TreeDimensional Journal, Vol. IX, e022001, 1-5, 2022
DOI: https://doi.org/10.55746/treed.2022.04.001

Efficiency and productivity of skidder dragging full-trees of *Eucalyptus* sp.

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Abstract
The development of activities in the forestry sector is constantly evolving. The constant search for improvements in the production system in order to increase production and reduce costs are, therefore, necessary to maintain the growth of forestry. The forest harvesting stage corresponds to a large part of the financial amount spent on the activity and, therefore, it becomes the target of constant studies aiming at its improvement and evolution. The objective of this study is to carry out a technical analysis of the operation of a forest machine skidder operating in the drag of a eucalypts stand in the whole tree system. The technical analysis encompasses factors such as the study of times and movements, operational efficiency and productivity, evaluating the performance of the machinery for three different drag branch distances. In the study of times and movements, the operations "travel without load" and "travel with load" were the operations that demanded the longest total cycle time. The operational efficiency of the machinery approached 90% and the productivity of the skidder decreased according to the increase in the distance from the skidding branch, being in the order of 19.36 m^3. h^{-1} for the 100-meter skid road, 14.01 m^3. h^{-1} for the 200-meter skid road and 8.35 m^3. h^{-1} for the 300-meter skid road.

Keywords
Forest Harvesting — Operational Efficiency — Mechanization — Forestry Machines — Logistics

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1. Introduction

The search for renewable energy sources, such as the products from eucalypts energy farms, is a current issue, given the increase in global concern that aims to mitigate the advance of the effects of global warming, through the reduction of energy production generated by the burning of fossil fuels (Sette et al., 2020; Freitas & Silva, 2020).

The Brazilian planted tree sector, according to the report by the Brazilian Institute of Trees (*Instituto Brasi-leiro de Árvores*, 2020), is responsible for a share of 1.2% of the national gross domestic product (GDP), adding up to a gross revenue of more than BRL 97 billion, having grown 12.6% in the period between 2018 and 2019 (IBÁ, 2020). Also, according to the report presented, the sector's exports represent 10% of the entire amount handled by Brazilian agribusiness, which contributes to the entry of hard currency into the national market.

Recent surveys indicate that the area planted with *Eucalyptus* sp. in the national territory is about 6.97 million hectares (IBÁ, 2020). The main uses of eucalypts are linked to the pulp and paper industry, metallurgy and steel – as inputs to the boilers, in addition to the furniture industry and plywood and reconstituted wood panels. Due to excellent climate and soil conditions and the constant genetic improvement and forest management techniques, the productivity of *Eucalyptus* sp. in Brazilian territory reached a value of 35.3 m^3. ha^{-1}.$year^{-1}$ in the period 2018 – 2019 (IBÁ, 2020).

Harvesting is the forestry operation that concentrates most of the company's financial expenses on the silvicultural process (Teixeira et al., 2018; Miyajima et al., 2020). Throughout the advance of this activity in Brazil, there was a process of gradual mechanization of the operation, which aimed not only at increasing production, but was also linked to the reduction of operating costs related to the harvest (Lopes et al., 2007).

For timber extraction The most used machines for timber extraction are the skidder and the forwarder. Determining the influence of variables related to the efficiency and productivity of such cutting and forest extraction ma-

Received: 2022/03/07 | **Accepted:** 2022/04/19 | **Online published:** 2022/06/13

chines, aims to provide subsidies for the planning of forest operations, aiming greater productivity and lower operating costs. Such analysis is one of the tools that provides technical basis for improvement processes involving harvesting, being fundamental for forestry planning and for maintaining the viability of the enterprise.

Therefore, this study aims to verify the efficiency and productivity operational of the skidder, through the method of time and motion analysis, in the full-tree dragging of *Eucalyptus* sp., in three different lengths of skid roads.

2. Materials and Method

2.1 Characterization of the study area

The study was carried out in a plantation of *Eucalyptus grandis* W. Mill ex Maiden x *Eucalyptus urophylla* ST Blake (E. urograndis), located in the municipality of Ipameri – Goiás, at 17º 42'35" S and 48º 07'40", with an average altitude of 808 m. The climate of the region, according to the Köppen classification, is of the mesothermic Aw tropical savanna type (de Morais Júnior et al., 2012). The average annual rainfall is 1,750 mm, distributed similarly to what occurs in most of the Brazilian Savanna, with a rainy season that starts in mid-October and lasts until the beginning of April, and a dry season that occupies the complementary period of the year.

The soil was classified as a dystrophic yellow-red Latosol, according to the classification by dos Santos et al. (2018). Soil preparation based on chemical analysis was carried out with application of limestone, gypsum and forest subsoil. The control of ants was done throughout the region through the application of sulfluramid, and the control of invasive plants was done with glyphosate.

The process of harvesting a plantation of the hybrid E. urograndis was evaluated, the implantation of the system was made with a spacing of 3 x 1 m being managed through the high forest system with the cutting of the individuals carried out at 7 years. The harvesting system used was the full-tree system, where a feller-buncher cut and piled the trees inside the forest stand.

2.2 Data collection

For this study, the operational cycle of a John Deere track-skidder model 1648, was analyzed without variation on the operator. The operational cycle was divided into six stages, as follows:

i. No-load travel time (NL);

ii. Loaded travel time (WL);

iii. Personal time (PT);

iv. Maneuver load time (MT);

v. Unloading maneuver time (UT); and

vi. Mechanical interventions time (MI).

To determine the variables of interest: operational efficiency and productivity of the skidder, a technical evaluation was carried out based on the study of times and movements considering the stages of the operational cycle. Such technical evaluation was carried out in 3 different lengths of skid trails: 100, 200 and 300 meters, and for each distance 6 plots were marked.

Initially, a pilot study was carried out to define the minimum number of operational cycles required to maintain the maximum error within permissible levels, as expressed in the methodology proposed by Barnes (1977) and represented in equation 1:

$$n \geq \frac{t^2 * \mathrm{CV}^2}{E^2}$$

Where: n = Minimum number of cycles required; t = *Student*'s t, considering (n-1) degrees of freedom and desired accuracy level; CV = Coefficient of variation, in percentage; and E = Permissible error, in percentage.

After the calculations, the number of required cycles was set to four, however, six plots were analyzed in order to reduce the error associated on the process. The data collect from the time and motion analyses for the forest machine know as skidder was realized by the multimoment time study, with a frequency of 15 seconds between each mark. To measure the time spent in each activity of the operational cycle, a digital stopwatch was used.

2.3 Data analysis

The analysis of the time spent in each stage of the operational cycle of the skidder it was made through descriptive statistics, based on the percentage of each of the stages. Operational efficiency was determined as proposed by Alves et al. (2018) (equation 2) and productivity according to equation 3 (Moreira et al., 2004):

$$EOp = \left(\frac{\mathrm{Tef}}{T}\right) * 100$$

Where: EOp = Operational Efficiency (%); Tef = Effective time (h); and T = Total time (h).

$$P = \left(\frac{n * IMV}{\mathrm{Tef}}\right)$$

Where: P = productivity ($m^3 . h^{-1}$); n = number of chopped trees (un); IMV = individual mean volume (m^3); and Tef = Effective time (h).

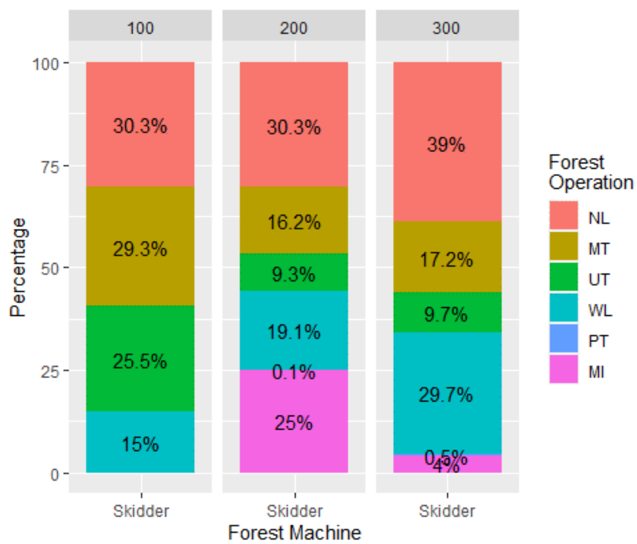

Figure 1. Proportional concentration of time per activity performed by the skidder in three different skid trial lengths. Being no-load travel time (NL), loaded travel time (WL), personal time (PT), maneuver load time (MT), unloading maneuver time (UT), mechanical interventions time (IM)

The effect of the drag distance was verified through the design entirely randomized, with three treatments (distances from the skid trails) and six repetitions (operational cycles). The outliers were measured and the normality of the data was tested by Shapiro-Wilk's test, as well as the assumption of homogeneity of variance was verified by Bartlett's test, and analysis of variance (ANOVA) was applied. Tukey's test was applied in order to verify the significant effect at 5% probability.

3. Results and Discussion

3.1 Time and motions

The data presented graphically in Figure 1, indicate that for the 100 meters skid trial, the highest concentration of time is in the stages of "no-load travel time" (30.3%), "maneuver load time" (29.3%) and "unloading maneuver time" (25.5%).

For the 200-meter trial, the highest time concentration was in the stage "no-load travel time" (30.3%). The "mechanical interventions time" stage ranked second as the most time-consuming activity, requiring 25% of the analyzed time, followed by the "loaded travel time" which occupied 19.1% of the time. Considering the 300-meter extension, the "no-load travel time" stage occupied 39% of the time, followed by the "loaded travel time" (29.7%) and "unloading maneuver time" stages (17.2%).

In general, the travel-stages, with and without load, took up most of the time analyzed on the operational cycle (Figure 1), corroborating the perception that the skidder machines are active during most of the operation, which is due to the existence of two phases of locomotion (Lopes et al., 2014; Lopes et al., 2017).

Table 1. Tukey test (5%) for time concentrations (%) at each skid trail distance

	NL	WL	MT	UT
5% Tukey's				
100 m	0.30 a	0.15 a	0.29 a	0.25 a
200 m	0.30 a	0.19 ab	0.16 b	0.09 b
300 m	0.39 a	0.30 b	0.17 b	0.09 b

Analyzing the time concentration by the Tukey's test, we obtained the results presented in Table 1 for the variables no-load travel time, loaded travel time, loading and unloading maneuver. There were significant differences in all variables with the exception of no-load travel. The loaded trip concentrated more time on the 300-meter branch, indicating a loss of efficiency for longer skidding roads to the detriment of shorter ones, which is corroborated by the results presented by Miyajima et al. (2020).

Means followed by the same letter, in the column, do not differ from each other at 5% probability. Being no-load travel time (NL), loaded travel time (WL), maneuver load time (MT), unloading maneuver time (UT).

For the loading and unloading maneuvers, the time concentration was higher on the 100-meter trial. Factors such as operator skill, number of trees transported and poor arrangement of bundles, contribute to the increase in time spent on such activities (Miyajima et al., 2020). The variables personal time and time for mechanical interventions did not show significant differences between treatments.

3.2 Operational Efficiency and Productivity

The increase in the productivity variable was inversely proportional to the length of the drag branch, as presented by Lopes et al. (2017), with the shorter skidding branch having an average productivity of 19.36 $m^3 . h^{-1}$, followed by 200-meter branches with a productivity of 14.01 $m^3 . h^{-1}$ and 300 meters with 8.35 $m^3 . h^{-1}$ for the same variable (Figure 2).

Operational efficiency indicates the overall performance of the machine. In this work, the calculated operational efficiency was 89.50%, a value that is similar to that obtained by de Oliveira & de Oliveira (2019). The high value

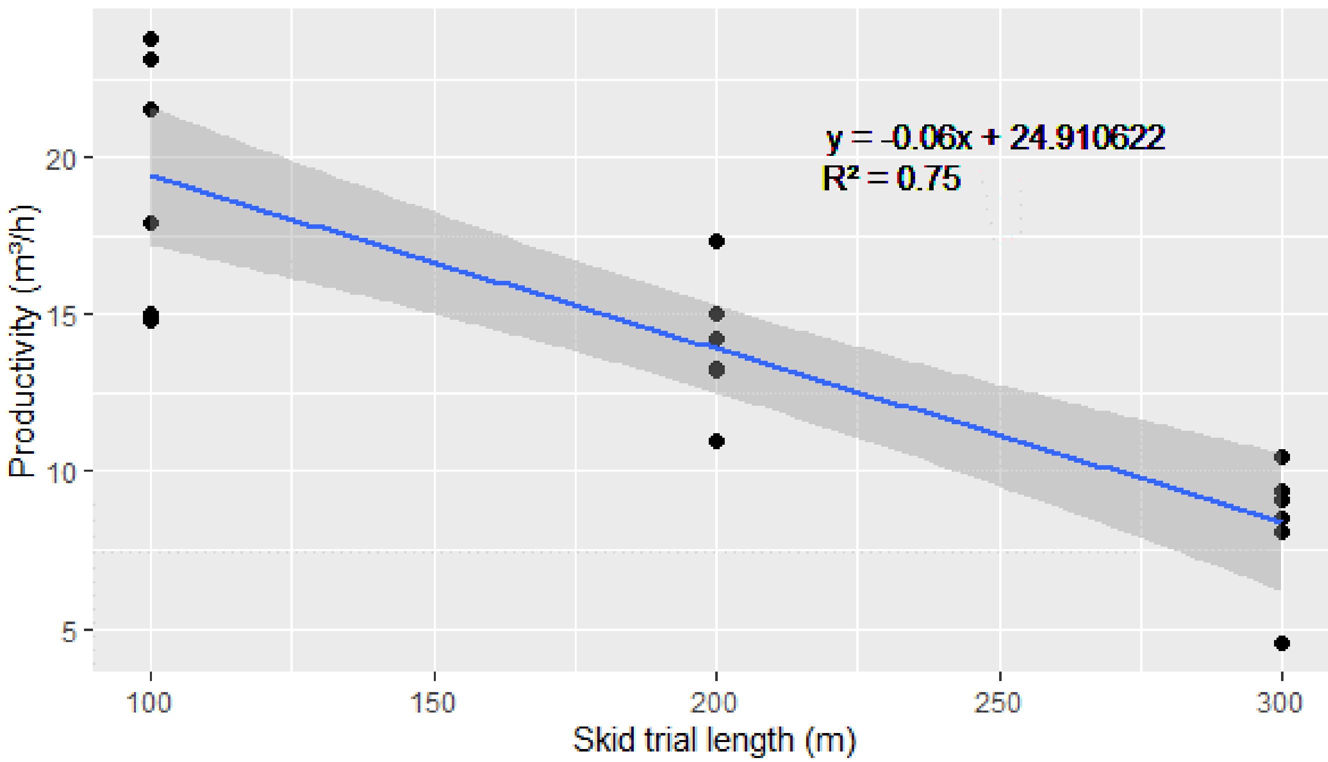

Figure 2. Estimation in linear model of the productivity of the skidder depending on the skid trial length

of this variable when compared to studies such as those carried out by Lopes et al. (2017) and dos Santos et al. (2013), indicates a small proportion of interruptions in the process, which may be related to adequate planning of preventive maintenance and the high degree of experience of operators.

4. Conclusions

The no-load travel activity concentrated the highest percentage of time among all the operating cycle stages of the skidder, regardless of the analyzed skid trial (100, 200 or 300 meters). The operational efficiency found was approximately 90%. The 100-meter road showed the highest average productivity, being, among those analyzed in this work, the one indicated for the hauling of wood logs.

Acknowledgements

The authors would like to thank to the Timber Quality and Bioenergy Laboratory (LQMBio), Forestry Breeding Laboratory and the CAPES system who provides the funding for the project.

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