Performance of a small eucalypt log sawmill: work productivity, operational efficiency and lumber yield

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Sawmills are components of the wood industry worldwide. The presence of sawmills processing small *Eucalyptus* spp. logs from planted forests has been increasing in countries of the Southern Hemisphere, such as Argentina, Brazil, Chile, South Africa and Uruguay. The general aim of this work was to evaluate the operational performance of a small *Eucalyptus* spp. log sawmill according to its work productivity, operational efficiency and lumber yield. The secondary aim was to analyze the influence of the substitution of the resaw on the lumber yield. The sawmill is located in the state of Espírito Santo, Brazil, and mainly produces pallets for supermarkets. The productivity was assessed from Monday to Friday using the work sampling statistical technique. The operational efficiency was calculated based on the volume (m³) of processed logs/worker/day. For the lumber yield, two treatments (processing methods) were evaluated, using 20 logs per treatment: 1) vertical resaw bandsaw; 2) substitution by a double arbor circular gang saw (multirip). The substitution of the resaw resulted in a significant increase of 8 percentage points in the lumber yield. Based on the results of yield, work productivity and operational efficiency, the sawmill’s performance was low, requiring corrective actions by the managers.

**Keywords:** Sawmilling, Resaw, *Eucalyptus* sp.
INTRODUCTION

According to the Brazilian Association of the Mechanical Wood Processing Industry (ASSOCIAÇÃO BRASILEIRA DA INDÚSTRIA DE MADEIRA PROCESSADA MECANICAMENTE, 2019), the Brazilian timber industry (except furniture) produces mainly lumber, secondary products (e.g., mouldings and flooring), prefabricated house components, veneers and plywood, produced by 53,107 companies in 2018. Of these, 37% are located in the Southeast Region, 2.4% specifically in the state of Espírito Santo.

Although *Eucalyptus* spp. account for the largest area of planted forests in Brazil, with 5.67 million hectares, this wood is not the main raw material handled by sawmills, instead of being consumed mainly for producing pulp and paper and charcoal, besides use as industrial firewood. On the other hand, wood of *Pinus* spp. is the main raw material in the Brazilian timber industry (including sawmills), representing a total of 82% of all raw material in this segment, whereas *Eucalyptus* spp. wood represents just 17% (INDÚSTRIA BRASILEIRA DE ÁRVORES, 2019).

According to data from the Center for Agribusiness Development (CENTRO PARA O DESENVOLVIMENTO DO AGRONEGÓCIO, 2011), sawmills in the state of Espírito Santo almost exclusively process *Eucalyptus* spp. wood, unlike the national pattern. However, most sawmills in Espírito Santo are small operators, according to the Associação Brasileira da Indústria de Madeira Processada Mecanicamente (2019) classification: family businesses, low technological level, raw material not managed for sawing, and no use of artificial drying.

Regarding the evaluation of sawmills, lumber yield is one of the most important aspects because it expresses the conversion of logs into lumber, and by deduction, the revenue obtained and volume of waste generated (slabs, edgings, trimmings and sawdust). Many factors influence the yield, although research has focused mainly on the log diameter (with sorting in diametric classes) and sawing pattern (CUNHA et al., 2015; CUNHA et al., 2016; FERREIRA et al., 2004; JUIZO et al., 2014; MELO et al., 2016; MURARA JUNIOR et al., 2013). Other factors regarding the raw material, such as log taper and length, have also been studied (BONATO JUNIOR et al., 2017; HORNBURG et al., 2012).

Machinery is also an influencing factor, but it has been little addressed, especially concerning the type of saw blade (MELO et al., 2016). For the same operating conditions, circular saws are expected to produce more sawdust than bandsaws, because of the greater kerf, negatively impacting yield (LEITZ 2020; TSOUMIS 1991; WINTERSTEIGER, 2020).

Work productivity and operational efficiency are also parameters for analyzing the performance of sawmills, but they have been less used than lumber yield (ABREU et al., 2005; BATISTA; CARVALHO, 2007; BATISTA et al., 2015; BATISTA et al., 2013). This is explained by the fact they are time-consuming to analyze, resulting in higher costs. However, they have
advantages, especially for diagnosing the company’s production mode to indicate corrective actions to increase productivity and improve the use of manpower and machinery.

OBJECTIVES

The general aim of this work was to evaluate the operational performance of a small *Eucalyptus* spp. log sawmill according to the work productivity, operational efficiency and lumber yield. The secondary aim was to analyze the influence of the substitution of the resaw on the lumber yield.

METHODS

Sawmill characterization

The study was carried out in a small *Eucalyptus* sp. log sawmill located in the municipality of Ibiraçu, state of Espírito Santo, Brazil. The logs were supplied by planted forest operators and ranged from 15 to 20 cm in diameter and 1.9 and 2.6 m in length, with no sorting into diametric classes.

The production line had eight workers and the logs were handled manually (no conveyors or other automation). Some machines were connected to the exhaust system for the removal of sawdust, but the slabs, edgings and trimmings were sorted manually for later chipping. The company produces mainly pallets for supermarkets.

Lumber yield

The lumber yield was evaluated according to two treatments, as described in Figure 1: a) Treatment 1 – original configuration, with a band-resaw, unidentified brand, model and manufacturing year, 800 mm wheels, blade of 100 x 1 x 5,700 mm (width, kerf and length), a 20 HP motor; and b) Treatment 2 – replacement of the band-resaw by a double arbour circular gang saw (multirip), Vantec (Xanxerê, Brazil), model SCM200, manufactured in 2012, with eight saw blades (350 mm diameter, 4.5 mm kerf) per arbour, a lower motor of 100 HP and upper motor of 75 HP. During this test, the multirip was provisionally installed in a position parallel to the productive layout. In both treatments, the resawing of cants was analyzed. It is noteworthy that the band-resaw is a machine designed to resaw large slabs, specifically from tropical wood. However, this machine was adapted for cant resawing and board edging. Resawing the slabs (Figure 1) was equal for both treatments.
During the evaluation, the company was producing slats with nominal dimensions of 15 x 43 mm and variable length (according to the log), for one of the pallet models, according to the sawing patterns shown in Figure 1. Forty logs from the storage yard were measured, 20 for each treatment, representative of those commonly processed by the company. These logs had no top cracks to negatively influence the yield. The debarked volume of the logs, the lumber volume and the yield were determined according to the method of Batista and Carvalho (2007). The logs’ taper was calculated according to the method of the Brazilian Institute for Forestry Development (INSTITUTO BRASILEIRO DE DESENVOLVIMENTO FLORESTAL, 1984). Since the company does not use slats for pallet production with wane longer than 50% of length, these slats were disregarded in the yield calculation. To compare the lumber yield between treatments, Student’s t-test was used at a significance level of 5%.

Work productivity and operational efficiency

Work productivity and operational efficiency were assessed according to methods reported in the literature for other small log sawmills (ABREU et al., 2005; BATISTA; CARVALHO,
The company allowed us to report only the results for Treatment 1.

The work sampling method was the statistical technique used to quantify the ratio of productive work and idle work. The data collection consisted of systematic sampling, by direct observation of the activities performed by the manpower-machine set, every two minutes, during the working hours (nine hours). The activities were classified as working time and idle time, in which the former was obtained by deducting 100% from the latter. The idle time was subdivided into nonproductive work, delays and idleness, and was quantified as a percentage of the total observations classified as idle time. The production was evaluated for five consecutive days (Monday to Friday), in the morning and afternoon shifts, always analyzing the same workers.

The sawmill’s operational efficiency ($m^3$/worker/day) was assessed concurrently with the work sampling method. The number of logs processed by the headrig per shift was registered and then multiplied by the mean log volume, according to the measurements to determine lumber yield.

RESULTS

The results of the lumber yield analysis are shown in Table 1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment 1</th>
<th>Treatment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log diameter (cm)</td>
<td>15.2 (11.0)</td>
<td>16.8 (12.2)</td>
</tr>
<tr>
<td>Log taper (%)</td>
<td>0.59 (48.7)</td>
<td>0.55 (71.3)</td>
</tr>
<tr>
<td>Lumber yield (%)</td>
<td>33.3 (15.5)</td>
<td>41.1 (15.4)</td>
</tr>
</tbody>
</table>

Numbers in parentheses are the coefficient of variation (%).

For a proper comparison of the effect of the resaw machine on the lumber yield, the log diameter, log taper and lumber dimensions needed to be homogeneous for both treatments, so as not to bias the results. The logs’ diameters were homogeneous because the difference (1.6 cm) between treatments was within the ranges commonly used for sorting reforestation logs into diametric classes (2 to 3 cm). The logs’ tapers of both treatments were smaller than 1% and had the best classification (superior), according to criteria established by the Instituto Brasileiro de Desenvolvimento Florestal (1984). Regarding the dimensions of the products, in both treatments, the lumber was the same (slats), according to the classification of standard NBR 14807 (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, 2002).
According to the statistics $F_c (0.40)$ and $t_c (0.0002^*)$ of the yield data, the variances of the treatments were homogeneous and there was a significant difference between their means (95% probability). The results of operational efficiency and work productivity shown in Figures 2 and 3, respectively. On Monday the production line had eight workers and on the other days only seven, by order of the manager. According to the work sampling method, working time was considered whenever, during the systematic sampling, at least one of the machines produced lumber.

The mean operational efficiency (Figure 2) of the sawmill was 2.43 m³/worker/day, ranging from 0.73 m³/worker/day (Monday) to 4.00 m³/worker/day (Tuesday), figures that can be considered below the mean for its technological level in comparison with reference data from the literature (ROCHA, 2002). Working time was predominant concerning idle time (Figure 3).
3), representing 72 % (mean) of the daily working hours, but did not reach the minimum of 75 % established by Martins and Laugeni (2003). However, excluding the Monday afternoon shift from the assessment, the mean productive work would be equal to 76 %, exceeding the referred target. Likewise, the mean operational efficiency of the sawmill would be greater, 2.86 m³/worker/day, when this shift is excluded from the analysis.

Operational efficiency was zero on Monday afternoon because of a power outage during part of this shift, caused by a natural phenomenon. Even after power restoration, the company’s management decided to redirect the workers from the headrig to functions other than lumber production. Hence, the workers in charge of the band-resaw processed the accumulated slabs in the morning shift. That is why, even with zero operational efficiency (Figure 2), there was productive work (Figure 3), although it had low value (36 %) because of the long idleness (Table 2).

The idle time was calculated by deducting 100% from the working time, and Table 2 presents its subdivisions into nonproductive work, delays and idleness, according to the classification described by Abreu et al. (2005).

<table>
<thead>
<tr>
<th>Days</th>
<th>Mean idle time (%)</th>
<th>Nonproductive work (%)</th>
<th>Delays (%)</th>
<th>Idleness (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday</td>
<td>45</td>
<td>21</td>
<td>10</td>
<td>69</td>
</tr>
<tr>
<td>Tuesday</td>
<td>21</td>
<td>69</td>
<td>7</td>
<td>24</td>
</tr>
<tr>
<td>Wednesday</td>
<td>28</td>
<td>36</td>
<td>54</td>
<td>10</td>
</tr>
<tr>
<td>Thursday</td>
<td>22</td>
<td>30</td>
<td>66</td>
<td>4</td>
</tr>
<tr>
<td>Friday</td>
<td>24</td>
<td>61</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>Mean</td>
<td>28</td>
<td>43</td>
<td>31</td>
<td>26</td>
</tr>
</tbody>
</table>

Tuesday was the day of highest operational efficiency (4.00 m³/worker/day) because the sawmill worked accumulating the slabs, that is, the headrig was used to the maximum, processing more logs on this day since no slab resawing occurred. It is noteworthy that the highest mean working time (79 %) and the shift with the highest absolute working time (82%, afternoon) occurred on this day. Tuesday’s results can be interpreted as caused by the performance of the headrig and the band-resaw since they were the only machines evaluated.

Similar to Monday afternoon, operational efficiency was zero on Wednesday morning. In this shift, the sawmill only resawed the slabs produced the day before, and some of the workers performed functions other than lumber production. The productive work of this shift (71 %) can be interpreted as the performance of the line of slab resawing because the corresponding machines were the only ones evaluated. This operation continued for part of the afternoon shift, with the beginning of log breakdown afterwards, which resulted in low
operational efficiency (1.26 m³/worker/shift). On the other hand, the working time increased slightly (two percentage points).

The operations on Thursday and Friday were identical to those on Tuesday and Wednesday, respectively, and reflected how the company worked in the evaluated week: a) on one day, the headrig and the band-resaw operated; b) the next day, slab resawing occurred, after which situation “a” was repeated. Situation “a” was characterized by greater operational efficiency and working time.

The sawmill processed 358 logs (average) per day, ranging from 121 logs on Monday to 583 on Tuesday, resulting in a volume of 15.02168 m³ of logs per day, meaning it is a small sawmill. Even considering the day on which the largest volume of logs was processed, the sawmill’s classification would not change, as it would result in 24.46268 m³/day, below the 50 m³/day thresholds established by Rocha (2002).

The mean idle time was 28 %, and similar to the discussion of work productivity, it would be 24 % if Monday were excluded from the analysis. On average, nonproductive work activities were the most observed in the composition of idle time, followed by delays and idleness, with 43 %, 31 % and 26 %, respectively.

The events that contributed to nonproductive work were, in order of importance: i) log handling; ii) empty return of the headrig carriage; iii) corrective maintenance during production; iv) internal machinery set-up; and; v) exchange of blades of the headrig and band-resaw.

The activities that contributed to the delays were, in order of relevance: i) pause in the production process (allocation of workers to carry out other activities within the company) and; ii) clean-up and sawdust collection. Idleness was mainly characterized by i) operators’ personal needs; ii) electrical power outage, and iii) insufficient log supply.

DISCUSSION

According to the results of the yield comparison (Table 1), the mean lumber yield of Treatment 2 was higher than Treatment 1, because the new sawing pattern was more suitable for the production of slats, resulting in a greater proportion of slats with less than 50 % wane in length.

The mean yields were 33.3% in Treatment 1 and 41.1 % in Treatment 2, both of which are below expectations compared to the range of 45 % to 55 % considered normal for hardwoods (ROCHA, 2002). Three factors were mainly responsible for these results: i) the small diameter of the logs; ii) a large number of breakdown operations with the circular saw, which has thick kerf; and iii) the small dimensions of the slats, which require a large number of cuts, increasing the production of sawdust.
In a work by Ferreira et al. (2004), the mean yield of the clone with the smallest diameter (25.7 cm) of a hybrid of *Eucalyptus* sp. was equal to 50%. The logs were broken down into boards with a nominal thickness of 30 mm, using a balanced live sawing pattern, parallel to the pith (split taper), edged to maximum width, and the slabs were resawn into slats. In this case, both the logs’ diameter and the dimensions of the main product were larger than those in this study, resulting in higher yield.

In another sawmill that processed *Eucalyptus* sp. into 20 x 30 mm slats, the mean yield was 53.6 %, also higher than in this study. For this comparison, the effect of the product was weaker, because they were equivalent. However, the mean diameter of the thinnest end of the logs was 26.1 cm (BATISTA et al., 2015), greater than in this study.

The results presented here reflect the reality of many small sawmills that make pallets, which are products with low added value. To reduce manpower cost, which is among the biggest problems in the vision of sawmill entrepreneurs in Espírito Santo (CENTRO PARA O DESENVOLVIMENTO DO AGRONEGÓCIO, 2011), in many situations during the week, production lines are do not have sufficient workers to operate all machines simultaneously. Hence, the logs are not fully broken down, as in medium and large sawmills.

This is not the only problem that causes small sawmills to have low operational efficiency. Other factors are the lack of production planning and control; the use of a single-blade bandsaw as headrig for small logs of *Eucalyptus* sp.; and resawing of slabs, which is a low-productivity operation that requires the mobilization of at least two workers, all of which cause low lumber yield.

The adequacy of the machinery to the logs has a direct influence on operational efficiency. For comparison purposes, another small-log sawmill that processed *Eucalyptus* sp. presented mean operational efficiency of 4.96 m³/worker/day (BATISTA; CARVALHO, 2007), i.e., twice that found by us. The machinery of that sawmill was suitable for its logs (ranging from 13.2 cm to 27.3 cm), with a double arbour circular saw (two saw blades per arbour) as headrig for the production of one cant per log, followed by a multirip (similar to Treatment 2) for resawing the cants, and resawing the slabs in a line like in this study.

The log volume, dependent on the diameter, significantly influences the operational efficiency, since it is used as the numerator in the efficiency calculation equation. For example, a sawmill with the same machinery and technological level as in this work presented mean operational efficiency of 5.06 m³/worker/day (BATISTA et al., 2013). However, the diameter of the *Eucalyptus* spp. logs was larger (ranging from 10 to 40 cm).

The product is also an important factor since logs processed into larger products (which require fewer cuts) are processed more quickly. The sawmill evaluated by Batista et al. (2013)
also produced slats, but it produced larger pieces as well (boards and rafters, for example), positively influencing the operational efficiency.

The distribution of idle time in the sawmill was heterogeneous over the production days, in which idleness predominated on Monday, nonproductive work on Tuesday and Friday, while delays were more pronounced on Wednesday and Thursday. The mean idle time (28 %) was slightly less than the 30 % reported by Batista et al. (2015), who evaluated a similar sawmill in terms of raw material, machinery, technological level, manpower and product, which is also reflected in the similar operational efficiency between the two sawmills.

Even when compared to sawmills with significantly greater idle time, such as the one evaluated by Batista and Carvalho (2007), who reported 46 %, the operational efficiency was still lower. In these last two comparisons, the negative effect of the small diameter of the logs stands out regarding the sawmill analyzed here, along with the negative effect of the inadequate machinery for the raw material.

Analyzing the idle time activities, the causes of the low operational efficiency of the sawmill were: i) no log processing during the Monday afternoon shift, due to electrical power outage; ii) an insufficient number of workers on the production line, due to reallocation to other areas of the company, such as the operation of tractors; iii) frequent breakdowns in the exhaust system, which caused production stoppage to clean the resawing circular saw (resawing slab line); iv) worker idle time; v) use of a single blade bandsaw as headrig; and vi) inadequate use of the band-resaw for resawing the cants and edging the flitches into slats.

CONCLUSIONS

The replacement of the band-resaw by a multirip for resawing the cants resulted in a significant increase of eight percentage points in the lumber yield.

The sawmill’s lumber yield was below average, regardless of the treatments analyzed, mainly influenced by the small diameter of the logs and the small dimensions of the lumber (slats).

The mean operational efficiency of the sawmill was lower than that of other companies with the same features, representing low productivity.

The mean working time was less than the minimum recommended by the literature, demanding corrective actions by the company.

Based on the performance metrics analyzed, the sawmill’s performance was low.
REFERENCES


