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VOLUMETRIC AND ECONOMIC LOSSES IN THE MECHANIZED FOREST HARVEST OF *PINUS TAEDA*L

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ABSTRACT

The objective of this paper was to quantify the volumetric and economic losses after clearcutting interventions in the mechanized forest harvest of *Pinus taeda* L. The study was carried out in a forest company in which the harvesting system of short logs is used in the mechanized modules. Different assortments were analyzed considering the dimensions and price marketed. The volume of the logs left in the field after the intervention was measured with Smalian method. The downgrade coefficients were determined for each assortment by dividing the percentage of the real volume by the assortment and the percentage of volume estimated by the assortment, and the economic losses generated. It was verified that the percentage of logs in the WPP assortment represented approximately half of the losses, followed by the PV01 assortment. The greatest losses in volume occurred in PV01 assortment and in monetary terms it occurred in the PV02 assortment.

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INTRODUCTION

The forestry sector has a respectable representation in the national economy, included in this branch the wood processing companies that work with pulp and paper, reconstituted wood panels, charcoal-fired steelworks and industrial timber, laminating and lumber (Indústria Brasileira de Árvores 2017). It is important to highlight that Brazilian forests have great economic potential, since the sector presents a better performance in terms of production, employment, income and tax collection when compared to other important economic sectors, such as transportation, commerce and miscellaneous services (Sousa *et al.* 2010). The ServiçoFlorestalBrasileiro – SFB (Brazilian Forestry Service) estimates that the forestry sector is responsible for 3.5% of Brazil's Gross Domestic Product (GDP of 2007), which is equivalent to US$ 37.3 billion and for 7.3% of the country's total exports, which is equivalent to US$ 10.3 billion, with the pulp sector accounting for US$ 4 billion, the lumber, plywood and high value wood products sector for US$ 2.9 billion, the furniture sector for US$ 1.05 billion and the coal-firedpig iron for US$ 1.65 billion. The area occupied by native forests in Brazil represents approximately 485.8 million hectares and 10 million hectares of planted forests, in a total of 4 985000 square kilometers, equivalent to 58% of the total area of the country (8 516 000 km²) (Serviço Florestal Brasileiro 2018). In assets driven to meet multiproducts (laminating, sawmill and pulp), there is great importance in measuring assortments, since market values are different. Besides measuring the assortments, there is the search for greater profitability of the investment with the optimization of the trees in logs, that will attend the different demands of the market. For the decision-making in the forestry sector, in addition to the quantitative and qualitative information, Serpe *et al.* (2018) points out a fact that is sometimes ignored, the losses caused by the harvesting activity, which may be higher or lower depending on the quality of the stand and the performed operations. The volume of losses or of waste, in the forest harvest, is the difference between the potential volume to be removed and the real volume removed (Serpe *et al.* 2018). The waste can be associated with cutting, dragging and the log yard operations (Barreto *et al.* 1998). Stroher *et al.* (2014) in a Harvester

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mechanized forest harvesting study on *Pinus taeda* L. plantations, identified wastes of approximately 4.57tha^{-1} in stump height and out of specification pre-bucking. The main forms of wood loss during the forest harvesting process, pointed are: high stumps, tree bole tip below a given pre-established diameter, logs which are lost, forgotten or unduly left in the field, and sawdust generated by the felling of the tree and it is sectioning in logs. According to the foregoing, it is evident that the volume of woody material left in the field during the harvest stage represents an operational problem and significant losses, so that knowledge of the yield and operational losses are necessary. Therefore, the objective of this study is to quantify the volumetric and economic losses after the mechanized clearcutting harvest of *Pinus taeda* L.

MATERIAL AND METHODS

Data source: This study was carried out on a farm belonging to a forest company located in the Santa Catarina State plateau, in the south region of Brazil. The most prominent soil is the Nitosol (NitossoloHáplico), the average altitude of the region from the sea level is of 950m and the annual rainfall ranges from 1300 to 2400mm. In the evaluated area, 4 to 6 thinnings are usually performed, followed by the clearcutting. Besides these interventions, pruning was carried out in the stands to obtain high quality wood without the presence of nodes. The situation after the clearcutting activities was evaluated in order to quantify the losses of wood left in the stands. The dendrometric characteristics of the stands are shown in Table 1, below.

Table 1. Dendrometric characteristics of the stands of Pinus taeda L. destined to clearcutting

Dendrometriccharacteristics	
Species	*Pinus taeda* L.
Stand age (years)	34
Total area (ha)	174.5
Plantation spacing (m)	2,0 x 3,0
Mediumdiameterat DBH (cm)	45.8
Mediumheight (m)	34.8
Individual medium volume (m³)	2.5
Expected production in the intervention (m³/ha)	582.3
Declivity (º)	5 - 10/ 10 - 15
Density removed in the intervention (N/ha)	233

Source: Analyzed Forest Company, 2018.

Table 2. Classification of the multiple uses from the forests of Pinus taeda L.

Assortment	Diameter (cm)		Length (m)	Wood Price w/ bark (R$ t)	Possibledestinations
	Inferior	Superior			
WPP	8	18	2.7	40.00	Energy
PV01	18	25	2.7	119.00	Cellulose
PV02	25	35	2.7	197.00	Sawmill
PV04	35	42	2.7	270.00	Veneer

Source: Analyzed Forest Company, 2018

According to the forest organization's productive process, there is a range of multiple uses of wood from its forests. For this work, the assortments comprising logs free of nodes "PV" (*Pinus* veneer) and "WPP" (wood for *Pinus* processes) were analyzed. The wood products available for commercialization, considering the wood loaded with "PV" logs and logs in the "WPP" stand, were determined according to the company's classification (Table 2).

Characterization of mechanized forestry harvesting operations: The harvesting system of short logs used in the mechanized modules, is composed by a Harvester, a Forwarder and a mechanical loader. For this study, the evaluation was performed in a mechanized harvesting module. The technical specifications of the cutting, processing and bucket machines used in harvesting are shown in Table 3.

Data collection and processing: In order to survey the information in the clearcutting operation, a pilot sampling was carried out with 10 sampling units, adopting the fixed area method and the random sampling process, with an area of 400 m^2 and a quadrangular shape (20m x 20m). Thus, the diameter of the "thin point" and the "thick point" and the length of the logs found inside the sample units were collected. For better interpretation of the results obtained, a descriptive statistical analysis was performed. Subsequently, the definitive sample (number of plots) was defined as a function of the total volume (m^3) for each plot, using the Equation 1, recommended bySanquetta *et al.* (2006) for an infinite population:

$$n = \frac{t^2 * CV\%^2}{E\%^2} \qquad \text{..........................(1)}$$

In which: n - number of plots required; t - tabled value of t for significance level of 95%; CV - coefficient of variation (%); E - maximum permissible error (10%).

Determination of volumes: The measurement of wood volume for quantification of the losses was taken using a dendrometric caliper and a diameter tape. Then, the Smalian method (Finger 1992)was used. This method is widely used in the forest environment and indicated for logs that have a paraboloid trunk shape.

Thus, it was determined the volume in cubic meters of each section of wood left in the field after the operations in the area ended. The volume is obtained by the product of its length and the arithmetic mean of the extremity areas gi an gs, according to Equation 2.

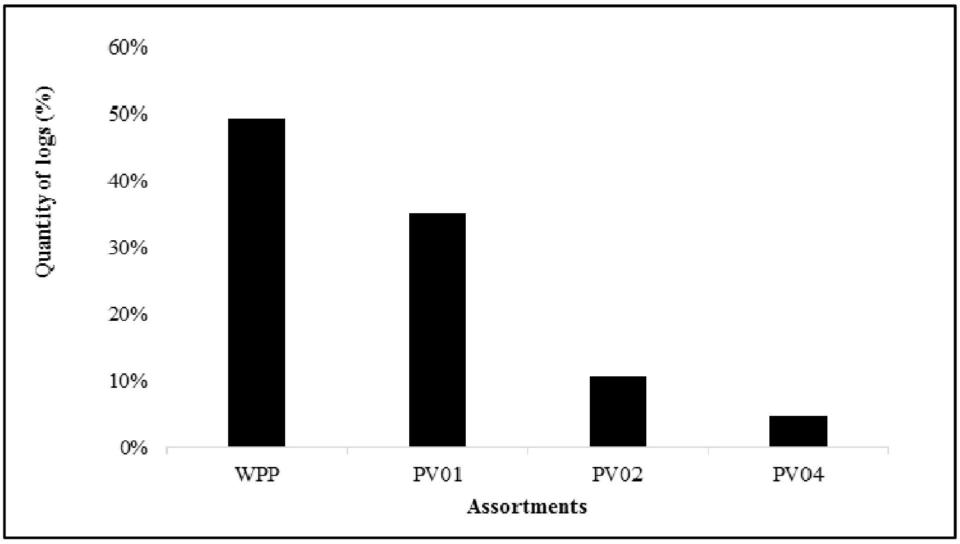
$$Vi = \frac{gi + gs}{2} * L \qquad \text{…………...(2)}$$

In which: Vi - volume of the log (m^3); gi and gs - areas of the lower and upper extremities (m^2); L - Length of the log (m). Subsequently, the volume was transformed into mass and quantified, due to the pricing of multiple uses occurs in tonnes.

Table 3. Description of the machines used in the mechanized forest harvesting modules

TechnicalSpecifications	Machine
Harvester John Deere 909MH;HeadHTH 624C (1WA624CXLF0000345)	
John Deere Forwarder 1910E 8x8	
John Deere Forwarder 1910E 6x6	

Source: Analyzed Forest Company, 2018.



Graph 1. Quantity of logs (%) found in the stand for the different assortments. PV: Pinus veneer; WPP: Wood for Pinus process

For this, the conversion factor of 0.956 was used for the genus "*Pinus* with bark" and the quantification of losses by assortments in tonnes per hectare (t ha^{-1}) and monetary value per hectare (R$ ha^{-1}) was obtained.

Downgrade of assortments and economic losses: Estimates of assortments in wood piles after clearcutting interventions do not take into account the losses occurred in the process. Despite the strict planning of the mechanized forest harvesting, the downgrade of assortments may be due to mechanical factors, because of the imprecision of the process heads that can generate log diameter and length errors, due to lack of operator experience, declivity, changes in harvesting modules, among others. The coefficients for the assortments were measured by dividing the percentage of the real volume by assortment and percentage of volume estimated by assortment. To survey the estimated volume, it was used the stacking factor of 1.65, proposed by Nunes and Soares (2017) for forest stands of 2.0 x 3.0m spacing.

Thus, the coefficient was obtained according to the equation adapted from [6].

$$\text{Dgs} = \frac{\%\text{VR}}{\%\text{VE}} \quad \text{................(3)}$$

In which: Dgs = downgrade coefficient for assortment; %VR = Percentage of real volume per assortment; and %VE = Percentage of estimated volume per assortment. Subsequently, the economic losses generated by the downgrade of assortments were calculated by multiplying the estimated volumes and real volumes by assortment, by the prices of the wood practiced by the company and once againthe volumes were transformed in mass and quantified, because the pricing occurs in tonnes.

RESULTS AND DISCUSSION

Volumetric and economic losses

The calculation of sample intensity with 10 pilot sampling units resulted in the application of 28 plots. The log diameters found after clearcutting interventions were of 8 cm for the minimum diameter, 40 cm for the maximum and 19.7 cm of mean diameter. Thus, the quantity of logs left in the field in the different assortments corroborates the percentage of volumetric losses generated by the forest harvest, according to Graph 1. The percentage of logs in the WPP assortment accounted for approximately half of the losses (49.0%), followed by the PV01 assortment with (35.0%). In this context, losses that occur in the different assortments show nonconformities and the lack of investments in controlling measures during the processes.

The losses occur due to failures within the production process and are directly related to investments in quality factors. For Barreto *et al.* (1998), the waste can be associated with cutting, felling, dragging and operations on the yards. In addition, one of the relevant factors to the losses is the harvesting module that has recently been reformulated by the company, leading to the need for greater employee training. Another important factor for the efficiency of operations is the terrain declivity. In agreement with Simões and Fenner (2010)who evaluated the eucalyptus harvest with a mechanical forest Harvester, they concluded that the declivity of the terrain was one of the main factors that influenced in the operational income and that the productivity decreased with the increase on the percentage of terrain inclination.

Comparing this research that uses mechanized harvesting with the research of Pereira *et al.* (2012) for semi-mechanized harvesting, it was observed that, independently of the forest harvesting system, the lack of monitoring and planning of the activities can lead to volumetric losses and, consequently, financial losses for any company. In this context, among other papers found in the literature that address the reasons that lead to losses in the various assortments of the forest harvest, we highlight: Akay *et al.* (2004) andRosa and Oliveira (2014). By measuring the logs left in the field, it has been verified that the wood losses occurred more expressively in the assortments (PV02 e PV04), mainly in the node-free wood logs, representing reductions in production and revenue (Table 4).

Table 4. Quantification of assortments in tonnes per hectare (t ha^{-1}) and monetary value per hectare (R$ ha^{-1}) for each assortment. PV: Pinus veneer; WPP: wood for pine processing

Assortment	t ha^{-1}	R$ ha^{-1}
WPP	3.29	131.6
PV01	4.07	484.3
PV02	4.38	862.9
PV04	1.93	521.1
Total	13.67	1 999.9

In relation to the volume, the largest losses occurred in the PV01 assortment, with 4.07 t ha^{-1}. In monetary terms the largest losses occurred in the PV02 assortment, representing 862.9 R$ ha^{-1}. These results represent the internal failures by the forestry Company under study, indicating nonconformities in relation to it is planning process. Vatraz and Borges (2014) evaluated losses in the *Pinus* spp harvest in the municipality of Doutor Ulysses, located in the State of Paraná - Brazil, with losses of 43.12 m³ ha-1. Previously, Ferreira *et al.* (1995) when evaluating the harvest losses of wood in a commercial forest, verified losses of 8.1 st ha^{-1}, representing economically a loss of R$ 659 545 60 for the total area of the company.

Assortments Downgrade: From the determination of the downgrade of assortments in forest stands of *Pinus taeda* L. of 34 years in a management that includes thinnings, the conversion coefficients by assortment should be considered (Table 5), obtaining information closer to the marketable volumes, from the minimum diameters of use established for each type of assortment. The assortments with bark of each class of assortments, verified in the company's planning, can be multiplied by downgrade coefficients.

Table 5. Downgrade coefficients for assortments

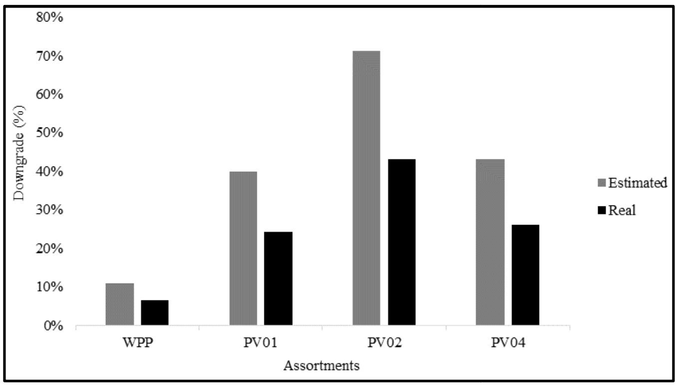
Assortments	% assortments		*Downgrade*
	Real	Estimated	
WPP	24.06	39.71	0.6060
PV01	29.74	49.06	0.6061
PV02	32.04	52.87	0.6061
PV04	14.15	23.38	0.6053

It was verified that all evaluated assortments had a downgrade from the estimated to the real numbers. Ferreira *et al.* (1995), when evaluating the harvest losses of wood in commercial/ industrial forest, verified that 62.9% of the non-transported logs could be used in the pulp industry; 37.10% of the total number of logs found had a diameter greater than 14 cm, which would allow its use for other purposes. Vatraz and Borges (2014) recorded a percentage of 6.68% in relation to the commercial volume harvested and the estimated volume when evaluating losses in *Pinus* spp. in the municipality of Doutor Ulysses – State of Paraná – Brazil. The economic effects considering the downgrade of assortments after the clearcutting operations are presented in Table 6.

Table 6. Economic effects of losses by downgrade of Assortments

Assortments	Gross Revenue (R$ ha^{-1})		*Downgrade* (R$ ha^{-1})
	Real	Estimated	
WPP	154.40	254.80	100.40
PV01	567.63	936.53	368.90
PV02	1 012.58	1 670.56	657.98
PV04	612.90	1 012.50	399.60
Total	2 347.51	3 874.39	1 526.88

The assortments downgrade directly impacted the revenue of all assortments, representing a gross revenue of 1 526 88 R\$ ha^{-1}. Graph 2 shows the economic difference (%) among estimated and Real revenue for the different assortments. The PV02 assortment showed the largest reduction among revenues, declining from 71.0% to 43.0% followed by the PV04 assortment, declining from 43.0% to 26.0%. These results points to operational problems during the harvest stage, since they were more representative in the assortments with higher added value, representing wood free of nodes. According to Serpe*et al.* (2018), when evaluating the coefficients for assortments of logs originated from mixed plantations of *Pinus elliottii* Engelm and *Pinus taeda* L., it has been verified that the downgrade of assortments directly impacted the income of the "Sawmill 1" which presented a reduction of 15.67%. With the reclassification, the gross revenue decreased by 1 300 95 R\$ ha^{-1} (5.41%).



Graph 2. Economic difference (%) among the estimated and the real revenue for the different assortments

Fiedler *et al.* (2013) previously analyzed the operations performed by the semi-mechanized method in eucalyptus plantations in flat and undulated terrain in the eastern part of the State of Minas Gerais - Brazil and verified that 20.42% of the analyzed logs in the flat terrain and 35.80% in the undulated areas presented nonconformities with the company's determined standard. Hébert *et al.* (2016) evaluated the effect of tree spacing on tree growth volume, morphology and wood properties in a 25-year *Pinus banksiana* plantation located in the boreal forest of Quebec, and pointed out that the number and size of the nodes might cause a downgrade, reclassifying the quality characteristics of the wood destined to civil construction. In their research, Mccurdy *et al.* (2005) measured the development of color in *Pinus radiata* plaques during the drying process and found that the nonconformities of the coloring decrease the value of the products, triggering a downgrade in which the final product is reclassified. In view of the above, the use of methods to maximize the production of multiple uses of forest products is evident, positively contributing to the optimization of raw materials and the reduction of losses (Arce *et al.* 2004).

Conclusions

All the four evaluated assortments presented losses, especially WPP and PV01, which represented the majority of the losses. In relation to volume, the largest losses occurred in the PV01 assortment and in monetary terms it occurred in the PV02 assortment, which represents internal failures by the forest Company in their node free wood assortments. In the estimation of the coefficients, all evaluated assortments had a downgrade from the estimated to the real, impacting directly on its gross revenue, with emphasis on the PV02 assortment that presented the highest percentage of the economic difference from the estimated to the real revenue. Therefore, the reduction of the wood loss can be achieved with corrective and preventive actions of the activities. It is recommended the use of quality tools in order to minimize the losses and to apply the downgrade coefficients of assortments to attenuate the differences between the estimated volume and the marketable volume by assortment.

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