ASSERTIVENESS OF A LOG LENGTH SENSOR ALLOCATED IN DIFFERENT POSITIONS ON THE HARVESTER HEAD

Josiane Maria da Silva[1*], Lucas Santos Santana[2], Carlos Eduardo Silva Volpato[2], Ana Beatriz Alves da Silva[3], Tauan Bonin Goiz[4].

[1*]Federal University of Lavras, Forest Engineering Department, Lavras, MG, Brazil – josiane.engflorestal@gmail.com
[2] Federal University of Lavras, Agricultural Engineering Department, Lavras, MG, Brazil - lucas.unemat@hotmail.com, volpato@ufla.br
[3]Federal Rural University of Rio de Janeiro, Forest Engineering Department, Seropédica, RJ, Brazil - anabeatriz.engflorestal@gmail.com
[4]University of São Paulo, Luiz de Queiroz College of Agriculture, Forest Engineering Department, Piracicaba, SP, Brazil - tauanbg@hotmail.com

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Resumo

Assertividade do sensor de comprimento de toras alocado em diferentes posições no cabeçote do harvester. A variabilidade no comprimento das toras pode afetar o rendimento operacional e a produtividade nas operações de colheita e transporte florestal. Comprimentos assertivos atendem critérios positivos de qualidade do produto entregue à fábrica de celulose. Portanto, fazem-se necessárias pesquisas para aferir a assertividade na mensuração do comprimento das toras. Dessa forma, objetivou-se avaliar a exatidão do sensor de comprimento em posições distintas no cabeçote do *harvester*. Foram definidos os seguintes tratamentos: sensor acoplado na roda de medição sem peça protetora (T1); sensor acoplado na roda de medição com peça protetora (T2); sensor acoplado no rolo alimentador sem peça protetora (T3) e sensor acoplado no rolo alimentador com peça protetora (T4). O estudo foi realizado em um plantio de eucalipto destinado à produção de celulose e, por meio de aferições diárias de comprimento de toras no campo foram obtidas 8373 medições. Esses dados foram submetidos à ANAVA, testes de média (Tukey e Scott-Knott), Controle Estatístico de Processo (CEP) e distribuição de frequência. T1 e T3 apresentaram comprimento médio correspondente a 6,46 m e desvio padrão igual a 0,11 e 0,17 m, respectivamente. T2 e T4 apresentaram média de 6,42 m e desvio padrão igual a 0,12 e 0,16 m, respectivamente. T1 apresentou frequências assertivas de distribuição com 80% das toras processadas dentro do limite estabelecido (6,30 e 6,70 m) enquanto T2, T3 e T4 apresentaram 55%, 45% e 40%, respectivamente. Conclui-se que o sensor acoplado na roda de medição e sem a peça protetora obteve maior exatidão no comprimento final das toras.
Palavras chave: Colheita florestal. Medição. Variabilidade. Exatidão.

Abstract

Wood length variability can affect operational yield and productivity in harvesting and forest transport operations. Assertive lengths meet positive quality criteria for the product to cellulose factory delivered. Therefore, research is needed to assess assertiveness in measuring wood logs' length. Thus, the objective was to evaluate length sensor accuracy at different positions in the harvester head. The following treatments were defined: sensor coupled in measuring wheel without a protective piece (T1); sensor coupled in measuring wheel with protective piece (T2); sensor coupled in feed roller without protective piece (T3) and sensor coupled in feed roller with protective piece (T4). The study was carried in a eucalyptus plantation destined for the production of cellulose pulp and, through daily measurements of wood log length in the field, 8373 measurements were obtained. Data were submitted to ANOVA, mean tests (Tukey and Scott-Knott), Statistical Process Control (SPC) and frequency distribution. Treatments T1 and T3 presented average length corresponding to 6.46 m and 0.11 and 0.17 m standard deviation, respectively. T2 and T4 presented and average of 6.42 m and standard deviation equal to 0.12 and 0.16 m, respectively. Treatment T1 presented assertive distribution frequencies, presenting 80% of the logs processed within the established limit (6.30 and 6.70 m) while T2, T3 and T4 presented 55%, 45% and 40%, respectively. It is concluded that the sensor coupled in measuring wheel and without the protective piece obtained greater accuracy in wood logs final length.
Keywords: Forest harvest. Measurement. Variability. Accuracy.

INTRODUCTION

Wood harvesting is composed of a series of operations involving cutting, debarking, processing, removal, transport, and unloading of wood in the manufacturing process (SANTOS *et al*., 2018). Considered the forest operation cycle final stage, the harvesting operations are mechanized methods that use machines of high production capacity and high added value. Therefore, it is necessary to rationalize activities to guarantee an increase in productivity and reduction in costs within a pre-established plan (RODRIGUES *et al*., 2018).

Considered the final stage of the wood production process, harvesting is regarded as one of the essential steps for the success of a forestry company since it is the most expensive production cost (SCHETTINO *et al*., 2019). The resources used for optimization in forest harvesting guarantee the company's permanence in the competitive market. Determining systems types and equipment available to carry out this activity is necessary to rationalize these resources use (SOMAN, 2019).

Among the harvesting systems used in Brazil, the short log system stands out. Characterized by activities complementary to cutting (delimbing, topping, logging) carried out where the trees are felled (OLIVEIRA, 2013). In this system, logs up to 7 meters long are arranged in bundles and removed to the stand edge, forming piles (MALINOVSKI *et al*., 2014).

The “short log” system presents variability in the length of the logs. This factor influences harvesting the forest, affecting operation productivity and significant economic losses (MEDERSKI *et al*., 2018; SERPE *et al*., 2018). Logs with different lengths interfere with load compartment optimization of extraction machines and wood transport vehicles. In addition, sizes below the established can cause accidents during the truck's journey (NADOLNY *et al.*, 2019). In studying wood length influence in transport costs, Lopes *et al*. (2016) showed that the increase in transport costs relates to assertiveness in the length of the logs particularly because of the better load use on vehicles.

Given this assumption, to achieve greater harvest productivity and economic gains in forestry logistics, the log length adopted for this study was 6.50 meters. Production of logs with standardized dimensions is a requirement of the market, so products beyond the established measures may be refused (OLIVEIRA *et al.*, 2017; BEMBENEK *et al*., 2015). To meet the final product quality criteria delivered at the factory, greater assertiveness in the wood length is necessary.

Measurement sensor position can influence the assertiveness in the length of the wood logs. Same showing satisfactory operation from a mechanical point of view, there are still problems of variability in wood measurements. The measurement sensor is usually installed on one of the *harvester* head rollers, measuring each movement that the roller produces. This movement can be influenced by wood rotation, bark, shaft diameter, humidity, and terrain slope. Therefore, measuring the measurement assertiveness according to sensor position in the head can reduce errors in the final length of the logs.

Changes in measurement sensor position in the harvester head can be an efficient alternative for final log length assertiveness improvements. The gains obtained may be related to harvest optimization, avoiding wood waste, and contributing to a cargo compartment use of trucks in forest transport. In addition to collaborating for improvements in factory supply flow, uneven lengths lead to difficulties in the factory supply.

Thus, the objective of this work was to evaluate wood length sensor assertiveness in different positions on the harvester head to ensure accuracy in the established target length.

MATERIAL AND METHODS

The experiment was conducted in an area of 537.40 hectares in a forestry company plantation eucalyptus destined to manufacture and export cellulose pulp. Forest stand was located in the municipality of Reginópolis, state of São Paulo, within the geographic coordinates 49º11' 31.761” W and 21º 59' 9.586” S. According to the Köppen’s climate classification, adapted by Alvares *et al*. (2013), the climate in the region is Cfa-type, the average temperature of 21.7 °C and average annual rainfall of 1186 mm. The harvesting system used in this area was the “short logs” in which the activities complementary to the cut (delimbing, topping, debarking, logging) took place where the trees were felled. The length for cutting the logs was 6.50 meters, arranged in bundles and removed to stand edge, resulting in the formation of piles.

The base machine used in this experiment was the John Deere 2144G crawler, equipped with a John Deere 6-cylinder engine, 159 hp at 1800 rpm, 585 l capacity, 25 t operating weight, coupled with an 8.50-m boom standard and long reach boom of 8.31 m (JOHN DEERE, 2017). The head was from the Waratah brand, model H215E, maximum cutting capacity of 550 mm, a maximum roll opening of 550 mm, a mass of 1690 kg, and expected service life of 30000 h. The heads were equipped with sensors for measuring the diameter and length of wood logs (WARATAH, 2017). The same configuration system was used to reduce the interference in the cutting system.

Length sensor allocation in the harvester head allows ensuring assertiveness in log processing. As the processing takes place automatically, the sensor assists in the accuracy and precision of the length of the logs. This sensor was attached to the measuring wheel and the head traction roller. In addition, a protective piece was installed on the measuring wheel to soften impacts on the head parts caused by wood traction. (Figure 1).

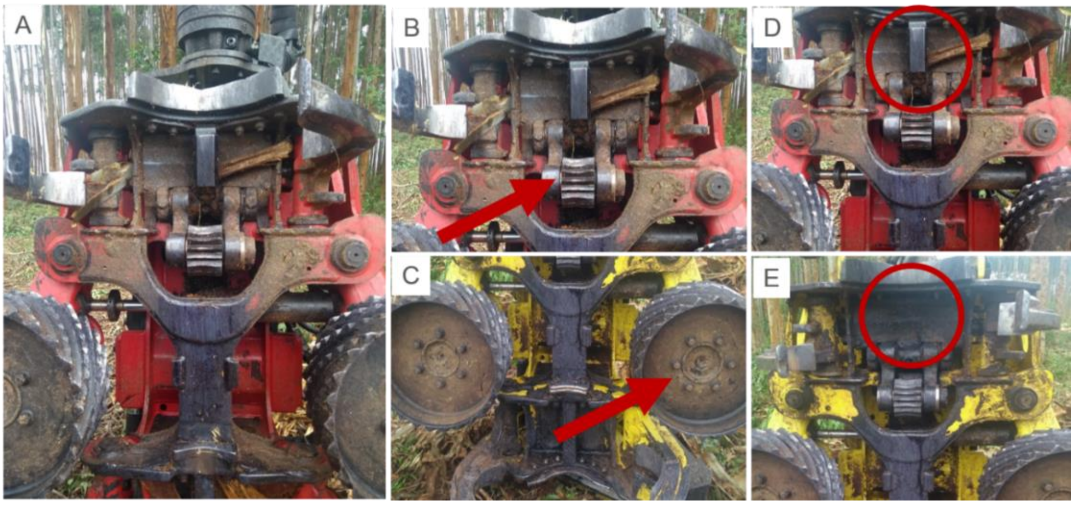

Figure 1. Length sensor and protective piece allocation in harvester head. A) Head; B) Length sensor attached to the measuring wheel; C) Length sensor attached to the feed roller D) Head with protective piece and E) Head without protective piece.

Figura 1. Sensor de comprimento e alocação da peça protetora no cabeçote do *harvester*. A) cabeçote; B) sensor de comprimento acoplado na roda de medição do cabeçote; C) sensor de comprimento acoplado no rolo alimentador. D) cabeçote com peça protetora e E) Cabeçote sem peça protetora.

Samples number was obtained statistically following Conaw (1977). Thus, samples' necessary minimum number was defined to provide a maximum sampling error of 10%.

$$n \geq \frac{t^2 * s^2}{e^2} \tag{1}$$

Where: n = samples minimum number needed, t = t value, for the desired probability level (n-1) degrees of freedom, s = sample standard deviation; e = the permissible error, in percentage (10%).

The evaluations of each shift's work cycle and operational performance showed that the number of trees processed on average was 450. Therefore, the calculated minimum number of samples, according to equation 1, was 45 considering an error of 10%. The samples were obtained from the bundles of wood logs produced by the harvesters. In each bundle, four wood logs length was randomly collected with a tape measure aid.

The experimental arrangement was defined in four treatments according to the length sensor location on the harvester head. Thus, four machines were selected for evaluation, defined as treatments 1, 2, 3, and 4. The treatments observed in this study were:

- T1 - sensor placed on the measuring wheel without a protective part;
- T2 - sensor placed on the measuring wheel with protective part;
- T3 - sensor placed on the feed roll without a protective part; and
- T4 - sensor located on the feed roll with a protective part.

The experiment was carried out in a completely randomized design, the bundles of wood logs produced by each machine were considered one treatment, so, in each treatment, 2093 samples were obtained. Then, the collected data were submitted to analysis of variance (ANOVA). For such analysis, the statistical software SISVAR 5.6 was used. Statistical tests were organized into lengths (response variables) and treatments (independent variables). The F test was used based on the ANOVA results, followed by the Tukey and Scott-Knott test at 5% error probability in treatments that had significant differences.

The data were presented in control charts, using the Statistical Process Control (SPC) to identify erroneous points in wood logs length related to sensor positioning influence and protective piece. The SPC chart is a branch of statistics used to monitor and control processes (YOUSEFI *et al.*, 2019). The application of SPC charts contributes to performance variations detection and identifies important factors that affect the process (OAKLAND, 2007).

Upper and lower limits represent the SPC chart based on the analysis. Therefore, values found within moving range limits are considered acceptable. Lower Control Limit avoids negative values (LIC), which is applied as a null value (LIC=0, for the chart of individual values and LIC=1 in the moving amplitude chart).

Equations 2, 3, and 4 proposed by Molnau, Montgomery, and Runger (2001) were used to estimate the mean lines and limits of the control charts.

$$X = \mu \quad (2)$$
$$UB = \mu + 3\sigma/(c^2\sqrt{n}) \quad (3)$$
$$LB = \mu - 3\sigma/(c^2\sqrt{n}) \quad (4)$$

SPC analyses were performed in Minitab *software*. This analysis was possible by inserting the data extracted from the field forms and tabulated in electronic spreadsheets. The charts resulting from the SPC analyses were of the X BAR S type, presented in two ways: considering collected samples averages (Graph of means) and relation to samples standard deviation (Graph of range). In the SPC analysis, errors identification can also be made from an established average line. Thus, an average limit of 6.50 meters was defined, representing the projected cutting length.

The frequency distribution graphs were used to data variation evaluate the established target. This analysis represents respective frequencies associated with all the different observed values of the variable under study. This form of data presentation is considered adequate for representing continuous quantitative variables by frequency class building (MISHRA *et al.*, 2019). The class frequency graph described the variation in wood log lengths with established tolerance values. The tolerance represents the variation in centimeters that wood logs length can present about the target.

Building a frequency graph by class, tolerance values equal to 0.10 were established; 0.20 and 0.40 m to verify wood cut variation at different established tolerance levels. Making it possible to verify cut variability in percentage and each treatment's frequency within the tolerance.

RESULTS

Average lengths analyses of the logs were obtained from 8373 samples in the field, showing a typical c assertiveness for each treatment. The average lengths were characterized by a bar graph and the standard deviation by a variable line (Figure 2).

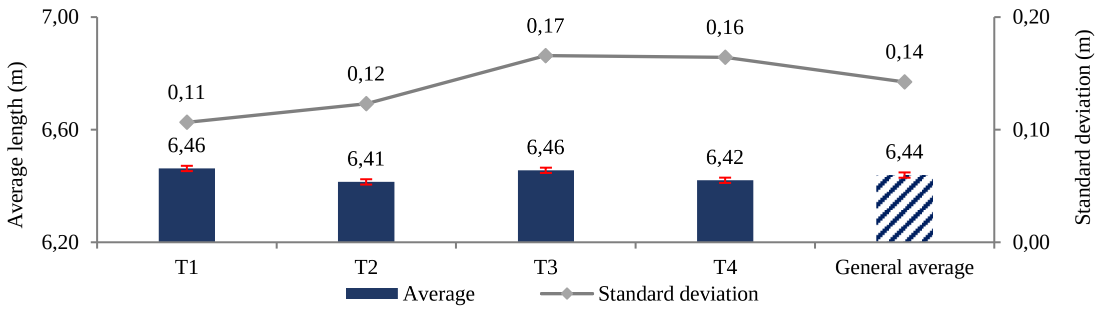

Figure 2. Average length of logs and deviation from treatment standards T1: sensor coupled in measuring wheel without protective piece; T2: sensor coupled in measuring wheel with protective piece; T3: sensor coupled in feed roller without protective piece and T4: sensor coupled in feed roller with protective piece.

Figura 2. Comprimento médio das toras e desvio padrão dos tratamentos T1: sensor acoplado na roda de medição sem peça protetora; T2: sensor acoplado na roda de medição com peça protetora; T3: sensor acoplado no rolo alimentador sem peça protetora e T4: sensor acoplado no rolo alimentador com peça protetora.

The means found for Treatments T1 and T3 were 6.46 meters and treatments T2 and T4 averages corresponded to 6.42 meters. However, when analyzing the standard deviation between treatments, small variations were observed with the sensor attached to the head measuring wheel (T1 and T2). The treatments with the sensor coupled to the feed roller (T3 and T4) showed lengths with high variability, increasing the standard deviation values (Figure 2). High variability values result in an uneven operation in mechanized operations and contribute to a difficult adjusting of the mechanized sets.

The average lengths of logs shown in Table 1 offer the distinct formation of two groups of treatments that did not differ statistically from each other, treatments T2 and T4 (with the protective piece) and treatments T1 and T3 (without protective piece). This differentiation confirms protective piece interference in log length assertiveness, emphasizing that the absence of the piece conferred greater accuracy in log cutting. In general, the sensor attached to the measurement wheel without the part showed a lower standard deviation and an average closer to the established target.

Means of log lengths were subjected to analysis of variance and average tests (Tukey and Scott-Knott) at the 5% error probability level. The statistical differences between sensor positions in the head and the potential influence of the piece protective device were identified (Table 1).

Table 1. Variation analysis and mean tests (Tukey and Scott-Knott) for mean log lengths.
Tabela 1. Analise de variância e testes de média (Tukey e Scott-Knott) para os comprimentos médios de toras.

Variation Source	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**	**Fc**
Treatments	3	3.431184	1.143728	56.281
Error	8129	165.195031	0.020322	
CV (%) =	2.21			

Treatments	**Means**	**Test Results**
T1	6.462	a2
T2	6.416	a1
T3	6.455	a2
T4	6.420	a1

Means tests showed the formation of the following treatment groups: T1 and T3 (without protective piece) and treatments T2 and T4 (with the protective piece). Within these groups, no statistically significant differences were observed in the average lengths of the logs. These results showed the influence of the protective piece logs' final length as treatments with the protective piece (T2 and T4) had an average size lower than treatments without the allocated piece (T1 and T3).

The complete verification and quality points responsible for log length assertiveness in each treatment are demonstrated by SPC charts (Figure 3). The moving average SPC chart (Figure 3a) characterizes the variations in mean lengths and range type. The SPC chart (Figure 3b) represents the standard deviation of log lengths for each treatment.

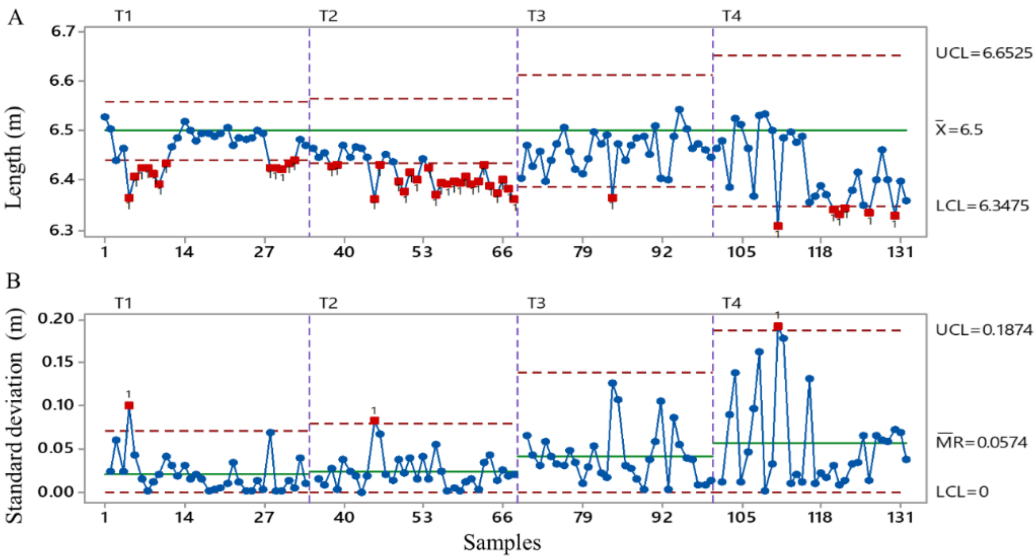

Figure 3. Process Quality Control Charts. a) average variation of wood log lengths for each treatment; b) wood logs lengths standard deviation for each treatment; $\bar{X}$: established target length (target); LCL: lower control of lengths; UCL: upper control of lengths and $\overline{MR}$: mean standard deviation.

Figura 3. Cartas de controle de qualidade de processo. a) variação média dos comprimentos das toras de cada tratamento; b) desvio padrão dos comprimentos das toras de cada tratamento; $\bar{X}$: comprimento alvo estabelecido (target); LCL: limite inferior dos comprimentos; UCL: limite superior dos comprimentos e $\overline{MR}$: desvio padrão médio.

The SPC charts analysis showed that the log lengths that exceed the acceptable moving amplitude limits are represented by the red dots, indicating low current quality in the process. In the moving average SPC chart (Figure 3a), it is possible to observe that the treatments T3 and T4 presented superior performance than the others for having lower densities of red dots. As observed in the range-type charts (Figure 3b), the best results were obtained by treatments T1 and T2 due to the lower standard deviation values, contrary to the results found in the moving average graph. Although treatments T3 and T4 demonstrate greater typical deviation amplitude, their values are still located within the lower and upper limits. When considering the assertiveness of the lengths within the upper and lower limits, these results give apparent superiority to the T3 treatment.

Assertiveness in log length is related to the percentile reached by the treatments through established tolerance. The frequency distribution analyses applied to 0.40 m of tolerance (Figure 4) demonstrated the high assertiveness of the treatment within this tolerance range.

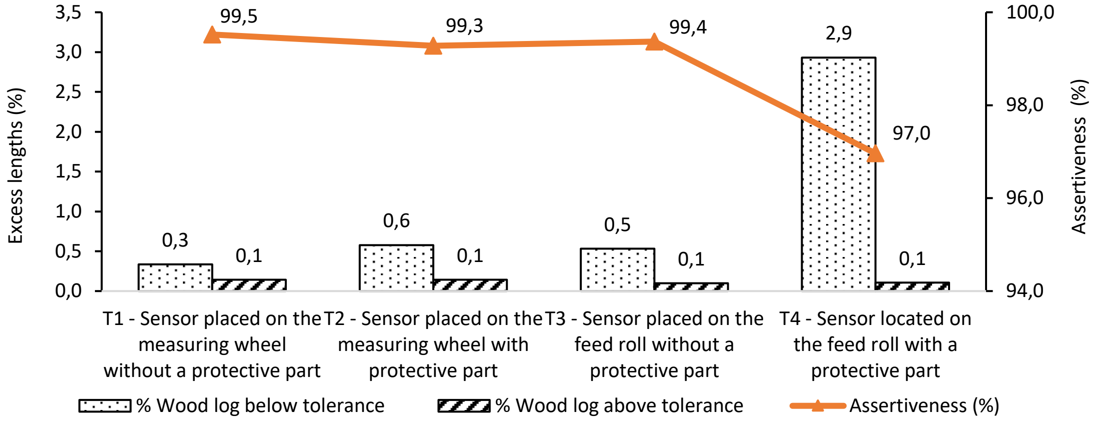

Figure 4. Frequency distribution graph of wood log lengths for an established tolerance of 0.40 m. % of logs below tolerance: logs smaller than 6.10 m; % of logs above tolerance: logs larger than 6.90 m and assertiveness: logs between 6.10 and 6.90 m.

Figura 4. Gráfico de distribuição de frequência dos comprimentos de toras para tolerância estabelecida de 0,40 m. % de toras abaixo da tolerância: toras menores que 6,10 m; % de toras acima da tolerância: toras maiores que 6,90 m e assertividade (%): toras entre 6,10 e 6,90 m.

Although all treatments (Figure 4) presented satisfactory results, it is observed that the assertiveness of treatment 1 was superior to the others, showing a 99.5 percentage within limits (6.10 and 6.90 m). In this established limit of assertiveness in the length of the logs, there is a tendency for errors in smaller measurements. Among the errors below the defined limits, treatment 4 presented an expressive value in relation to the others, in which 2.9% of the identified sizes were below 6.10 m.

Frequency distribution application at 0.20 m of tolerance in wood cut length assertiveness (figure 5) showed the superiority of Treatment 1 compared to others. This treatment resulted in a percentage of 95.10 assertiveness within the limits (6.30 and 6.70 m).

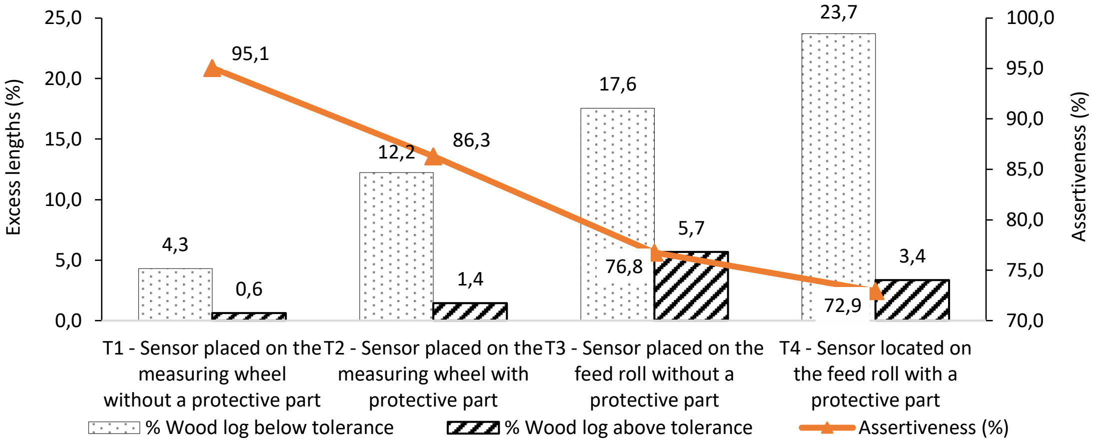

Figure 5. Frequency distribution graph of wood log lengths for an established tolerance of 0.2 m. % of logs below tolerance: logs smaller than 6.30 m; % of logs above tolerance: logs larger than 6.70 m and assertiveness: logs between 6.30 and 6.70 m.

Figura 5. Gráfico de distribuição de frequência dos comprimentos de toras para tolerância estabelecida de 0,2 m. % de toras abaixo da tolerância: toras menores que 6,30 m; % de toras acima da tolerância: toras maiores que 6,70 m e assertividade (%): toras entre 6,30 e 6,70 m.

At this tolerance level (0.20m), the lowest performance was observed in the T4 treatment, with 23.70% of log lengths below the lower limit established. The reduction from 0.40 to 0.20 m in the established limit generated instability of treatments T2 and T3, as their assertiveness indexes within the established limits were reduced by 13% and 22.6%, respectively. This reduction in assertiveness, particularly evidenced in T3, indicates that the superiority of this treatment in the SPC charts does not apply to 20 cm of tolerance limits.

The frequency distribution analyses applied to 0.10 m of tolerance (Figure 6) demonstrate that the treatments performance and percentage of log lengths were above and below the established limits and the assertiveness is in the defined tolerance (6.40 and 6.60 m).

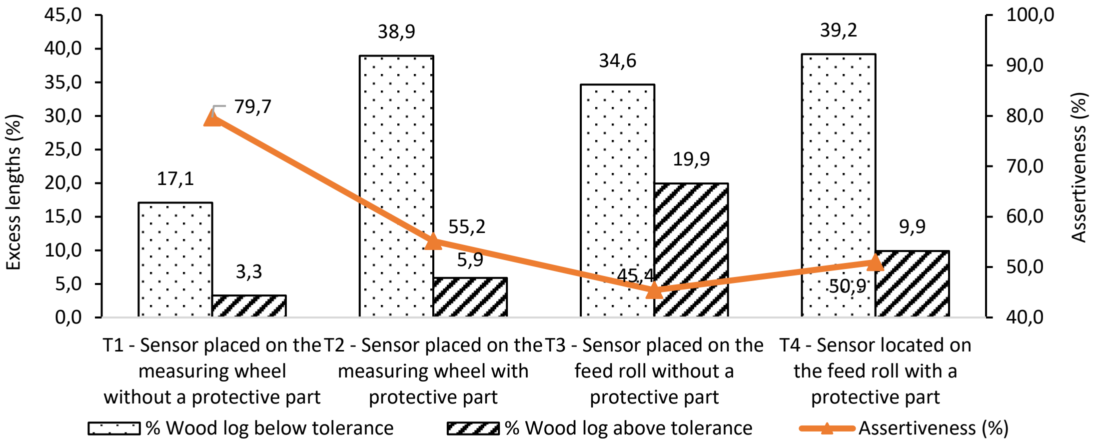

Figure 6. Frequency distribution graph of wood log lengths for an established tolerance of 0.1 m. % of logs below tolerance: logs smaller than 6.40 m; % of logs above tolerance: logs larger than 6.60 m and assertiveness: logs between 6.40 and 6.60 m.

Figura 6. Gráfico de distribuição de frequência dos comprimentos de toras para tolerância estabelecida de 0,1 m. % de toras abaixo da tolerância: toras menores que 6,40 m; % de toras acima da tolerância: toras maiores que 6,60 m e alvo estabelecido: toras entre 6,40 e 6,60 m.

Despite the reduction of 0.10 m in the tolerance limits, it is observed that the assertiveness in logs length of treatment 1 remains superior to the others, presenting a percentage equal to 79.70 within the established limit (6.40 and 6.60 m). Treatments T2, T3, and T4 showed similarity in the portion of log lengths below the defined lower limit, with values equal to 38.9%, 34.6%, and 39.20%, respectively. Assertiveness similarity in the established target (6.40 and 6.60 m) of treatments T2, T3, and T4 are observed, with the respective percentages of 55.20, 45.40, and 50.90.

DISCUSSION

Treatments T1 and T2 (sensors attached to the measuring wheel) showed the best results. This occurrence in length assertiveness is associated with the fact that the measurement wheel is not directly impacted by the wood pulling movement during log processing.

Wood spin occurrence during debarking can be a limiting factor for the excellent functioning of the feed roller sensor (T3 and T4). A work by Nieuwenhuis and Dooley (2006) showed that the errors obtained in logs length could be associated with the head measuring tool, which occurred by counting the number of turns performed by the measuring roller during wood processing. Wood spin happens by feed rollers action with symmetrical helical blades and the resistance wood displacement inside the head. These points create a unique and necessary equation for effective peeling.

The feed roller has a length measurement sensor attached to its axis, so it measures each movement that the roller produces. The linear length can be affected by the diameter and the rotation intensity of the bole in this process. In some situations, trees with larger diameters may be below the established one and smaller diameters tend to have larger logs. This can be explained due to tree rotating movement, as the roller measures in a helicoidal manner. In addition, the traction roller movement causes the wood to slip, implying an error in the length.

The control system of the machine cannot adjust the spin and slip phenomenon, as the measurement pulses typically arrive at the onboard computer. The proposal of a measuring device located in a different position (head measuring wheel), which is not linked to tree traction, guarantees greater accuracy in the measurement, as it eliminates the errors caused by wood spin.

When analyzing the installation protective piece influence, greater assertiveness was observed in treatments T1 and T3 (without the protective piece) about treatments with the protective part (Figure 2). It is noteworthy that allocation defensive part purpose was to guarantee head roller parts useful life, mitigating the impacts when the wood is fractioned. However, it was observed that the piece influenced the final length of the logs as treatments with protective components showed values beyond the target (6.50 m) in comparison to the others. Low assertiveness in operations with the defensive part may occur due to the entrapment of shells, interfering with the measurement made by the sensor.

Processed wood intended for cellulose pulp production requires the absence of bark on the logs. So, in this operation, two or more passages of the head rollers are carried out to perform the wood debarking. In this case, the operator interrupts roll movement, returning after pulling the shaft. This alternative movement changes the shaft measurement to be processed by the equipment (JACOVINE *et al.*, 2005). When analyzing wood processing quality in two mechanized systems, Rosa *et al*. (2014) observed these same factors in the final quality of the wood cutting.

Even with lower values than the treatments without the protective part, it should be observed that the objective of applying the piece is to reduce the maintenance costs. Therefore, the purpose of the allocation is more related to the advantages that this part brings to equipment protection from the roll and not its influence on measurement sensitivity wood length in the head. The advantages of using the mechanical feature to stop the reduction and guarantee a longer useful life for the equipment. As the maintenance of the mechanized set is essential for forestry production, its correct application avoids operational visits, therefore contributing to greater mechanical availability, productivity, and cost reduction (LIMA; OLIVEIRA, 2020).

Moving average SPC charts (Figure 3a) demonstrated that treatments T1 and T2 are considered poor quality operations for the calculated limits (UCL and LCL). In these treatments, special causes can be observed, characterized by red dots below the lower limit of the process graph. According to Martins and Laugeni (2005), errors in the production process identified in SPC charts can be classified by common and special causes in which common cause is when the variables follow a normal distribution and are intrinsic to the process and special causes is when the points found (red) can be eliminated after identifying the anomaly. Occurred reasons are observed through the change in the moving average and standard deviation process parameters.

Treatments T1 and T2 presented significant points below the lower limit (Figure 3a). However, these treatments showed lower standard deviations when analyzing the SPC range graphs (Figure 3b). Considering that the points below the lower limit are caused by special causes, it is possible to conclude that treatments T1 and T2 are the best, as the points in red can be eliminated in further operations or adjustments to the machines. According to Chioderoli *et al.* (2011), special causes in agricultural operations can be linked to several factors such as incorrect equipment adjustment, operator experience, differences in soil conditions, variations in travel speed, and pest attacks.

The treatments T1 and T2 presented lengths below the established limit. This occurrence is justified due to special-cause factors related to the diameter of the shaft, the presence of bark, and the slope of the terrain. Treatments T3 and T4 presented lower points beyond the tolerance limit; however, they presented greater variation about the moving average. Therefore, they are considered with low accuracy due to the high variability around the average.

Companies must adopt a tolerance margin to meet quality criteria and continuous frequency of logs with standard length, suggesting an established target length and minimum and maximum error limits. As shown in the frequency distribution graphs, when representing 0.40 m of tolerance (Figure 4), treatments T1, T2, T3, and T4 presented frequency within the established target corresponding to 99.5% and 99.3%,99.4%, and 97%, respectively. At this level of tolerance, all treatments showed satisfactory results. Therefore, the adoption of this tolerance in the cutting operation makes protective piece use feasible with no need for a preliminary economic analysis.

The decrease in the tolerance to 0.20 meters (Figure 5) reduces the frequency values within the established error limit. In this analysis, treatment 1 stands out, as it presented a higher frequency within the regular target (6.30 and 6.70 m), which was around 95.1%. It is important to point out that this treatment has the sensor attached to the head measuring wheel, confirming the thesis that the installation of the measuring sensor wheel guarantees assertiveness in the length of the logs.

Tolerance reduction to 0.10 m (Figure 6) showed that the assertiveness of treatments T2, T3, and T4 significantly reduced with values corresponding to 55.20%, 45.40%, and 50.90, respectively. In addition, the reduction in the error tolerance caused an increase in samples with lengths below the lower limit. Thus, there is a tendency to reduce the limits for errors in smaller measurements. This occurrence may be related to the manufacturing process requirements in which the length of logs is limited to 7 meters, inducing the operator to perform cuts below the established. Another explanation for shorter cuts is related to operational procedures reported by Mederski *et al.* (2018).

The authors evaluated wood trunk length accuracy and the efficiency of the harvester in oak processing, which showed logs with lengths shorter than expected due to the inverse movement of the feed rollers with the partially-open knives.

The T1 treatment stood out in all evaluations. In the SPC charts, the moving average graphs showed special causes, initially demonstrating to be of low quality but with a lower standard deviation. In addition, in the frequency distribution graphs, this treatment showed greater assertiveness in length in all established tolerance limits.

When analyzing the treatments with a protective piece (T2 and T4), the best performance was observed in the T2 treatment, whose sensor is located on the measuring wheel. In the SPC charts, the T2 treatment presented similar characteristics to the T1 treatment, as special cause points and lower standard deviation were found. Despite the good results found in the SPC charts, the performance of this treatment was not satisfactory when establishing a tolerance limit between 0.20 and 0.10 m. In further studies, a financial analysis is necessary to evaluate whether the installation of protective parts helps reduce the cost of maintenance of parts of the measuring wheel, enabling the use of protection.

CONCLUSION

- The sensor attached to the head measuring wheel without the protective part showed greater accuracy and assertiveness in log lengths.
- Treatments with the sensor attached to the measurement wheel had lower standard deviation and greater assertiveness.
- Protective piece evaluation showed a significant impact on the accuracy of the wood cutting operation, as the treatments without the protective piece were more assertive.

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