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Operational analysis of the semi-mechanized harvesting in eucalyptus stands in south Tocantins

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Abstract: This work aimed to operationally analyze the semi-mechanized forest harvesting activity for charcoal production in the forest cultivation in the state of Tocantins. The study was conducted in an experimental area of the farm “Vale Verde”, located in the municipality of Aliança do Tocantins-TO. Was evaluated or semi-mechanized harvesting system composed by crawler tractor, chainsaw, stump truck and farm tractor with attached trailer. The same evaluated in mechanical availability, economical and efficient. The results show that a reduction activity takes longer, consuming 85% of the downed duty cycle, within a work cycle of 74% consumed tracking and delimbing element processing activities and required 46% extraction or item element processing activities. of activity time. All activities selected mechanical availability below 80%. The highest operational efficiency value found was 85% in felling activity and the lowest in activity extraction with 51%. The values selected in this study, serving as a basis for producers in the region, establish the operational planning of semi-mechanized forest harvesting activities.

Key words: Curves system, Study of times and movements, Operational efficiency.

Análise operacional de colheita semimecanizada em povoamentos de eucalipto no sul do Tocantins

Resumo: Este trabalho objetivou analisar operacionalmente a atividade de colheita florestal semimecanizada para a produção de carvão vegetal em povoamento florestal no sul do estado do Tocantins. O estudo foi conduzido em uma área experimental na fazenda “Vale Verde”, localizada no município de Aliança do Tocantins-TO. Foi avaliado o sistema de colheita semimecanizada composto por trator de esteira, motosserra, caminhão toco e trator agrícola com reboque acoplado. O mesmo avaliou a disponibilidade mecânica, eficiência operacional e produtividade. Os resultados mostram que a atividade de abate demandou maior tempo, consumindo 85% do ciclo operacional da derrubada, dentro do ciclo de trabalho da atividade de processamento o elemento traçamento e desgalhamento consumiu 74% e na atividade de extração o elemento carregamento demandou 46% do tempo da atividade. Todas as atividades apresentaram disponibilidade mecânica abaixo de 80%. O maior valor de eficiência operacional encontrado foi 85%, na atividade de derrubada e o menor na atividade extração com 51%. Os valores obtidos neste estudo, servirão como base para produtores da região estabelecerem planejamento operacional das atividades de colheita florestal semimecanizada.

Palavras chave: Sistema de toras curtas, Estudo de tempos e movimentos, Eficiência operacional.

Introduction

The Brazilian forest potential is huge, with an area of 7.83 million hectares of reforestation that accounts for 1.3% and 6.2% of industrial GDP in the country, reaching a total revenue of R$ 86.6 billion. The Brazilian planted tree industry is currently a world reference for its performance based on sustainability, competitiveness and innovation. Aimed at the production of pulp, paper, wood panels, laminate flooring, charcoal and biomass, planted trees are the source of hundreds of products and by-products present in our homes and daily activities, playing a key role in mitigating the effects of climate change and climate change various environmental services (Ramage et al., 2017).

Harvesting wood is the most important stage from an economic point of view, as it represents 70% of the costs of the forest enterprise and comprises three basic activities, namely cutting and processing, extraction and transportation (Lijewski et al., 2017).

There are some harvesting methods and systems, which in turn is influenced by forest species, settlement age and timber destination (Chaudhary et al., 2016). The cut-to-length system is the most widely used in Brazil, and in this method trees are processed at the felling site and transported to the roadside in the form of logs up to 6 meters long (Engler et al., 2016). This system has the advantages of increasing productivity, reducing production costs, requiring a lower degree of mechanization and ease of travel over short distances, low aggression to the environment especially in relation to the soil (Garren et al., 2019).

Tree felling is the first logging operation that can be done semi-mechanically, using a chainsaw, and mechanized using machines. Following is the delimbing that can be done manually, semi-mechanized and mechanized (Engler et al., 2016). According to Salmeron (1980), the delimbing yield will depend on the diameter of the tree and branches, the length of the trunk and which tool will be used. The tracing of logs in pre-established dimensions can also be performed in a semi-mechanized and mechanized manner. Productivity is based on tree diameter, length of sticks, which tool will be employed, how trees are arranged after fall, operator training and site topography (Engler et al., 2016).

Logging is the process of removing wood from the field and bringing it to a temporary storage location, such as a roadside, a carrier, an intermediate yard or a processing site. The extraction of this wood ends up becoming one of the critical points of the forest harvest, requiring operation planning in order to use the most suitable equipment within each system. Factors that can influence forest extraction are: field density, site topography, soil type, volume of each tree, transport distance and capital availability (Bicknell, Struebig & Davies, 2015).

The study of times and movements is the systematic study of work systems with the objective of developing the best system and method within the various limitations (Lopes, et al., 2017). Regardless of the degree of mechanization of the harvest, the study of times and movements is used to evaluate the system, allowing corrections or changes in the production process to be made in order to improve results (Dimou & Milios, 2015).

In Brazil there is a great diversity of wood harvesting systems. The choice for one system or another is due to the availability of technological and financial resources and the quality of the forests, as well as the edaphic, topographic and demand factors (Fardusi et al., 2017). Since the southern region of the state of Tocantins is characterized by low annual average increment Eucalyptus sp. stands, small producers with little financial resources and the destination of wood for the charcoal sector, the need arose to adopt the system. of short logs (low degree of mechanization) with full utilization of trees (roots) to increase wood yield per field. Normally companies that adopt this system do not take advantage of the roots, thus generating a lack of technical and economic information about this type of system.

Given the above, eucalyptus producers in the southern region of Tocantins do not have a database to optimize the shortwood system adopted in the region. This work aimed to evaluate the mechanical availability, operational efficiency and productivity of harvesting activities in this system, which will serve as a basis for producers in the region to establish operational planning of harvesting activities.

The objective of this work was to evaluate the cutting and extraction operation of Eucalyptus sp. using a bulldozer, chainsaw and agricultural tractor with cart in the municipality of Aliança do Tocantins - TO, for charcoal production.

Material and methods

The research was carried out in homogeneous forest stands of the first cut eucalyptus genus, eight years old, for charcoal production.

The experimental area is located in the south of the state of Tocantins, in the municipality of Aliança do Tocantins. The area has 105 hectares, flat relief, average altitude of 330 m above sea level, climate classified as Tropical Savannah (Aw) according to Köeppen classification, presenting the driest season in winter, where the driest month has a lower rainfall. than 4% of total annual precipitation, average temperature of 26.1 °C and average annual rainfall of 1617 mm.

The soil present in the study area was classified as Latossolo Vermelho distrófico (Santos et al., 2018). According to pre-harvest inventory records, at harvest time there were approximately 1660 trees per ha with 3 x 2 m spacing and an average bark volume of 170 m^3ha^{-1}.

The harvesting system evaluated was cut to length, where the tree is processed inside the field. This system consisted of tree felling (root exposure) operations, with a crawler tractor, chainsaw trimming and delimbing, rowing, manual (assisting) and extraction (bucket) with attached tractor trailer and "stump" truck.

The choice of the short log system by the farmer was for a specific reason, the area in question would be used for agriculture, thus the need for root removal. In addition to this system, allow a greater utilization per tree, since the roots were also used for charcoal production.

Machine Characterization

Data were collected between May and June 2019, the work was divided into three stages (Description 1). The first was the assessment of

the felling with a crawler tractor, it felled the trees with their roots in a 1 row eit. After felling, a soft burn was done in the area for 7 to 14 days to partially remove branches and leaves from the trees and to drive away venomous animals from the field, facilitating subsequent operation.

The second step was the chainsaw operator processing, which started the activity after burning in the area. The processing was done in a three-line stream, the logs were drawn at 1.5 m in length.

Before the third stage (extraction) was performed, the area was made by rowing (logging) of the logs drawn along the cutting line. This activity was done manually by a helper, with the purpose of cleaning the rail for the extraction machine passage and assembling the logs for easy loading. The activity was not evaluated in the study due to the lack of standardization, it was not possible to evaluate the volume of mulch wood at the end of the workday.

The third and last stage was the extraction (bucket), made by a "stump" truck and an agricultural tractor with a trailer, both working simultaneously inside a field. Each machine entered a line and was operated by a worker. Each worker was loading the roped logs into the load compartment of his machine. After loading, the machines moved to the charcoal furnace area, which was in the vicinity (<500 m) of the field. In the area of the ovens, the machines were unloaded by the operator himself by hand.

All activities started around 6am and did not have a fixed workday. Because the form of payment was for productivity, workers determined the length of their workday. Because it was exhausting work, everyone chose to start early in the morning to avoid the hours with the highest temperatures, so the hours worked per day of each activity varied widely.

The methodology used for the study of times and movements was the continuous time, where there is no stopwatch. The times of the partial elements of the felling, tracing, delimbing and extraction activities were obtained according to the time study (Description 2).

According to the methodology proposed by Barnes (1999), a pilot study was initially carried out in the study area to define the minimum number of observations required in order to provide a sampling error of a maximum of 10% through equation 1:

$$n \geq \frac{t^2 + CV^2}{E^2} \qquad (1)$$

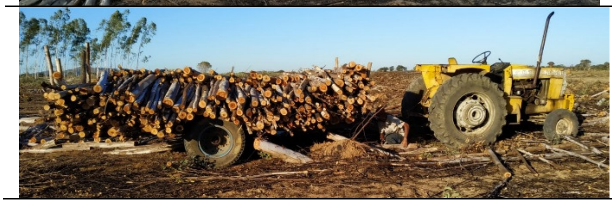
n = minimum number of operational cycles required;

t = t value (Student table) for desired probability level degrees of freedom (n-1);

CV = Coefficient of variation (%);

E = Allowable error stipulated for the job (10%).

Description 1 - Characterization of the machines used in the study.

Machine	Description
	Bulldozer; Model: Fiatallis AD7B; Power: 92CV; Year: 1982
	Chainsaw: MS 361; Displacement (cm³): 59; Chain 26 RS 3/8 ”; Weight (kg): 5.6; Power (kW / hp): 3.4 / 4.6
	Toco truck; Mercedes 1113; Power (hp): 130; Year: 1970
	Tractor: CBT 8240; Engine: Perkins; Power: 85 hp; Year: 1986

Description 2 -Time distribution of partial elements of felling and processing activity.

Partial Elements	Description
Displacement	Time the machine has moved to the cutting edge.
Slaughter	Time the crawler tractor touches the tree until it touches the ground.
Maneuver	Time after felling the last tree from the eit until the crawler tractor moves to start felling the first tree in the next row.
Break	Stop activity for various reasons.
Heating	Time the machine was turned on, until the time it started traveling to the field.
Empty offset	How long the machine has been idling after being unloaded and leaving the seat to the field.
Full offset	Time the machine has made the full displacement of the field to the ovens after being loaded.
Loading	Time from the moment the first log was placed on the machine until the last log was placed.
Unloading	Time the first log was removed from the machine until complete unloading.
Break	Stoppage of activity for various reasons.

It can be observed that during the work, 200 cycles of the felling activity with the crawler tractor were sampled, being the minimum required by the sampling were 62 cycles, 35 cycles of the chainsaw processing activity, being required 24.06 by the sampling. , and in the extraction activity made by the agricultural tractor and stump truck were sampled 10 cycles, being required 5 by sampling.

Mechanical availability is the percentage of time the machine is mechanically fit for the job, considering the time it is repairing or maintaining. Being expressed by equation 2 (Diniz et al., 2017).

$$Dm = \frac{H - TPM}{H} \ x \ 100 \qquad (2)$$

Dm = Degree of mechanical availability in %;

H = Total hours (H);

TPM = Time the machine was maintained.

According to Oliveira, Lopes and Fiedler (2009) operational efficiency is the percentage of time worked actually related to the total time scheduled for a journey. Expressed by equation 3:

$$Eo = \frac{He}{He + Hp} \ x \ 100 \qquad (3)$$

Eo = operational efficiency in %;

He = Hours worked effectively;

Hp = Hours of operational downtime.

The determination of the productivity ($m^3 \ h^{-1}$) of the activities was estimated by the average volume per tree, provided by the pre-cut inventory table, and its value multiplied by the number of trees felled, drawn and extracted within the hours actually worked. Expressed by equation 4:

$$Prod = \frac{(na \ x \ va)}{He} \qquad (4)$$

Prod = Productivity in ($m^3 \ ha^{-1}$);

na = Number of trees harvested in a workday;

va = Average volume per tree in m^3;

He = Effective working hours.

Results and discussion

The percentage distribution of the times that make up the felling activity is presented in Figure 1A. The values represent the percentage time each partial element consumed within the operational cycle of the felling activity. The 2% travel time is due to the crawler tractor remaining in the field at the end of the workday, drastically reducing the time spent traveling**.**

The longer time of the felling operational cycle was destined to the felling operation (85%), this fact is due to the longer length of the tree line of the field (approximately 1,000 m) and the mechanization of the activity (less physical effort), allowing the performing the operation several times during the cycle. Noting that the working hours of this operating cycle were determined by the operator, they often lasted 4 hours a day.

The time spent with the maneuver was 8%, corroborating with the fact that the length of the cutting line is long.

According to Nascimento et al., (2011) evaluating Feller-buncher felling activity in a eucalyptus stand, obtained felling values of 66% and displacement of 21%. These smaller values for slaughter and larger for displacement compared to those found in this study, are probably due to the length of 1000 m of the lines, and the tractor always be inside the field.

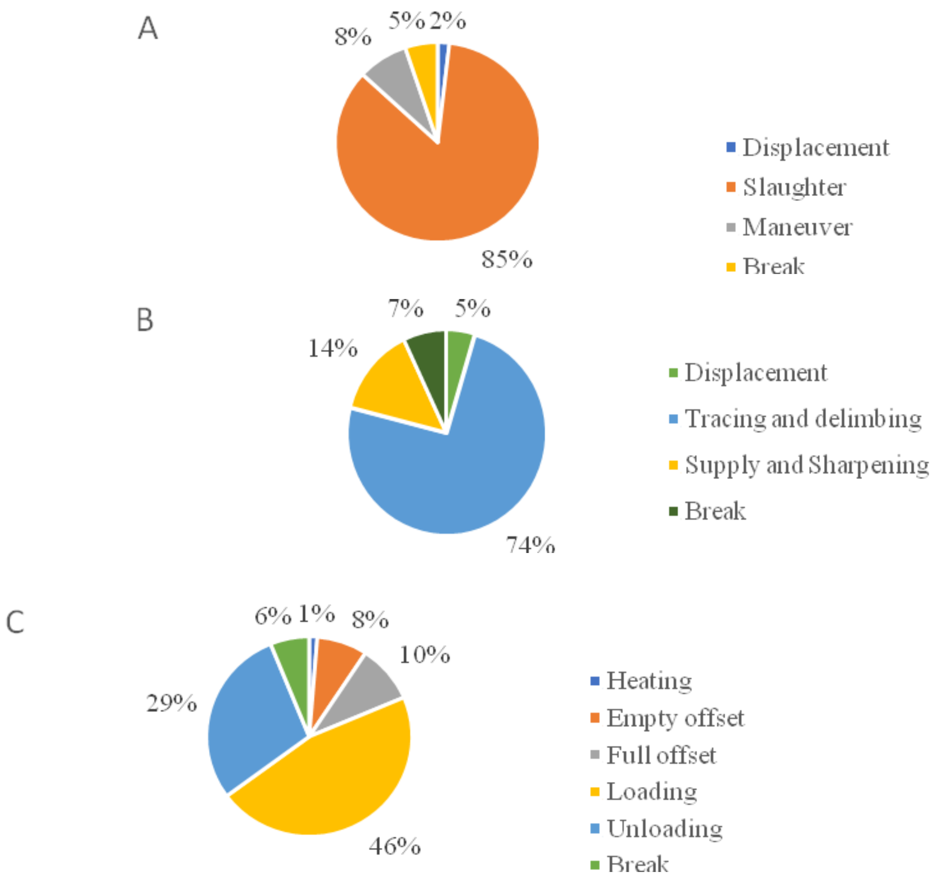
The percentage distribution of the times that make up the processing activity and extraction activity is presented in Figure 1B. Within the work cycle of the evaluated activity, the element tracing and delimbing was the one that consumed the longest time (74%). This fact is due to the tracing of trees in 1.5 m torches and the proximity between them, reducing the travel time between a traced tree and another to be **traced.**

The second longest time was from sharpening and refilling operation, 14% of the total cycle time. This can be explained by the need to refuel the machine several times during the day and blade sharpening is of great importance for productivity as a blade that does not have a good sharpening compromises cutting.

According to Gonçalves et al. (2016) evaluating semi-mechanized harvesting activity in southern Espirito Santo, obtained values of 48% in the measurement and tracing operation. The higher values found in this study compared to the author cited are probably due to the fact that the trees are closer, decreasing the travel time within the activity area and possibly being a shorter workday, providing higher productivity.

The partial loading element was the one that demanded the longest time (46%) of the total cycle. This fact is explained by the operation being performed by a single worker, where he manually loaded the trailer with the logs and still operated the machine displacement within the field.

Figure 1 - Timing arrangement of the towing activity with a crawler tractor; disposal of processing activity times with the chainsaw and disposal of extraction activity with stump truck and towed agricultural tractor.



The empty and full displacement elements required 18%. The high level of depreciation of the machines contributed to lower travel speed and consequently time consumption in the activity.

Unloading consumed 29% of total activity time, 37% more efficient than loading activity, as it was done with the machine stationary at one location, and logs were stacked on the ground, making the activity much faster.

According to Fiedler et al. (2017), evaluating forwarder in eucalyptus forest harvesting systems, obtained loading and unloading values together of 80% and displacement of 13%. The lower loading and unloading values found in this study are probably due to the smaller load compartment of the machines, consequently the loading and unloading time is shorter. For the displacement values higher than the one presented by the aforementioned author, it is probably due to the high depreciation of the machines, slowing down and increasing the activity time. Mechanical availability values are presented in Table 3.

Table 3 - Mechanical availability, operational efficiency and productivity values of the machines evaluated in cutting activities, processing and extraction

Activities	Mechanical Availability (%)
Knocked down	58
Processing	72
Extraction	50
Activities	Operational efficiency (%)
Knocked down	85
Processing	69
Extraction	51
Activities	Productivity ($m^3 h^{-1}$)
Knocked down	54.62
Processing	7.12
Extraction	7.84

All activities presented mechanical availability below 80%, a value considered ideal for forest harvesting machines. Silva et al. (2010), found values of average mechanical availability of harvesting machines (Harvester) of 90.3%, while Linhares et al. (2012) found 92% for the extraction machine (Forwarder). The mechanical availability of forest machines is around 92% for new equipment and 85% for equipment with longer use (Malinen et al., 2016).

Very low values of mechanical availability directly affect the productivity of the activity, as it reduces the available time worked, consequently negatively affecting the harvesting activities. Increasing the availability of a machine implies reducing the number of failures that occur, increasing the speed with which they are corrected, and improving work and logistics procedures, as well as the interdependence of these factors (Anderson & Mitchell, 2016).

According to Peloia and Milan (2010), measuring and controlling the operational performance of forest machines is fundamental to control and assist in decision making, from strategic to operational level. The operational efficiency values are presented in Table 3.

Operational efficiency values varied widely within activities. The highest value (85%) was found in felling activity and the lowest (51%) in extraction activity. The literature recommends a minimum operational efficiency of 70% for forest harvesting machines (Allman et al, 2017).

The higher operational efficiency of the felling may be due to the activity being the only one among the others to perform the operating cycle in a fully mechanized manner, the higher the degree of mechanization of the activity usually the higher the operational efficiency. According to Linhares et al. (2012), the operational efficiency found can be considered satisfactory, however, it is possible to increase it, reducing the hours in which the machines were stopped and, consequently, increasing the effective working hours.

The low operating efficiency of the extraction can be explained by operator wear and tear when carrying out the loading operation manually. The more physical effort the activity requires, the longer the break time during the work cycle, thus impairing the efficiency of the operation. Another factor is the high degree of depreciation of the machines used in the activity, causing increased downtime.

To increase the efficiency of machinery and equipment in forest harvesting, it is necessary to know the reasons that cause the waste of time in activities, periodically perform preventive maintenance, properly plan the wood harvesting system and reduce the time that these machines are stopped (Obi & Visser, 2017).

The productivity values of forest harvesting operations are presented in Table 3. The felling had the highest productivity with 54.62 $m^3 h^{-1}$, being a mechanized activity, does not require as much physical effort of the operator as in the other activities evaluated. Gonçalves et al. (2016) found a productivity of 33.75 $m^3 h^{-1}$ for the same activity. The higher value of felling observed in this study can be attributed to the operation factor being done in a fully mechanized way, different from that evaluated by Gonçalves et al. (2016), who used a chainsaw.

Processing presented the lowest productivity of harvesting activities with 7.12 $m^3 h^{-1}$. Because it is performed with chainsaw is the activity with the lowest degree of mechanization among the others evaluated, therefore, has a lower yield.

Conclusions

All evaluated activities showed low mechanical availability for forest harvesting machines.

The activities with higher degree of mechanization presented higher operational efficiency values.

Mechanical availability, operational efficiency and productivity values in semi-mechanized harvesting activities evaluated in this study will serve as a basis for local producers to establish operational planning of harvesting activities.

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