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Quality Indicators of The Forest Harvesting Process In Clear-Cut Operations of Eucalyptus Stands For Energetic Purposes

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ABSTRACT

Background: Some organizations in the Brazilian forestry industry do not follow the development pace of other industries, in order to adopt tools and quality management methodologies. As a result, the low quality and high instability of processes create a lot of waste in the sector. This is intensified in forest harvesting operations because this is one of the activities that most contribute to the production costs of a forestry business. **Objective:** Evaluate quality indicators in activities of tree felling, tree bucking in the field and log cutting at the company yard to subsidize future improvements that may increase the quality and profitability of the forest harvesting process. **Results:** The tree felling and log cutting at the company yard activities are in nonconformity, exceeding the lower and upper limits of statistical process control. Whilst, the trees bucking in the field can be considered a statistically stable process, being in accordance with the specifications of the company. **Conclusion:** In general, adjustments can be made to improve the quality of the analyzed operations and increase revenues by avoiding losses of wood in the forest harvesting process. The methodology of Statistical Process Control has proved to be an important tool for the quality management of forest operations.

INTRODUCTION

The concern with quality indicators is not a recent fact. When products used to be handcrafted, there was a direct contact between the artisan and his customers, which made it possible to control the quality of purchased products. Thus, from a corrective approach, there was the inspection of the entire production. With the industrial revolution, there was a need to increase production to meet the demand of the population, which was also growing. This fact has resulted in the creation of industries with the focus on the quantity produced. Then problems with the quality of the products acquired started to worry the consumers (Trindade *et al.*, 2012).

Over time, customers have become more demanding, which prompted companies to strive for excellence in the quality of their products. For this, organizations operating in different sectors of the economy have adopted preventive approaches by applying quality characteristics to their production processes and, consequently, preventing product failures from reaching customers.

As follows, the search for tools that facilitate the identification of nonconformities and allow decision-making in a timely manner was intensified. However, in the Brazilian forestry sector, some organizations have

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uncertain survival due to not keeping pace with the development and adoption of quality management tools and methodologies (Trindade *et al.*, 2007; Martins, 2017).

Thus, to ensure survival, it is necessary for the Brazilian forestry sector to create a "quality culture", adopting verification procedures and quality monitoring in its activities to raise its competitiveness in the international market. Nevertheless, the concern should not only be with the final product obtained, but with each stage of production, in order to reduce costs, guaranteeing the quality of the whole process, obtaining a final product of high quality and at cost competitive (Rezende *et al.*, 2000).

Although Brazil is globally recognized for the high productivity of its forests (Indústria Brasileira de Árvores, 2017), the low quality scenario is due to the lack of investment, as well as the lack of research that proves the feasibility of adopting quality tools forest production activities. Nevertheless, it is important to highlight the difficulties in adapting the methodologies of the quality tools to the specificities of the wholesilvicultural process, compared to the studies carried out in wood processing or in other sectors of the economy.

Thus, among the stages of forest production, harvesting and transportation have great importance, given the risks of losses involved in these activities and the high cost of this operation, which may represent more than 50% of the price of wood that comes to industry (Siqueira *et al.*, 2004; Machado *et al.* 2014). Therefore, the implementation of quality programs in this area possibly brings bigger and faster returns comparing to the other segments of the forestry productive chain (Jacovine and Trindade, 2014).

In this context, the objective of this study was to evaluate the quality of tree felling operations, tree bucking in the field and log cutting at the company yard. This evaluation was in order to infer if the process is operating within specified limits in the company and, therefore, can subsidize future improvements that may increase the quality and profitability of the activity.

MATERIAL AND METHODS

Characterization of the study area:

The study took place in areas of a forest company located in the city of Rio Negrinho, which is located in the Northern Plateau Region of Santa Catarina in Brazil. Moreover, the city is located at an average altitude of 791 meters above sea level, ranging between 800 and 1050 meters. According to the classification of Köppen, the climate of the region is Cfb. This indicates a tempered and constantly humid climate, without a dry season and with a fresh summer. The average annual temperature varies between 15 and 17 ° C, with average maximum temperatures ranging from 26 to 24 ° C and minimum of 10 to 11 ° C (Alvares *et al.*, 2013). The mean annual rainfall is 1720 mm, with relative air humidity ranging from 80 to 86% (Epagri, 2009).

In the areas, *Eucalyptus* spp. plantations were cultivated with planting spacing of 3 x 1.80 m and an average density of 1500 tree ha⁻¹. At the age of 14 years old, end of the rotation cycle, the plantations had an average height of 26.0m, mean of diameter at breast-height of 23.0 cm and mean of the volume per tree of 0.308m³ tree⁻¹. The final goal of the production of wood was for energy purposes or, in other words, for logs to feed boilers in an industrial process. In general, we can characterize the relief of the cultivated areas as being from plain to wavy.

Characterization of the evaluated harvesting system:

The harvesting of the forest stands happened under clear-cut regime. Full Tree harvesting system was employed, with all the harvesting steps on the field and in the company yard performed with machines.

First, on the field, a Timberjack Feller Buncher 608 S, cut the trees and then they were left there for around 180 days. After that, the trees were dragged from the core to the edge of the field using a Valtra Tractor BM 100 with a winch (technical specifications in Table 1). Later, the felled trees were bucked into logs of 2.20m length and then stacked and loaded in transport vehicles by two alternatives of machines: (1) Timberjack Grapple Saw 608 S coupled to a Dinamac cutting device DC600 (technical specifications in Table 2); or (2) Valtra Grapple Saw Tractor BM 125i coupled to a Dinamac cutting device DC250 (technical specifications in Table 3).

After the operations on the field, the wood was transported to an intermediate yard of the company where its unloading took place. A final processing into logs of 1.10m in length happened and using a Valtra Grapple Saw Tractor BM 125i, which loaded the logs for the final transportation. The machine has same technical specifications as previously mentioned (Table 3).

Table 1: Technical specifications of Valtra Tractor BM 100.

Specifications	Description
Brand	Valtra
Model	BM 100
Engine	AGCO POWER 420DS, 4 cylinders
Gross power	104.6hp (77.2 kW)
Fuel capacity	142 L
Traction	4WD
Type of wheel	Tires
Usage time	± 4 years

Table 2: Technical specifications of Timberjack Grapple Saw 608S.

Specifications	Description
Base machine	
Brand	Timberjack
Model	608S
Engine	Cummins 6CT8.3 turbo, 6 cylinders
Gross power	205.2 hp (153 kW)
Fuel capacity	568 L
Boom lifting capacity	1315 kg
Maximum Boom Reach	7.80 m
Type of wheel	Crawler tracks
Usage time	±10 years
Cutting device	
Brand	Dinamac
Model	DC600
Grapple opening area	0.600 m ²
Usage time	± 2 years

Table 3: Technical specifications of Valtra Grapple Saw Tractor BM 125i.

Specifications	Description
Tractor	
Brand	Valtra
Model	BM 125i
Engine	AGCO POWER 420DSA
Gross power	130.2hp (96,7 kW)
Traction	4 x 4
Type of wheel	Tires
Maximum permissible weight	7392kgf
Usage time	±4 years
Cutting device	
Brand	Dinamac
Grapple opening area	0.576 m ²
Usage time	± 2 years

Quality Analysis:

The quality of the processes of tree felling, tree bucking in the field and log cutting at the company yard were evaluated by following variables: (1) stump height on the tree cutting stage; (2) precision on the bucking of the trees on the field; and (3) precision on the log cutting at the company yard.

In order to collect data of the height of stumps 10 sample plots with an area of 378 m² (18 x 21 m) were set up. From the sample plots, measurements of diameters and heights of the stumps and the mean slope of each plot were taken. According to the company specification, 10 cm was considered as the desired height limit of the stumps. With this information, the volume of wood that remained in the field above the standard cutting height and the loss of revenue per hectare, assuming a market price of wood of US \$ 19.25 per m³, were calculated.

For the analysis of the precision of bucking trees on the field and log cutting at the company yard, 17 and 10 samples composed of 15 and 10 replicates, respectively, were measured for each of the conditions. The standard compliance of the logs intended by the company was from 2.00 to 2.40 m for field cutting of trees and from 1.00 to 1.20 m for yard bucking.

Afterwards, with the data of the variables, the Statistical Process Control (SPC) analysis was performed. This analysis were done using control charts (mean and dispersion), according to the methodologies presented by Oakland (2003) and Montgomery (2004). For the control charts that considered the means of the processes the mean line (AL), the upper limit of control (UCL) and the lower limit of control (LCL) (Equations 1, 2 and 3) were obtained. Charts of dispersal control for standard deviation had their AL, LCL and UCL calculated based on Equations 4, 5 and 6, respectively.

$$AL = \frac{\sum x_i}{k} \quad (1)$$

$$UCL = \frac{\sum x_i}{k} + \left(A_3 * \frac{\sum s_i}{k} \right) \quad (2)$$

$$LCL = \frac{\sum x_i}{k} - \left(A_3 * \frac{\sum s_i}{k} \right) \quad (3)$$

$$AL = \frac{\sum s_i}{k} \quad (4)$$

$$UCL = B_4 * \frac{\sum s_i}{k} \quad (5)$$

$$LCL = B_3 * \frac{\sum s_i}{k} \quad (6)$$

Where: $\bar{x}_i$ is the mean value of each sample; s_i : mean standard deviation of each sample; k : number of samples; A_3 : constant used in the elaboration of control charts of the mean by the standard deviation; B_3 and B_4 : constants used in the elaboration of control charts of the mean by standard deviation.

RESULTS AND DISCUSSION

The mean height of the stumps ($\pm$ standard deviation) was 10.83 cm ($\pm$ 6.18 cm) (Figure 1), being out of the standard compliance according to the desired specification and over the limits of the specified statistical process control map (Figures 2A and 2B).

Fig. 1: Dispersion of stump height values by sample plot; Black line: general mean of all plots; Dashed lines: general mean plus or minus one value of standard deviation.

Fig. 2: Statistical process control charts for stump height, considering the mean (A) and standard deviation (B). AL: mean line; LCL: lower limit of control; UCL: upper limit of control.

The points below the LIC are desirable as they infer that less wood was left on the field. However, regardless, the average height of stumps showed number above the limit specified by the company.

In relative terms, 46.6% of the evaluated stumps were above the specified limit and, in general, the occurrence of stumps above the standard did not show any relation to the terrain slope (Figure 3A).

Fig. 3: Mean height and percentage of stumps above the specified limit as a function of terrain slope (A) and stump diameters classes (B).

Stumps above the standard occurred in greater proportion in the intermediate diameter classes (between 10 and 30 cm) (Figure 3B). Meanwhile, the greatest values of the heights of the stumps were observed in either the lowest (0 - 10 cm) or the highest class (> 40 cm), respectively.

The greatest heights of the stumps were observed in the lowest diameter class because tree belonging to this class were not felling by the action of the cutting implement (Feller Buncher). Most of the times they were felling by adjacent larger trees that fell over them. However, in the highest class (over 40 cm) the high stump heights observed may be associated with the operator's difficulties while performing the felling operation, which is also reported by Jacovine *et al.* (2005).

Similar results were reported by Martins (2017), which evaluated the activity of tree felling of pine stands by Feller Directional, and found a mean stump height of 10.86 cm, result of a statistically unstable process according to the statistical control charts of the process. Another similar result is from Pereira *et al.* (2012) which analyzed the eucalyptus tree felling activity using chainsaws and found a mean stump height of 10.49 cm, being therefore out of compliance with the desired pattern. According to the authors, the average value of wood loss in the assessed situation was $2.43 \text{ m}^3 \text{ ha}^{-1}$, which economically represented a loss of income of $55.21 \text{ US\$ ha}^{-1}$.

In the present study, wood losses, accounting stumps above the desired standard, averaged $1.06 \text{ m}^3 \text{ ha}^{-1}$ which represents a loss of revenue of approximately $20.41 \text{ US\$ ha}^{-1}$. However, besides the economic wood losses, stumps are physical impediments to the operations with soil preparation machines during the land reform for a next planting (Casselli, 2013), which results in operations of withdrawing or lowering stumps, burdening the reform costs and reducing the income of the forest production (Moro *et al.*, 1988; Seixas and Mendo, 1990).

In this way, it was observed that in addition to the decrease in revenue from wood loss, there will be an indirect increase in silvicultural costs, which will also contribute to a decrease in the profitability of the plantations. Fact described by Pereira *et al.* (2013), in areas with eucalyptus stumps with a mean height of 21.00 cm, which reported that the operation of lowering stumps with chainsaws cost $157.60 \text{ US\$ ha}^{-1}$, in addition to revenue losses due to wood waste.

Considering the accuracy of the precision on the bucking of the trees on the field, only 1.20% of the logs were outside the desired limit of conformity (Figure 4) and the process could be considered stable since the upper limit control was violated only by one mean (Figures 5A and 5B).

Fig. 4: Dispersion of log length values by sample plot. Continuous line: desired specification (2.20 m); Dashed lines: upper and lower specification limits.

Fig. 5: Statistical process control charts for length of logs in the field, considering the mean (A) and standard deviation (B). AL: mean line; LCL: lower limit of control; UCL: upper limit of control.

Figure 6 shows the results for the log cutting at the company yard process where 10.3% of the sampled logs length were below the desired standard, 23.8% above and 65.9% in compliance.

Fig. 6: Dispersion of log length values by sample plot. Continuous line: desired specification (1.10 m); Dashed lines: upper and lower specification limits.

The quality item above presented a higher variation in relation to the other items violating the LIC and LSC limits (Figure 7A and 7B). This violation demonstrates that the process is not under control and can be justified by the operational characteristics of the equipment used (Grapple Saw), which does not have a template to perform the operation and, therefore, resulting in length errors after log cutting.

Fig. 7: Statistical process control charts for length of logs at company yard, considering the mean (A) and standard deviation (B). AL: mean line; LCL: lower limit of control; UCL: upper limit of control.

Rezende *et al.* (2000) analyzing the bucking of eucalyptus trees on the field process with chainsaw, observed that the process was unstable due mainly to the lack of training of the operators and recommended greater investment in the supervision and control procedures of the activity. Fiedler *et al.* (2013) also observed this fact and realized that, in addition to the losses of wood and revenue, the low quality of forest harvesting operations can trigger several problems in subsequent operations of raw material processing and use.

Overall, actions are necessary in order to improve the quality of operations, reduce possible wastes, improve logistics and reduce redoing costs of the wood industrial supply.

Conclusions:

Among the three items related to the quality of the forest harvesting process in clear-cut operations of eucalyptus stands for energetic purposes, only the tree bucking in the field showed compliance and, hence, being statistically controlled. Tree felling and log cutting at the company yard have not been compliant and are out of statistical control.

The quality of the eucalyptus tree felling activity, represented by the stump height, did not present a relation to the terrain slope, with the mean stump height being higher in classes with a diameter of 0 to 10 cm and greater than 40 cm, which was caused due to lack of training and skill of the operator.

In addition to the economic loss of revenue from wood waste on non-compliant stumps, the low quality of tree felling activity reflects on higher stumps that cause subsequent problems in silvicultural operations, burdening implantation costs and reducing forest production revenue.

The quality of the tree bucking in the field, represented by the length of logs, presented only 1.20% of logs outside the desired limit of compliance, therefore, the process was stable and there was no need for measures to improve this process, although it is recommended that the process be evaluated and supervised.

The quality of the log cutting at the company yard activity presented high variation and dispersion of values in relation to the log length precision, due to the lack of process control. Nevertheless, the equipment used for the activity does not have any device to measure the quality of work, being the quality of the activity dependent of operator's ability.

The present work showed how important it is for adopting tools to improve quality management in forest operations, especially in the timber harvesting. When the initial forest operations process have low quality, they affect all subsequent operations and the losses are greater, given the chain effect.

In general, the Statistical Process Control tool was efficient in evaluating the timber harvesting process of the present situation, demonstrating the need for investment in supervision and training of personnel to avoid wood waste and financial losses in forest production. Still, it is also recommended to evaluate alternatives for using other forest harvesting equipment with the objective of improving the quality of operations and increasing the profitability of the production process.

Not all harvesting operations and all possible consequences of lack of conformity were evaluated in this study, but it is believed that most of the quality problems occurred during the harvesting operations were from these items, and the others could be studied. Therefore, because of the high potential for economic losses, investment in quality can be rewarding. Thus, any investment in prevention and evaluation could increase the returns of forest enterprises.

It is also recommended that other situations, harvesting systems and production objectives be studied, as well as the costs and consequences of low quality in forest operations, since there is scarce work in the specialized scientific literature and will certainly support decision making in planning of forest operations.

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