

The average diameters measured in all treatments in both stands were below the value scheduled in the on-board computer of the machine. However, the values are very close to the established goals, and the error of 5% was only exceeded in either stand in the treatment where the diameter limit of the co-product was 12 cm. This may be related to the diameter location on the stem, such as the base of the crown or the presence of thick branches, as visually observed during data collection. Burla (2001) reports that errors in mechanized operations should remain below 5%. Considering the sigma scale, it can be stated that the best quality in processing the stem occurred in diameters between 8 and 10 cm, in both stands studied.

The data population distribution can be inferred from the histogram shape. This distribution should have the highest frequency in the diameter values scheduled on the on-board computer of the machine (i.e. 8, 10, 12 and 14 cm). However, this did not happen in the treatment with a diameter limit of 12 cm, agreeing with the results obtained through the error percentage and the sigma scale of this treatment, where the error was approximately 6% for both *E. urophylla* × *E. grandis* and *E. saligna* stands, respectively.

The results obtained in the quality evaluation were considered satisfactory, the search for operational improvements should be continuous, and constant attention from the operator is required in making measurements on the diameters processed during the work shift, calibration and daily maintenance of the machine and processing head. After all, the operational measure for improving the accuracy of the diameter limit value is the operator's constant visual care combined with frequent calibration of the head, and only then will it be possible to maintain and/or improve the quality standard of the operation.

The diameter limit treatment of 8 cm in the *E. saligna* stand showed the mean value closest to the desired log length (7.20 m), with the smallest error (0.6%). The diameter limit treatment of 8 cm in the

E. urophylla × *E. grandis* stand showed the value furthest from the expected value, with an average of 6.27 m. This is explained by the characteristics of the forest stand, especially in relation to the greater number of branches and forked trees in the forest canopy, as these characteristics impair the head tools in the correct measurement of the processed logs.

As there was great utilization of the stem at the diameter limit of 8 cm, the non-conformity can be attributed to the fact that the location where the last log was cut was often in the middle of forks. Therefore, it was necessary to cut the stem before the fork and the rest was destined to the co-product. This problem could be mitigated by increasing the value of the coproduct's diameter limit, as the cut is located lower in the stem, thus avoiding forking. In addition, the assortment performed during the evaluation was exclusively for pulp production, and the limiting length was 7.20 m. This length is used to optimize the cargo box of the transport vehicles. Another limiting factor for the length is the space between the stanchions of the transport vehicle, therefore the minimum accepted value is 2.50 m, which influenced the average log length.

The results show that the logs from the *E. saligna* stand were the closest to the desired length, and also presented the smallest percentage error. The closer the length value is to 7.20 m, the more favorable the log extraction, loading, and final transport operations will be, since the cargo box of the transport vehicles will be better used. Additionally, studies state that the length of the wood influences the times consumed by transport vehicles, especially in loading and unloading productivity (Lopes et al., 2016).

5.CONCLUSIONS

The operational cycle time of the harvester in the wood process decreased with the increase in the diameter limit of trees for use as co-products for biomass, but with consequent reduction of wood volume for pulp and increase of the biomass destined for energy purposes. The forest stands influenced machine productivity in the wood process due to the variation in the number of branches and forked trees; in addition, productivity decreased as the diameter limit increased.

The length of the processed logs was within the acceptable limit according to the parameters stipulated by the forest company; however, the values obtained in processing the *E. saligna* stand came close to the scheduled values.

The machine productivity and the wood processing quality were higher at the 10 cm stem diameter limit, with this value being recommended to be adopted by the company in operational terms, as it presents a balance between the amount of material destined for pulp and for energy biomass.

AUTHOR CONTRIBUTIONS

Conceptualization of research: Prates E, Lopes ES, Rodrigues CK, Silva DA; Execution of the the experimental tests: Prates E, Rodrigues CK, Silva MKC; Statistical analysis: Prates E, Rodrigues CK, Silva MKC; Analysis of results: Prates E, Rodrigues CK; Writingreview & editing: Prates E, Lopes ES, Rodrigues CK, Silva DA; Supervision and coordination of research: Lopes ES, Silva DA.

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