HARVESTER PRODUCTIVITY AND COSTS IN CLEAR CUTTING *Pinus taeda* STANDS UNDER DIFFERENT MANAGEMENT REGIMES

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Resumo

Produtividade e custos do harvester no corte raso de povoamentos Pinus taeda sob diferentes regimes de manejo. O aumento da demanda por diversos produtos florestais torna necessária a aplicação de diferentes regimes de manejo nos povoamentos, podendo influenciar as operações de colheita de madeira. Este estudo teve como objetivo avaliar o efeito dos volumes médios individuais das árvores obtidos através de diferentes regimes de manejo, na produtividade e no custo de um harvester, possibilitando a geração de informações para os gestores florestais. O estudo foi conduzido em três povoamentos de *Pinus taeda* L. em operação de corte raso, com diferentes volumes médios individuais das árvores (AIV): I (0,367 m^3); II (0,582 m^3); e III (0,766 m^3). Os tempos dos ciclos de trabalho, a produtividade por hora produtiva da máquina, o rendimento energético e os custos de produção e foram obtidos por meio de um estudo de tempos e movimentos. As atividades dos ciclos de trabalho do harvester foram afetadas pelos regimes de manejo florestal, principalmente os elementos parciais de deslocamento e processamento, com diferença estatística significativa entre os povoamentos, porém sem diferença entre os tempos totais dos ciclos de trabalho. Os valores médios obtidos foram comparados pelo teste de Tukey-Kramer ($\alpha \leq 0,05$). O regime de manejo aplicado aos povoamentos florestais influenciou o espaçamento e o volume do tronco, o que consequentemente aumentou a produtividade média da máquina de 36,8 para 74,1 m³ por hora produtiva da máquina nos tratamentos I e III, respectivamente, e reduziu 50% os custos de produção. Portanto, os regimes de manejo florestal aplicados influenciaram a operação de corte raso com harvester.

Palavras-chave: Volume médio individual, planejamento, colheita de madeira.

Abstract

The increased demand for several forest products makes it necessary to apply different management regimes in forest stands, which may influence the wood harvesting operations. This study aimed to evaluate the effect of average individual tree volumes obtained through different management regimes on harvester productivity and costs, thereby enabling to generate information for forest managers. The study was carried out in three *Pinus taeda* L. stands under clear cutting with different average individual tree volumes (AIV): I (0.367 m^3); II (0.582 m^3); and III (0.766 m^3). Working cycle times, productivity per productive machine hour, energy yield and production costs were obtained by a time and motion study, in which the average values obtained were compared by the Tukey-Kramer test ($\alpha \leq 0.05$). The work elements of the harvester's work cycles were affected by forest management regimes, mainly the movement and the processing, with significant statistical difference between stands, but no difference between total working cycle times. The management regime applied to forest stands influenced the spacing and whole trunk volume which consequently increased the average productivity of the machine from 36.8 to 74.1 m³ per productive machine hour in treatments I and III, respectively, and reduced production costs by 50%. The forest management regimes influenced the clear-cutting operation with harvester.

Keywords: Individual average volume, planning, wood harvesting.

INTRODUCTION

Planted forests cover approximately 9 million hectares in Brazil, with emphasis on the *Pinus* sp. genus. This corresponds to 1.64 million hectares planted in the country, with the largest representation in Paraná (44% of its planted area) and Santa Catarina States (26%) (IBÁ, 2020). Brazil is in a privileged location in the world, with the best soil and climate conditions for forest production, presenting mild temperatures and no water deficit (DOBNER JÚNIOR; CAMPOE, 2019). These conditions accordingly result in one of the highest growth rates in the world for the pine genus, with an average annual increment of 30 m³ per hectare per year (OLIVEIRA *et al.*, 2018).

The *Pinus* genus presents high quality wood and serves as raw material for various industrial segments in the form of veneer logs, sawn logs, pulpwood and firewood (KOHLER *et al.*, 2014). These products supply both domestic and foreign markets, and this genre has been increasingly studied over the years for the production of many higher added value products such as veneer logs and sawn logs. Thus, it is necessary to apply some silvicultural treatments such as pruning and thinning to guarantee quality wood production without the presence of knag in wood and trees with higher volumetric yield (PEZZUTTI *et al.*, 2016).

Thinning in forest plantations has the objective to increase the spacing of the remaining trees, providing trees with higher average individual whole trunk volume when compared to those which did not have the same management regime (without thinning) (ELESBÃO; SCHNEIDER, 2011). This variation in tree volume has a direct influence on wood harvesting operations, especially when applied to clear cutting; however, these studies are limited to spacing in the initial planting conduct and in forest stands with increment variations related to the site index (RODRIGUES *et al.*, 2019).

Many studies have shown that harvesting operations with the harvester in a cut-to-length system is directly influenced by tree spacing and volume (MARTINS *et al.*, 2009; LEITE *et al.*, 2014). However, studies are needed to evaluate new machine technologies, as well as in various wood harvesting situations in forest stands that have received different management regimes on clearcutting operations, as thinning increases the distance between trees and the average individual volume of the trees.

The hypothesis that a harvester used in the forest harvesting operations presents higher productivity and lower costs in stands with higher average individual tree volumes obtained through different management regimes, even with higher spacing between trees was investigated in this study. Therefore, this study aimed to evaluate the effect of average individual tree volume obtained through different management regimes on the work elements, productivity and cost of a harvester, enabling to generate information for forest managers.

MATERIAL AND METHODS

This study was carried in forest company, located in Paraná State, Brazil. Thus, three *Pinus taeda* L. stands under different management regimes were evaluated in the experiment (Table 1), being defined as three treatments. Pulpwood, veneer log, and sawn log products were possible to be obtained from these forest stands (Table 2).

Table 1. Characteristics of *Pinus taeda* stands.
Tabela1. Características dos povoamentos de *Pinus taeda.*

Characteristics	**Stands**		
	I	**II**	**III**
Thinning	None	None	Two[1]
Individual average volume of wholes stem (m^3)	0.367	0.582	0.766
Initial spacing (m × m)	3.0 × 1.5	3.0 × 3.0	2.5 × 2.0
Cutting age (years)	15	16	17
Basal area (m^2 ha^{-1})	57.9	47.5	27.6
Trees number (n ha^{-1})	1,450	789	367
Average diameter at breast height (cm)	22.3	27.2	30.8
Average height (m)	20.1	21.8	22.3
Volume (m^3 ha^{-1})	531.7	458.9	280.7
Topographic slope (%)	10.0	14.0	5.5

Legend: [1] thinning at 11 years-old through geometric removal in the fifth row of trees and selective removal in the adjacent ones, totaling the removal of 50% of the initial individuals, followed by selective thinning at 14 years-old, with removal of 50% of the remaining individuals.

Table 2. Log assortment specifications.
Tabela 2. Especificações dos sortimentos de toras.

Assortments	**Length (m)**	**Minimum diameter over bark (cm)**	**Maximum diameter over bark (cm)**
Pulpwood 1	2.40	8.0	13.0
Pulpwood 2	2.65	13.1	18.0
Veneer log 1	2.65	18.1	23.0
Veneer log 2	3.20	23.1	33.0
Sawn log	2.65	33.1	-

A Ponsse Scorpion King harvester was studied (Figure 1), and the same technical configuration was used in all treatments. The harvester head was a Ponsse model H7, weighing 1,150 kg, with three feed rollers, four delimbing knives, and a maximum opening of 0.65 m. The accumulated amount of machine hours was 1,800 hours. This machine performed a tree-cutting operation with four rows of trees in treatments I and II, while treatment III consisted of three rows of trees, as one row had already been removed during the first thinning. Moreover, an operator with 20 years of experience was observed in the three treatments, being evaluated in a shift from 7h00am to 4h48pm.

Figure 1. Harvester (left) and head (right).
Figura 1. Harvester (esquerda) e cabeçote processador (direita).

A time study was applied to evaluate the harvester using a stop watch recording the accuracy in seconds, in which the minimum number of required working cycles was determined by a pilot study calculated by equation (1) proposed by Murphy (2005):

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

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

The following work elements were considered for the harvester: searching and cutting (time between the movement of machine's arm and head for searching a tree and separating it from the stump); processing (time between delimbing, bucking, debarking, and stacking of logs); and movement (machine's movement time between trees).

Mechanical delay represented the percentage of mechanical delay hours in scheduled machine hours (smh), and the utilization rate (%) considered the percentage of productive machine hours in relation to the scheduled machine hours, being calculated according to Spinelli and Visser (2008). The calculations of these variables were performed with all the data grouped, meaning without distinction between evaluated treatments due to the length of study in each treatment which was considered short to calculate separately, and not considering that the treatments could affect these variables. Harvester productivity (P_{PMH}) free-delay was subsequently calculated according to the equation proposed by Ackerman *et al.* (2014), which was calculated for each treatment.

Fuel consumption expresses the fuel consumed per unit of the machine's nominal power and was obtained multiplying the fuel density (g L^{-1}) considering 853 g L^{-1} for diesel fuel (PETROBRÁS, 2019) with the hourly consumption obtained from the company's history over the last six months (L PMH^{-1}), dividing by its nominal power of machine (kW). Then, energy yield (EY) was obtained by the ratio between the specific fuel consumption and the mean machine productivity, as proposed by United Nations Economic Commission for Europe (UNECE, 2007).

Operating costs were obtained by the accounting method using actual and estimated values, in which the total cost was defined as the sum of fixed, variable, and administrative costs (Table 3). Fixed costs (depreciation, interest, insurance, and surveillance) were determined the methodology adapted by Miyata (1980) with commercial data. Variable costs (fuels, lubricants, grease, hydraulic oil, tires, maintenance, repairs, and cutting equipment), as well as personnel costs (salary and social charges of the personnel), were calculated based on data provided by the forest company. The production cost was obtained by the ratio between operating costs and machine productivity using the methods of Spinelli and Magagnotti (2010).

Table 3. Harvester costs evaluated in the *Pinus taeda* stands.
Tabela 3. Custos do harvester avaliado nos povoamentos de *Pinus taeda*.

Investment cost (USD)	591,549.30
Economic life (years)	5
Utilization rate (%)	71.5
Annual utilization (PMH)	2,149.63
Salvage value (USD)	98,591.55
Fuel consumption (L PMH^{-1})	10.20
Fuel price (USD L^{-1})	0.43
Lubricant (% of fuel cost)	10
Labor cost (USD PMH^{-1})	6.88
Crew (n)	1
Fixed cost	
Depreciation (USD $year^{-1}$)	98,591.55
Interest (USD $year^{-1}$)	394,366.20
Tax (%)	12
Insurance and tax (USD $year^{-1}$)	9,464.79
Yearly fixed cost (USD $year^{-1}$)	108,056.34
Hourly fixed cost (USD PMH^{-1})	50.27
Variable cost	
Fuel (USD PMH^{-1})	1.32
Lubricant (USD PMH^{-1})	1.57
Repair and maintenance (USD PMH^{-1})	1.54
Tires (USD PMH^{-1})	3.87
Saber and chain (USD PMH^{-1})	0.92
Personnel (USD PMH^{-1})	6.88
Hourly variable cost (USD PMH^{-1})	16.10
Operating cost (USD PMH^{-1})	66.37
Administrative costs (%)	20.00
Administrative costs (USD PMH^{-1})	13.27
Total operating cost (USD PMH^{-1})	79.64

In which: Cost in dollars (USD) as of Jan 30, 2020: 1 USD = R$ 4.26 BRL.

Work elements and total time of work cycles, productivity, energy yield, and production costs were compared in different treatments studied (forest stands under different management regimes), with the values obtained in each working cycle being considered as repetitions. To do so, several normality tests such as Anderson-Darling, Kolmogorov Smirnov, Shapiro-Wilk and Ryan-Joiner ($\alpha = 0.05$) were applied, as well as in transformed data. Therefore, the Kruskal-Wallis non-parametric test ($\alpha = 0.05$) was applied for variance analysis, followed by Tukey-Kramer ($\alpha = 0.05$) for comparing the means.

RESULTS

A total of 1,633 working cycles were measured in treatment I, 787 in II and 1,054 III, and the study indicated a respective need for 577, 404 and 998 working cycles to meet the limit of permissible error of 5%. Therefore, the accuracy level obtained was 3%.

The processing work element consumed the longest harvester working cycle time, ranging from 59% to 65% in treatments I and II, followed by searching and cutting, and lastly by movement (Figure 2). All work elements showed a statistically significant difference between evaluated treatments (Table 4), since trees presented different spatial distribution according to the management regime adopted, and different assortments were generated due to variation in average individual whole trunk volumes. However, average total working cycle times were similar in all treatments, as variations in work elements contributed to similar times.

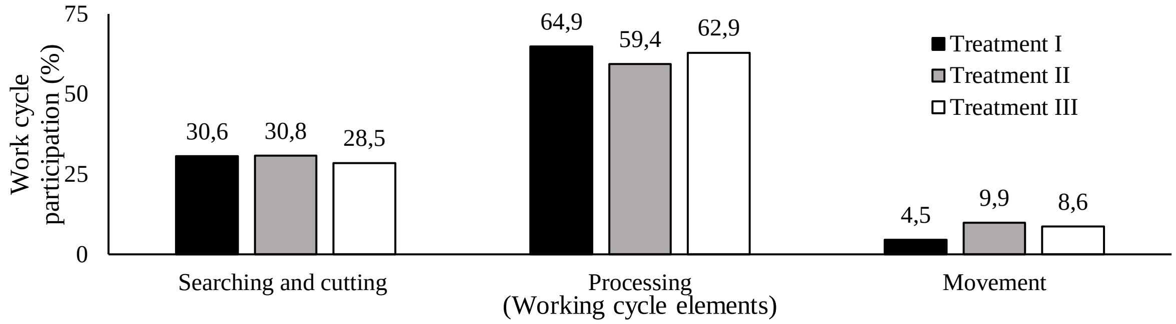

Figure 2. Participation of working cycle elements when cutting *Pinus taeda* stands.
Figura 2. Participação dos elementos do ciclo de trabalho no corte de povoamentos de *Pinus taeda.*

Table 4. Average times of working cycle elements in treatments I, II and III.
Tabela 4. Tempos médios dos elementos parciais dos ciclos de trabalho nos tratamentos I, II e III.

Treatments	**Work cycle elements (seconds)**			
	Searching and cutting	**Processing**	**Movement**	**Total**
I	13.0 a	27.7 a	1.9 a	42.6 a
II	13.4 a	25.8 b	4.3 b	43.5 a
III	11.8 b	26.0 ab	3.6 b	41.4 a
Average	**12.7**	**26.5**	**3.3**	**42.5**

Legend: Values followed by the same letter in columns do not differ statistically by the Tukey-Kramer test ($\alpha \leq 0.05$).

The mechanical delays corresponded to 12.8% scheduled machine hours, and the machine utilization rate was 71.5%. It was verified that the productivity per productive machine hour free-delay increased with the increase in the average individual tree volume, with a significant statistical difference (Figure 3). In addition, the energy yield showed an inverse relationship, representing 2.42 g kW^{-1} m^{-3} in treatment I, 1.55 g kW^{-1} m^{-3} in treatment II, and 1.12 g kW^{-1} m^{-3} in treatment III.

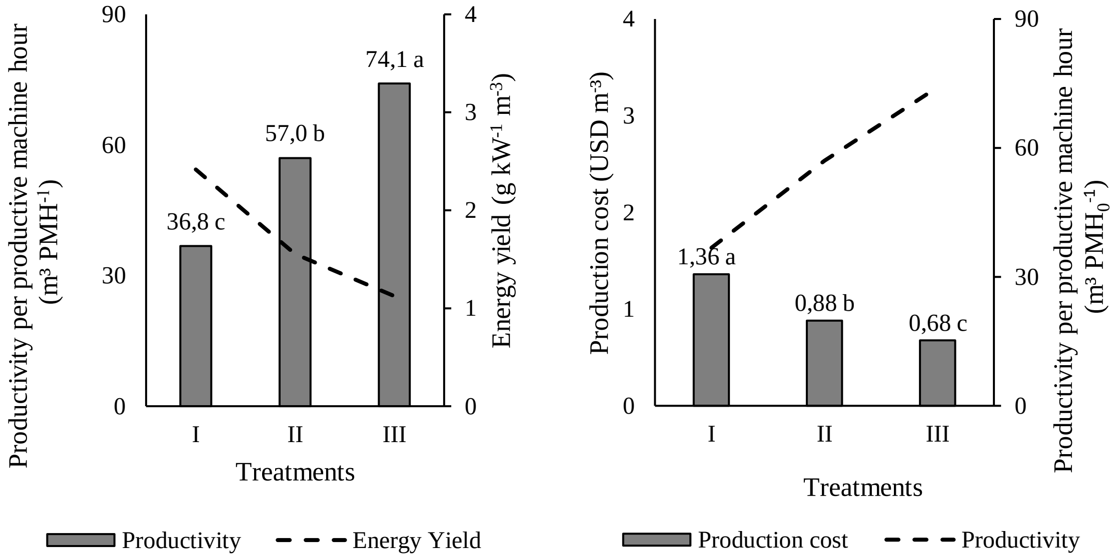

Figure 3. Productivity per productive machine hour and energy yield (left); Harvester productivity and costs in treatments I, II and III (right). Averages followed by distinct letters differ statistically by the Tukey-Kramer test ($\alpha \leq 0.05$).

Figura 3. Produtividade por hora produtiva da máquina e rendimento energético (esquerda); e Produtividade e custos do harvester nos tratamentos I, II e III (direita). As médias seguidas de letras distintas diferem estatisticamente pelo teste Tukey-Kramer ($\alpha \leq 0.05$).

The harvester's operating cost was USD 79.64 per productive machine hour, being represented by 57% of fixed, 28% by variable, 8% by administration and 7% by personnel costs (Figure 4). Machine depreciation (including the implement) corresponded to 37% of the final value among the fixed cost variables, while fuel represented 16%. Maintenance had a 3% representation, as the machine's useful life was only 1,800 hours.

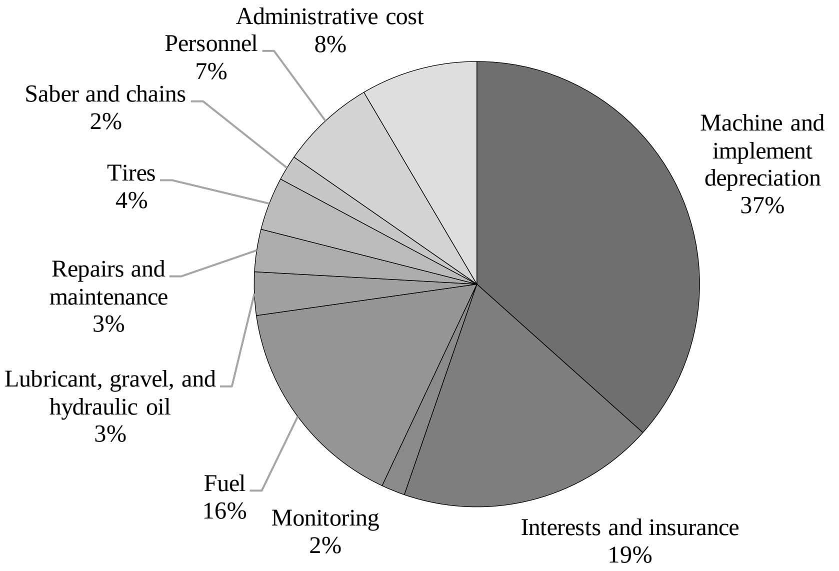

Figure 4. Percentage share of harvester operating costs.
Figura 4. Participação percentual dos custos operacionais do harvester.

The production costs decreased with the increase in the average individual tree volume, being USD 1.36 m^{-3} in treatment I and USD 0.68 m^{-3} in treatment III, meaning that the increase in the average individual tree volume from 0.367 m³ to 0.767 m³ led to a reduction of approximately 50% in production costs (Figure 3). Thus, there was a great influence of the management regimes in the clearcutting harvesting operation.

DISCUSSION

The most representative element in all harvester working cycles was "processing" since the machine spent most of its time processing, with the influence of the average individual whole trunk volume on the times consumed, followed by the search and cut work elements, and then movement, with a significant statistical difference between treatments I, II and III. However, the great amplitude between the times consumed in the movement work element stands out due to the different management regimes which generated variations in the spacing between individuals, and required a greater need for machine movement.

Treatment I showed greater time consumed in organizing the log stacks during the processing. This was due to treatment I providing thinner logs, which led the need to perform quality control more frequently, and constituting one of the reasons for the low machine utilization rate. Therefore, it is known that logs with smaller diameters lead to greater errors during the measurements performed by the tools and sensors present in a harvester's processor head (MEDERSKI *et al.*, 2018; NADOLNY *et al.*, 2019).

The topographic slope influenced the values obtained in the "movement" work element because the terrain presented a slope of 5.5% in treatment III, which presented a statistical difference from treatments I and II, which presented slopes of 10 and 14%. Thus, it is believed that not only the average individual volume had an effect on the operational performance of the machine, but the terrain slope was also another variable of influence. This influence of topographic slope was also described by Gomes *et al.* (2018) when evaluating a Ponsse Beaver model harvester with an H6 head in 15-year-old *Pinus taeda* stands under clearcutting.

It was observed that there was no significant statistical difference between the treatments regarding the total time. This time was around 41 seconds, being superior to other studies such as that by Simões *et al.* (2010), who found an average total time between 18 and 20 seconds in studying a harvester in *Eucalyptus grandis* stands. This difference was caused by the need to generate multi-products (Table 2), with a high time being consumed in separating the logs in the various assortments produced. Moreover, although the time consumed in the work cycles was similar in all three treatments, the average volume influenced productivity and production costs the most. Thus, it was evident that the harvester used in the forest harvesting operation presents higher productivity and lower costs in stands with highest individual average whole trunk volumes obtained through different management regimes, even with increasing distances in spacing between trees.

The harvester's average productivity varied between 36.8 and 74.1 m³ per productive machine hour in treatments I and III, respectively, confirming the effect of tree volume on machine productivity, with greater evidence in the processing element. Therefore, although the total work cycle times were the same (Table 4), the productivity increased as a function of the average individual volume. This productivity may be related to the innovative characteristics of the machine in terms of visibility, comfort, mobility and operator safety. These benefits are designed through the crane located on the cab, as well as the leveling system that facilitates executing activities, allowing the harvester to maintain high productivity.

Delays were caused by the time consumed by fuel supply, followed by calibration, due to the need of the support vehicle to attend more than one farm, as well as the lack of knowledge by the operator to perform the calibration, which needed supervision support. Thus, a need for logistic planning of the convoy vehicle and recycling operator training to calibrate the machine stands out (LOPES *et al.*, 2008; DINIZ *et al.*, 2017).

The machine utilization rate was 71.5%, being similar to the results obtained by Seixas and Batista (2014) who obtained a maximum utilization rate of 71% in studying different harvester machines. According to the authors, this low utilization rate has great potential for improvement after remedying the main causes of delays through reducing the waiting time for supplying and training operators to calibrate the machine and store log stacks.

The values obtained for the energy yield (Table 5) are below the values described in the literature, such as in the study conducted by Simões *et al.* (2010), who obtained an energy yield between 4.48 and 4.91 g kW^{-1} m^{-3} for a machine with 103 kW of power. This can be explained by the high power of the harvester studied (210 kW), and the average fuel consumption (18.5 L PMH^{-1}).

Operating costs were directly impacted by machine and implement depreciation, followed by interest and insurance (Figure 4). This representation is due to the high acquisition value of the machine and implement, being different from other studies such as that performed by Santos *et al*. (2016) in a hydraulic excavator adapted with a with a Ponsse head model H7, which had a higher percentage share of repairs and maintenance and fuel. This shows the influence of the low number of accumulated hours of the evaluated machine.

As a result of the machine's productivity values in the evaluated treatments and low maintenance of the machine (Figure 5), it was found that there was a 50% reduction in production costs between treatment I and III when the AIV went from 0.367 m^3 to 0.766 m^3. Therefore, this study evidences that AIV is an important variable to be considered when planning timber harvesting in planted forests.

CONCLUSIONS

- The work elements of the harvester's work cycle were affected by the forest management regimes, mainly movement and processing, but no difference between total working cycle times occurred;
- The topographic slope influenced the movement work element and may have contributed to the productivity and cost values of the machine in the cutting execution, and is also an operational variable to be considered in planning;
- The harvester's productivity and production costs were influenced by the management regimes applied to the forest stands, and consequently by the average individual whole trunk volume, being an important variable to be considered when planning wood harvesting in planted forests;
- According to the applied forestry management, the evaluated treatments doubled the productive capacity of the machine and reduced operating costs by half when the AIV went from 0.367 m^3 to 0.766 m^3.

REFERENCES

ACKERMAN, P.; GLEASURE, E.; ACKERMAN, S.; SHUTTLEWORTH, B. **Standards for time studies for the South African forest industry**. 2014. Disponível em: <http://www.forestproductivity.co.za/?page_id=678> Acesso em: 17 mar. 2021.

DINIZ, C. C.; LOPES, E. S.; MIRANDA, G. M.; KOEHLER, H. S. Manutenção preventiva como determinante para redução de custos de manutenção de um feller buncher. **Biofix Scientific Journal**, Curitiba, v. 2, n. 2, p. 43–47, 2017.

DOBNER JÚNIOR, M.; CAMPOE, O. C. Meteorological effects on 30-years-grown *Pinus taeda* under a gradient of crown thinning intensities in southern Brazil. **Forest Ecology and Management**, v. 453, p. 117624, 2019.

ELESBÃO, L. E. G.; SCHNEIDER, P. R. Produção do *Pinus taeda* L. em povoamento desbastado na região dos Campos de Cima da Serra, Rio Grande do Sul. **Ciência Florestal**, Santa Maria, v. 21, n. 1, p. 119–124, 2011.

GOMES, C. A. F. C.; PALUDETO, J. G. Z.; PORTELA, R. M.; MARCOLIN, G. Influência da declividade na produtividade e altura de tocos no corte de *Pinus taeda* L. por harvester. **Revista Técnico-Científica**, v. 13, p. 1–13, 2018.

INDÚSTRIA BRASILEIRA DE ÁRVORES – IBÁ. **Sumário Executivo 2019**. 2020. Disponível em: <https://iba.org/datafiles/publicacoes/relatorios/relatorio-iba-2020.pdf> Acesso em 30 mar. 2021.

KOHLER, S. V.; WOLFF II, N. I.; FIGUEIREDO FILHO, A.; ARCE, J. E. Dynamic of assortment of *Pinus taeda* L. plantation in different site classes in Southern Brazil. **Scientia Forestalis**, Piracicaba, v. 42, n. 103, p. 403–410, 2014.

LEITE, E. S.; MINETTE, L. J.; FERNANDES, H. C.; SOUZA, A. P.; AMARAL, E. J.; LACERDA, E. G. Desempenho do harvester na colheita de eucalipto em diferentes espaçamentos e declividades. **Revista Árvore**, Viçosa, v. 38, n. 1, p. 1–8, 2014.

LOPES, E. S.; CRUZINIANI, E.; ARAUJO, A. J.; SILVA, P. C. Avaliação do treinamento de operadores de harvester com uso de simulador de realidade virtual. **Revista Árvore**, Viçosa, v. 32, n. 2, p.291–298, 2008.

MARTINS, R. J.; SEIXAS, F.; STAPE, J. L. Avaliação técnica e econômica de um harvester trabalhando em diferentes condições de espaçamento e arranjo de plantio em povoamento de eucalipto. **Scientia Forestalis**, Piracicaba, v. 37, n. 83, p. 253–263, 2009.

MEDERSKI, P. S. MARIUSZ, B.; ZBIGNIEW, K.; ZENON, P.; AGNIESZKA, Ł. Investigation of log length accuracy and harvester efficiency in processing of oak trees. **Croatian Journal of Forest Engineering**, Zagreb, v. 39, n. 2, p. 173–181, 2018.

MIYATA, E. S. **Determining fixed and operating costs of logging equipment**. St. Paul: USDA Forest Service. (General Technical Report, NC-55). 1980. 16 p.

MURPHY, G. Determining sample size for harvesting cost estimation. **New Zealand Journal of Forestry Science**, v. 35, n. 2/3, p. 166–169, 2005.

NADOLNY, A.; BERUDE, L. C.; LOPES, E. S. FIEDLER, N. C.; RODRIGUES, C. K. Qualidade na operação de corte florestal em povoamentos submetidos a dois modelos de desbaste mecanizado. **Pesquisa Florestal Brasileira**, Colombo, v. 39, e201801689, p. 1–7, 2019.

OLIVEIRA, R. K.; HIGA, A. R.; SILVA, L. D.; SILVA, I. C.; GONÇALVES, M. D. P. M. Emergy-based sustainability assessment of a loblolly pine (*Pinus taeda*) production system in southern Brazil. **Ecological Indicators**, v. 93, p. 481–489, 2018.

PETROBRÁS. **Ficha de Informação de Segurança para Produtos Químicos (FISPQ) BR0140, versão 10: Produto: Óleo Diesel B S10 Adit**. Petrobras Grid. Cidade Nova, Rio de Janeiro, 2019.

PEZZUTTI, R. V.; FLEIG, F. D.; FINGER, C. A. G.; SCHNEIDER, P. R. Estudo e modelagem do crescimento em diâmetro de povoamentos de *Pinus taeda* L. submetidos a podas e desbastes na Argentina. **Ciência Florestal**, Santa Maria, v. 26, n. 4, p. 1225–1237, 2016.

RODRIGUES, C. K.; LOPES, E. S.; PEREIRA, A. L. N.; SAMPIETRO, J. A. Effect of individual tree volume on operational performance of harvester processor. **Floresta**, Curitiba, v. 49, n. 2, p. 345–354, 2019.

SANTOS, D. W. F. N.; VALENTE, D. S. M.; FERNANDES, H. C.; FORASTIERE, P. R.; SILVA, R. M. F. Análise técnica e econômica do harvester operando em dois subsistemas de colheita de madeira. **Revista Engenharia na Agricultura**, Viçosa, v. 24, n. 6, v. 484–490, 2016.

SEIXAS, F.; BATISTA, J. L. F. Comparação técnica e econômica entre harvesters de pneus e com máquina base de esteiras. **Ciência Florestal**, Santa Maria, v. 24, n. 1, p. 185–191, 2014.

SIMÕES, D.; FENNER, P. T.; ESPERANCINI, M. S. T. Avaliação técnica e econômica da colheita de florestas de eucalipto com harvester. **Scientia Forestalis**, Piracicaba, v. 38, n. 88, p. 611–618, 2010.

SPINELLI, R.; MAGAGNOTTI, N. Performance and cost of a new mini-forwarder for use in thinning operations. **Journal of Forest Research**, v. 15, p. 358–364, 2010.

SPINELLI, R.; VISSER, R. Analyzing and Estimating Delays in Harvester Operations. **International Journal of Forest Engineering**, v. 19, n. 1, p. 36–41, 2008.

UNECE - UNITED NATIONS ECONOMIC COMMISSION FOR EUROPE. 63rd session: **Fuel consumption for vehicle powered refrigeration units based on a conception of standard vehicle engine**. INF.3. Geneva, Switzerland: UNECE, 2007.