DAMAGE CAUSED TO THE REMAINING TREES OF A *PINUS* STAND SUBMITTED TO TWO MECHANIZED THINNING MODELS

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Abstract

The objective of this study was to evaluate the damage to remaining trees of pine stand submitted to two models of mechanized thinning. Data were collected in the wood harvesting areas of a forest company in Southern Brazil during the first commercial thinning with 10-year-old trees. The thinning was executed by a harvester in cutting the trees and a forwarder in extracting the logs, which was defined by thinning in the 5th planting line (treatment T_1); and by a chainsaw in felling the central trees, by a harvester in cutting the other lines, and by a forwarder in extracting the logs in the experimental area defined by thinning in the 7th planting line (treatment T_2). The damage to remaining trees in the stand in relation to the dimensions and location of the machinery operating trail was evaluated, and data were analyzed through descriptive statistics. The results showed that treatment T_2 caused greater damage in the remaining trees due to greater handling of felled and processed trees and a higher concentration of wood piles in the operating trail of the machines. In addition, there was greater contact of the harvester with the remaining trees when searching for the trees felled by the chainsaw was conducted to perform the final processing. Treatment T_1 proved to be more suitable for thinning pine stands.
Keywords: Timber harvesting, quality, commercial thinning.

Resumo

Danos nas árvores remanescentes de um povoamento de pinus submetido a dois modelos de desbaste mecanizado. O objetivo deste trabalho foi avaliar os danos causados nas árvores remanescentes de um povoamento de pinus submetido a dois modelos de desbaste mecanizado. Os dados foram coletados nas áreas de colheita da madeira de uma empresa florestal na região sul do Brasil durante o primeiro desbaste comercial com 10 anos de idade. O desbaste foi executado por um *harvester* no corte das árvores e por um *forwarder* na extração das toras, definido pelo desbaste na 5ª linha de plantio (tratamento T_1); e por uma motosserra na derrubada das árvores centrais, por um *harvester* no corte das demais linhas e por um *forwarder* na extração das toras na área experimental definida pelo desbaste na 7ª linha de plantio (tratamento T_2). Foram avaliados os danos causados nas árvores remanescentes do povoamento em relação às dimensões e localização na trilha de operação das máquinas, e os dados foram analisados por meio da estatística descritiva. Os resultados mostraram que o tratamento T_2 ocasionou maiores danos nas árvores do povoamento remanescente, ocasionado pelo maior manuseio de árvores derrubadas e processadas e maior concentração de pilhas de madeira na trilha de operação das máquinas. Além disso, houve maior contato do *harvester* com as árvores remanescentes no momento da busca das árvores derrubadas anteriormente pela motosserra para realização do processamento final. O tratamento T_1 utilizado pela empresa mostrou ser mais adequado para aplicação do desbaste de povoamentos de pinus.
Palavras-chave: Colheita de madeira, qualidade, desbaste comercial

INTRODUCTION

In Brazil, pine forest plantations can be managed through commercial thinning, with the first one usually being carried out between 8 and 10 years, the second between 12 and 14 years, and the final cut of the trees between 15 and 18 years. This silvicultural treatment is of great importance for managing planted forests, since it allows adding more individual volume and better quality and diversity of wood uses in the remaining trees due to less competition for water, light and nutrients (RIBEIRO *et al*., 2002; SCHNEIDER; SCHNEIDER, 2008).

However, when the thinning is mechanized, it becomes technically complex and has high costs due to the greater difficulty of the machines' mobility inside the forest caused by the restricted spaces, which can lead to low productivity and high production costs (SPINELLI; NATI, 2009; LOPES *et al*., 2016). In addition, several factors can impact the mechanized thinning method, such as: extraction distance, operator experience, individual volume, terrain declivity, species characteristics, spacing, the products and the cutting lines (OLIVEIRA *et al.*, 2009; BURLA *et al*., 2012; SEIXAS; BATISTA, 2014; BARBOSA *et al*., 2015). The traffic of the machines inside the stands subjected to thinning can also cause negative impacts such as loss of productive area, soil compaction and damage to the remaining trees (VASILIAUSKAS, 2001; LINEROS *et al*., 2003).

Wood harvesting in stands subjected to thinning is usually carried out by implementing the cut-to-length system, with a harvester in the felling and processing of the trees, and a forwarder for extracting the wood from the stand's interior to the roadside or to an intermediate stockyard. In most Brazilian forest companies, the implemented thinning model is characterized by the systematic removal of the 5th line of the plantation, thereby enabling machine access inside the stand, followed by the selective removal of trees in the lines adjacent to the traffic trails.

Although there is a great variety of machines available on the market that can perform thinning, damage caused to remaining trees is still common, occurring in a direct physical way (mechanical), and later indirectly. Depending on the intensity, this damage can jeopardize forest plantation growth. In addition, the extent and severity of damage to remaining trees can lead to qualitative and sanitary problems to the wood, as tree lesions can be attacked by fungi, affecting the wood/tree quality and causing significant economic losses (LINEROS *et al*., 2003; RIBEIRO *et al*., 2002).

In a study conducted in Sweden, Fröding (1992) found that wood harvesting machines affected an average of 5.9% of the remaining trees of a stand during thinning, with the greatest damage occurring in the region of the trunk close to the ground. In studying the impacts caused by a harvester and forwarder on commercial *pinus* thinning in Chile, Lineros *et al*. (2003) observed that 12.3% of the remaining trees in the stand were damaged, especially the codominant individuals, who presented injuries in the crown and lower sections by removing branches.

Therefore, performing mechanized thinning can cause significant mechanical damage to the remaining trees of a forest stand, necessitating the search for new models that allow gains in productivity allied with reducing possible damage and better value added to the wood.

The objective of this study was to evaluate the damage caused to the remaining trees of a *Pinus taeda* L. stand submitted to two mechanized thinning models, and to generate information that contributes to planning operations for the better use of wood resources and forest production sustainability.

MATERIAL AND METHODS

This study was carried out in a *Pinus taeda* L. stand submitted to its first commercial thinning, belonging to a forest company located in the state of Paraná (25° 26' 27" S, 52° 55' 17" W). The climate of the study region is classified as subtropical humid mesothermic (Köppen-Geiger), with average temperature between 18 and 22 ºC and average altitude of 604 m. Information on the studied stand is presented in Table 1.

Table 1. General information about the forest stand studied.
Tabela 1. Informações gerais do povoamento florestal estudado.

General Information	Value
Planted species	*Pinus taeda*
Stand age (years)	10
Stand area (ha)	16.3
Spacing (m)	3 x 2
Declivity (degrees)	10
Density (tree/ha)	1.666
Mean volume ($m^3 \cdot ha^{-1}$)	291.4
Mean height (m)	17.4

Mean diameter (cm)	20.5
Percentage of removed trees (%)	50
Removed wood volume ($m^3 \cdot ha^{-1}$)	145.7

This study considered two thinning models (treatments), as shown in Figure 1. Treatment T1 was applied in the experimental area characterized by removing the 5th line of the plantation in a systematic way and selectively removal pre-determined individuals in the two lines adjacent to the traffic trails of the machines, totaling a 50% removal of trees from the stand. This thinning model used by the company was executed by a harvester for felling and processing the trees and by a forwarder in extracting the logs.

Treatment T2 was applied in the experimental area characterized by removing the 7th planting line in a systematic way and selective removal of the three adjacent lines to the traffic trails of the machines, also totaling the removal of 50% of the trees. Due to the harvester being unable to reach the trees arranged in the two central cutting lines, these trees were initially felled using a chainsaw, followed by processing with the harvester. Then, the harvester itself cut the other trees determined by the systematic and selective thinning, after which the logs were extracted using the forwarder.

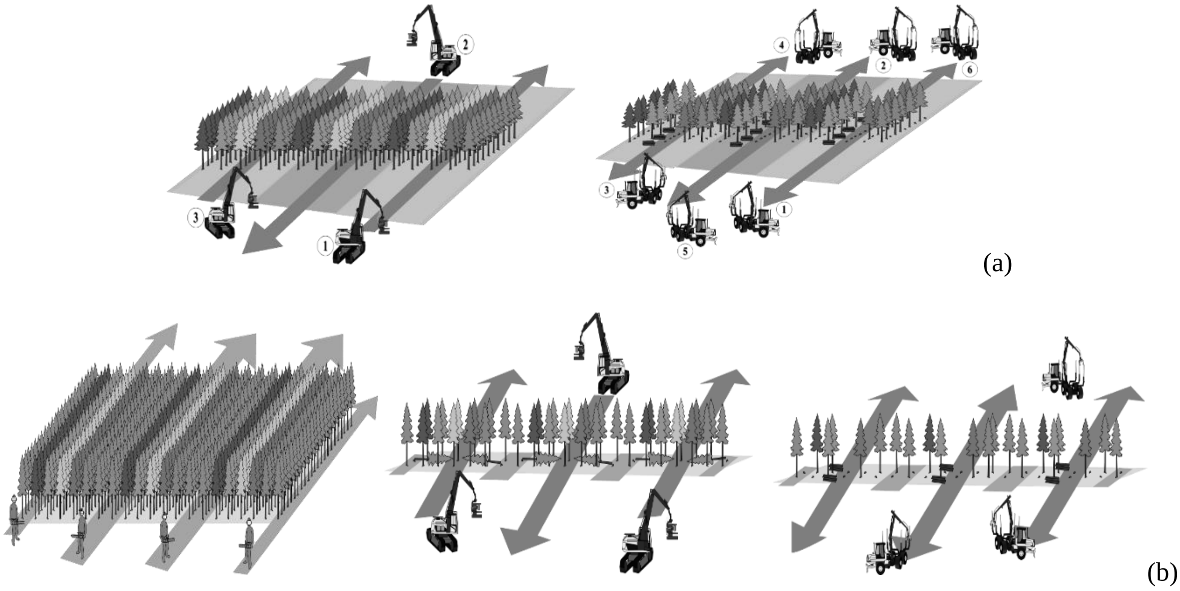


Figure 1. Execution scheme of the thinning models: (a) model 1; (b) model 2.
Figura 1. Esquema da execução dos modelos de desbaste: (a) modelo 1; (b) modelo 2.

The harvester studied had track wheels, with an engine power of 86 kW, operating weight of 17,280 kg, maximum crane reach of 7.2 m and equipped with a cutting head with a maximum opening of 515 mm. The forwarder had tire wheels, with a power output of 130 kW, an operating weight of 16,329 kg, a load capacity of 13,608 kg and a maximum reach of 6.9 m. Finally, the chainsaw had a weight of 6.6 kg and motor power of 3.9 kW.

In the experimental study areas, six sample plots of 15 x 42 m were installed in thinning model 1 (T1), and six plots of 21 x 30 m in thinning model 2 (T2), in order to maintain the same sample area (630 m²) and to contemplate the spacing variations of the machine operating tracks in the plots of both treatments (Figure 2).

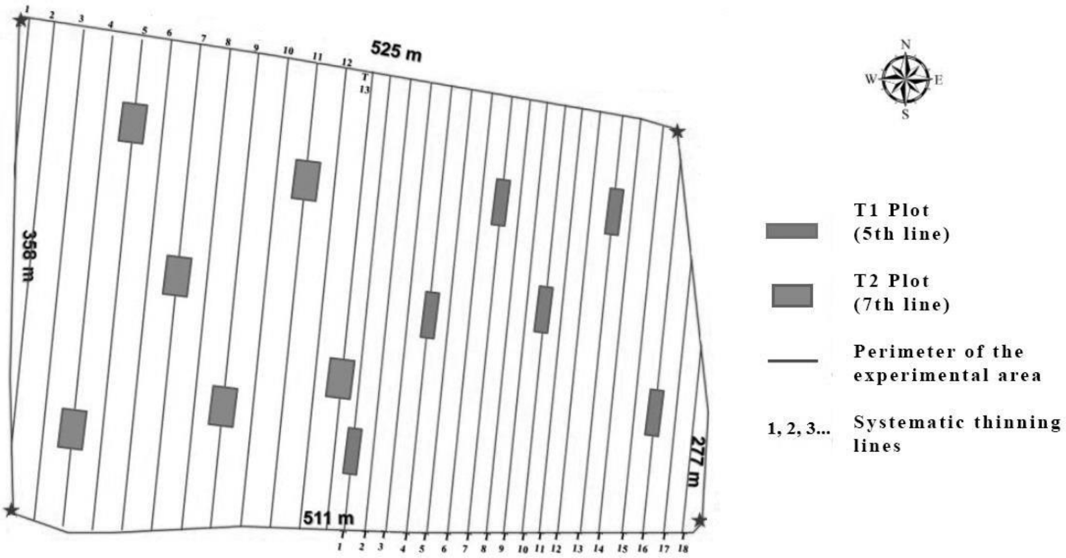


Figure 2. Installation scheme of the plots.
Figura 2. Esquema da instalação das parcelas.

The wood harvesting machine responsible for causing tree damage was identified by in situ demarcation using different color inks for the harvester and forwarder. The damaged area in the trees was obtained by measuring with a 1 cm² square-shaped mesh, and the number of damaged trees and the damage locations were obtained by counting. Data collection was performed after the cutting and extraction operations with the harvester and forwarder, respectively, meaning that a collection was performed after cutting with harvester and another after the extraction with the forwarder.

The total damage percentage in the different tree parts was evaluated by counting the damaged trees in relation to the crown, stem or base and by identifying the damage-causing machine, and the area was evaluated by relative and accumulated frequency graphs. The analyzes were performed using the methodology proposed by Lineros *et al.* (2003), where the all of the damage related to quantity, size and location were evaluated by descriptive statistics and graphical analyses.

RESULTS

After the thinning, a total of 630 remaining trees were counted in the experimental plots within each treatment. In the T1 thinning model, which used a harvester and forwarder in executing the systematic thinning in the 5th planting line, 13% of trees were found with damage. Meanwhile, in the T2 model which used a chainsaw, harvester and forwarder in performing the systematic thinning in the 7th line, the tree damage percentage increased to 17%. Both values can be considered high. The greater damage percentage observed in the T2 thinning model can be explained by the greater amount of wood produced and its arrangement in relation to the machine traffic trails. In addition, it was more difficult for the harvester to reach the trees initially knocked down by the chainsaw, and many were trapped in the trees remaining in the stands. It is important to point out that this situation occurred due to the irregular planting alignment in relation to the spacing, making it difficult to overturn the trees with the chainsaw. The damage location on the tree and the damage-causing machine are shown in Table 2.

Table 2. Damage distribution in the stand's residual trees and the damage-causing machines in the studied thinning models.
Tabela 2. Distribuição dos danos nas árvores remanescentes do povoamento e as máquinas causadoras nos modelos de desbaste estudados.

Characteristic	Location	Damage (%)	
		T_1	T_2
Location on the tree	Crown	0	0
	Upper trunk	78	63
	Lower trunk	22	37
	Base	0	0
	Roots	0	0
Damage-causing machine	Harvester	66	71
	Forwarder	34	29
	Chainsaw	0	0

Regarding the tree parts that were most affected and the damage-causing machine, we can notice a higher incidence in the upper part of the trunk, followed by the lower part; this is concerning because this is the tree section with the highest commercial value. Therefore, the results show a need to search for improvements in the machines' operational procedures during thinning performance in order to avoid damaging the stand's trees and future losses in terms of both impairments to forest growth and wood quality.

The damage to the remaining trees were mainly caused by the harvester during the cutting due to greater contact by the machine's crane with the upper part of the tree trunks arranged in the selective thinning lines, with 66 and 71% for the T1 and T2 thinning models, respectively. Next, there was the damage caused by the forwarder, with 34 and 29% for the T1 and T2 thinning models, respectively.

The preliminary tree-felling operation using the chainsaw in the T2 thinning model did not directly damage the remaining trees. However, it contributed to increasing the damage caused by the harvester caused by the machine's greater difficulty in finding and processing the previously-felled trees, as well as the greater number of log piles arranged along the machine's trails. The dimensions of damaged trees ranged from 4 cm² to 900 cm². Most of the damage produced in the operation was concentrated in the smallest class size (up to 75 cm²), with 70 and 51% for the T1 and T2 thinning models, respectively (Figure 3).

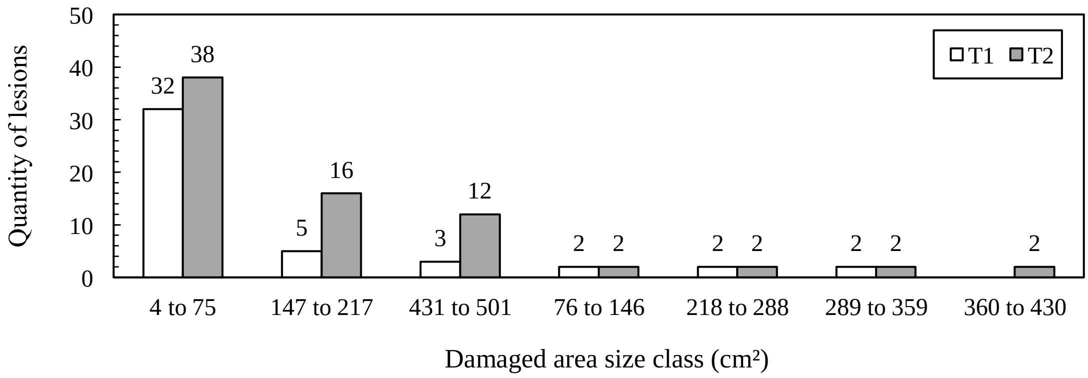
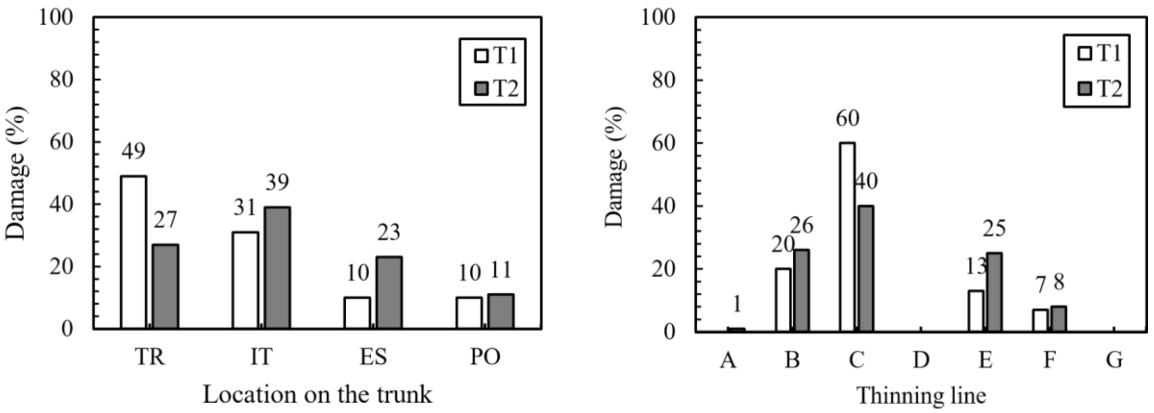


Figure 3. Damage distribution by area size class.
Figura 3. Distribuição dos danos por classe de área.

Smaller injuries in pine trees are usually closed, without causing future phytosanitary problems in the trees. However, it was observed that 30 and 49% of the injuries to the trees after performing the T1 and T2 thinning models presented larger dimensions, thus being able to cause phytosanitary problems and to affect the future growth of the stand's trees. The thinning treatment scheme with the percentage distribution of the trees that suffered injuries and their spatial location is presented in Figure 4.



TR: Traffic trail; IT: Interior from the field and opposite the road; R: Road; S: Stand; A: Center Field Line (left); B: Second closest trail line (left); C: Closest Trail Line (left); D: Operation trail; E: Closest trail line (right); F: Second closest trail line (right); and G: Center Field Line (right).

Figure 4. Percentage distribution of damage on trees associated to the operation trail of the machines (a) and exposure side (b).

Figura 4. Distribuição percentual dos danos nas árvores em relação à trilha de operação das máquinas (a) e face de exposição (b).

As can be seen, the highest percentage of damage occurred in the trees located in the planting lines near the traffic trails of the wood harvesting machines, with 73% for the T1 model and 65% for the T2 model. This result can be attributed to the greater proximity of the trees of this planting line to the machines. It should be pointed out that these were the trees that presented the highest damage intensities, which therefore shows the need for greater attention by the operator at the time of performing the operation.

In addition, the effect of the displacement direction and machines' positioning in performing the operations need to be stressed. The highest damage intensity occurred in the trees located to the left of the machine traffic trail, i.e. where the wood was processed and stacked by the harvester and then loaded by the forwarder.

Regarding the exposure side of the remaining trees, it was observed that the side of the tree facing the machine traffic trail presented the greatest amount of damage, mainly in the T1 thinning model (49% of damaged trees), with this side having greater exposure to the wood harvesting machines. The damage observed in the other lateral axes of the trees were caused by contact of the crane and harvester head at the time of cutting the trees located in the selective thinning lines.

A greater percentage of damage is noticed in the T2 thinning model, being 39 and 23% in the sides facing the interior of the stand and the road, respectively. This fact occurred due to the greater contact by the machine with the remaining trees caused by the greater difficulty in both searching and cutting in the selective thinning in three planting lines, as well as by processing the previously-felled trees by the chainsaw.

DISCUSSION

Although there are few recent studies on damaged trees in stands subjected to mechanized thinning, Fröding (1992) determined the damage level in a coniferous forest in Europe submitted to operation in the cut-to-length system by evaluating the percentage of trees affected by the machines, with values ranging from 3.4 to 5.9%. The values obtained in this study were considered to be high, therefore being higher than those determined in the literature, and characterizing it as high impact to the remaining forest.

As the characteristics of forests planted in Brazil are different from those found in Europe, tree damage still needs to be compared to results obtained in similar regions and operating conditions. In this sense, similar damaged tree values were found by Lineros *et al*. (2003), which presented 12.3% of damage in the first thinning of *Pinus radiata* at 10 years, performed under the cut-to-length system with systematic removal of the 5^{th} line. In addition, it is important to mention that the trunk sections of larger diameter trees are the most sensitive when affected by thinning damage (VASILIAUSKAS, 2001), with the possibility of not closing the lesion and it being attacked by fungi and insects, which therefore could cause significant damage to the final product.

The level of damage to the remaining trees in the stands may be related to the skill and work technique used by the machine operators. Thus, one way of reducing the incidence of greater damage is to train and improve the operators, as well as to develop specific procedures in the thinning operations and minimize the incorrect work techniques (Lopes *et al*., 2010).

The studied thinning models influenced the spatial distribution of damaged trees, being directly dependent on this factor. In the T2 thinning model, the central planting lines had almost no remaining trees afflicted with damage. However, the handling of the thinning trees at that site resulted in greater contact by the machines with the trees near the traffic trail, causing damage to the trees located in those places. The harvester's travel direction also had an effect on tree damage, as the machine performed log processing and stacking between the remaining trees on the left side of the booth while the forwarder handled the logs in the same space. This situation produced more contact and greater systematic damage to the trees.

When investigating mechanized thinning performed on the 4th and 7th lines using a harvester with tires, Mac Donagh *et al.* (2013) also identified difficulties in this second model, since the machine did not reach all lines and needed to perform additional maneuvers to complete the operation. When studying the operational variables in *Pinus* thinning in southern Brazil in a similar model to T2, Lopes *et al.* (2017) concluded that the reduced space inside the stand and the systematic thinning in the 7th planting line affected the machine's reach to cut the trees in the selective thinning, as well as contributing to a high operational cycle time and reduced productivity.

The location of the remaining trees in relation to the traffic trail and the type of machine used in performing the operation also influenced damage occurrence. The sides of the trees exposed to the traffic trail were the most damaged, indicating a direct effect of the machines resulting from the direct contact of the different machine parts such as its wheels, crane and head. The T1 thinning model presented the highest amount of this type of damage due to using machines that only operated in this location. The damage on the lateral sides of the remaining trees were higher in T2 caused by the crane and harvester head contact when retrieving the previously-felled trees (those felled by the chainsaw) for further processing and stacking on the operating track.

Reducing the occurrence of damage to remaining trees in thinning operations is not just an operational issue. Management also has participation, mainly in relation to performing late thinning operations, since with the stand's advancing age, the canopy closes and the possibility of greater damage problems in the remaining stand's trees increases. In addition, it is important to introduce efficient silvicultural practices during the stand's planting through adequate planting alignment, thus allowing the machines to perform operations with better efficiency and better adaptation to the restricted space.

Furthermore, it is recommended to carry out studies in relation to the other factors that affect damage occurrence, since its intensity is related to the time of year, the stand location and the physiological conditions (LAGESON, 1997). However, Jourgholami (2012) affirms that it is not possible to avoid damage occurring in the remaining trees of stands subjected to thinning caused by the movement of the wood and the machines. In contrast, Sirén *et al.* (2015) describe the need to plan thinning and develop better working techniques to reduce damage occurring to forest stand trees.

CONCLUSIONS

- The wood harvesting machines were responsible for significant mechanical damage to the remaining trees of the stand during thinning, presenting different types and intensities of damage.
- The most damage to the remaining trees in the stands occurred by performing the systematic thinning carried out in the 7th line due to the greater difficulty in cutting the trees by the harvester and the greater concentration of wood piles in the machine traffic trails.
- The damage occurred on the lower trunk part of the trees was significant, and could compromise the wood quality at the final cutting time.
- The percentage of trees damaged in the stands in both thinning models was considered high, even with low intensities and dimensions, indicating the need for improving the operational procedures.

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