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Operational Performance of Mechanized Forest Establishment Activities in Function of the Pluviometric Regime

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Abstract – **The knowledge of the productive capacity and of the variables that interfere in the machines' performance is fundamental for the planning and optimization of mechanized forest establishment operations. To evaluate operating performance and efficiency of agricultural tractors in mechanized activities of forest deployment depending on rainfall, this research was conducted in areas of afforestation deployment of eucalyptus a forest company in the municipality of Acailandia, in the South of the state of Maranhao, Brazil. Based on rainfall data, the months with rainfall less than 100 mm were considered as a dry period (April to October) and the others as a rainy period (November to March). Considering the activities of irrigation, fertilization and application and pesticides, from the number of scheduled and effective hours of work of the machines and reasons for stoppages, obtained from historical files from 2016/April to 2017/March of the company, the operational yield was calculated (ha.h-¹), effective hours of work (h) and operational efficiency (%) for all months in the period. The results, submitted to the T Test with 99% probability, demonstrated that there are significant differences between scheduled hours and hours actually worked when considering the rainy and dry periods throughout the year for all evaluated variables, being the worked hours, the yield and lower operational efficiency during the rainy season. It's concluded that the pluviometric significantly affects the operational performance and efficiency of agricultural tractors in mechanized forest establishment activities; and that the planning of mechanized forest establishment activities in a linear way throughout all of the year has not been effective, resulting in the lack of punctuality of operations.**

Keywords – **Forest mechanization, Forestry, Forest production, Operational efficiency.**

I. Introduction

With an approximately 8 million hectares of reforestation area [1], combined with the climate and favorable soils, the Brazilian forestry sector has been experiencing constant development, leading to increasing demands for forest-based products. In order to meet this growing demand, in a scenario where labor is increasingly scarce, the sector's competitiveness is increasing and the demands of globalized consumer markets are increasing, the mechanization of wood production activities became imperative for the sustainability of the forestry business. This seeks to minimize production costs, reduce dependence on labor, increase productivity, reduce labor accident rates and damage to the environment, in addition to ensuring a continuous flow of wood supply to consumer units [2]. In this context, the mechanization of silviculture has been identified as a decisive competitive factor in the Brazilian forest sector.

Although not all silvicultural areas and activities are subject to mechanization, there are operational situations whose combination of characteristics makes it viable, such as flat topography, extensive areas and availability of technical and economic resources [3, 4]. In these cases, without a doubt, the migration from manual to mechanized work has several benefits that allow the incorporation of this system into the productive environment, such as increases in yield, productivity, efficiency and quality and cost reduction.

With the intensification of mechanization in forest establishment activities, operations must be planned in a rational way, so that there is an increase in profitability in the field, since knowledge of productivity and the variables that interfere in the machines' performance are fundamental for the optimization mechanized forestry operations. Optimizing the performance of the machines becomes the main tool to guarantee efficiency during the work.

In this context, operational efficiency arises, which is defined as the percentage of time actually worked in relation to the time programmed for the work of a machine or a set of these. Thus, one should seek to increase the capacity in productive hours, reducing unproductive hours, because, in field situations, there are substantial differences between the hours available for work and those actually worked. The identification of the incidence of these unproductive hours should result in alternatives for their reduction [4, 5] and, consequently, greater efficiency and operational performance.

Operational performance is a complex set of information that determines the attributes of a machine in terms of the quality and quantity of operations that it performs under certain conditions, which are grouped together to determine a possible technical opinion of its behavior [6]. For this, the following points must be evaluated: operational characteristics, which include quality and quantity of work data developed by the machine; dynamic characteristics, which include data on the power required for the activation and development of work by the machine; and management characteristics, which cover aspects related to maintenance, adjustment, repairs and stability; while taking into account topographic and climatic factors.

From the perspective of these last factors, the pluviometric regime stands out, which is the measurement and understanding of rainfall volumes precipitated in a given region and in a given period [7]. Therefore, studies aimed at generating information related to adequate rainfall conditions for mechanized field operations are of great importance [8], since this represents a significant portion of the production cost [9], in addition to the fact that, when carried out under inadequate conditions, they cause significant negative impacts to the soil [10].

In view of the above, this study aimed to evaluate the operational performance and efficiency of agricultural tractors in mechanized activities of forest establishment according to the pluviometric regime in the southern region of the State of Maranhao.

II. MATERIAL AND METHODS

The study was carried out with machines working in areas of establishment of clonal eucalyptus forests in the municipality of Acailandia, in the southern region of the State of Maranhao, Brazil (04º56 '48 ”S and 47º 30' 17" W). The area is located in an ecotonal region between two of the largest South American biomes: the Amazon rainforest and the Cerrado. The climate in the region is tropical, presenting Koppen-Geiger climatic classification of type Aw [11]. It has two well-defined seasons, one very rainy and the other slightly rainy, with average annual rainfall of 1,334 mm, average annual temperature of 26ºC and average relative humidity of 80%. The region has an average altitude of 220 m in relation to the sea level [12], with eucalyptus plantations located only in areas with flat to smooth undulating relief.

The average data of 5 New Holland tractors, model TL 75, 4 x 4 TDA traction, closed cabins, 78 hp engine at

2,400 rpm and maximum torque of 280 Nm, year of manufacture 2015, were analyzed in the irrigation fertilization and application of pesticides activities, in forest areas of a company producing pulp. The data were obtained from the compilation of the Daily Operation Bulletins (DOB) completed by the operators according to the company's procedure, using monthly data on the number of scheduled and effective hours of work of the machines and reasons for stoppages, starting in April of 2016 and ending in March 2017. For all machines and in all activities, individually, were programmed eight hours of work per day for twenty days per month, totaling 160 monthly-programmed hours.

For the organization and treatment of field data, an integrated system developed in the Excel program was used, having worked on the following operational indicators: date of the activity, start time of the operation, end time of the operation, duration of the total activity time, time number, machine code, type of activities, operator, amount of hectares realized, reason for hours stopped, hours programmed and hours executed.

The evaluation period or seasons (dry or rainy) was determined according to monthly precipitation during the data collection period. Only for the purposes of this study, the months that presented less than 100 mm of precipitation were defined as belonging to the dry period and the months that presented above 100 mm were considered rainy period. Precipitation data were obtained from a meteorological station installed at the company's headquarters. Thus, it was defined that the dry period comprised the months from April to October 2016 and the rainy period from November 2016 to March 2017 (Table 1).

Table 1. Monthly precipitation volumes (mm) observed in the study region and period classification, with D being the dry period and R the rainy period.

Months	**2016**									**2017**		
	Apr	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
mm	76	95	26	16	12	40	68	120	296	274	311	257
Period	D	D	D	D	D	D	D	R	R	R	R	R

Source: field measurements performed by the authors.

To evaluate the operational performance (yield and productivity) and the operational efficiency of the machines, the methodology described by Mialhe [6] was used, being:

$$\mathrm{EH} = \mathrm{DP} - \mathrm{DS}$$

$$\mathrm{OI} = \mathrm{Ha}/\mathrm{EH}$$

$$\mathrm{OE} = \left(\frac{\mathrm{EH}}{\mathrm{DP}}\right) * 100$$

On what: EH = Effective hours of work (h); DP = Daily programmed hours (h); DS = Daily stopped hours (h); OI = Operating income ($ha.h^{-1}$); Ha = Amount of hectares realized (ha); OE = Operational efficiency (%).

The statistical analysis of the data was developed with the help of the SAS software [13], and the experiment was statistically evaluated by the Fully Randomized Design (FRD), with three treatments: treatment 1 (T1) - irrigation activity; treatment 2 (T2) - fertilizing activity; treatment 3 (T3): pesticide application activity.

The treatments were designed with five repetitions for the wet (rainy) period and seven repetitions for the dry period, these repetitions referring to the months evaluated, being tabulated through the monthly averages of pro-

-ductivity and operational efficiency.

The results obtained were compared using the T test at 99% probability, for each activity. As significant differences were observed between the expected and observed averages, the results were subjected to the Tukey test, at 95% probability, comparing the averages obtained in the dry and rainy periods for all evaluated variables.

III. RESULTS

Tables 2 to 4 shows the results of real hours worked, hours stopped, hectares performed, productivity and operational efficiency for each activity evaluated, during the study period.

Table 2. Operational results obtained during the study period for the irrigation activity.

Months	EH	DS	Ha	OI	OE
Apr/16	120	40	35,9	0,30	75,0
May/16	116	44	34,9	0,30	72,5
Jun/16	132	28	41,3	0,31	82,5
Jul/16	116	44	35,2	0,30	72,5
Aug/16	152	8	38,5	0,25	95,0
Sep/16	144	16	44,5	0,31	90,0
Oct/16	152	8	46,1	0,30	95,0
Nov/16	160	0	53,4	0,33	100,0
Dec/16	112	48	33,4	0,30	70,0
Jan/17	116	44	32,0	0,28	72,5
Feb/17	68	92	22,9	0,34	42,5
Mar/17	68	92	16,8	0,25	42,5
Avg	**121**	**39**	**36,2**	**0,30**	**75,8**
s^2	30	30	9,9	0,03	0,2
p	0,0009				
T	3,8162*				

Observation: EH = Effective hours of work (h); DS = Daily stopped hours (h); Ha = Amount of hectares realized (ha); OI = Operating income ($ha.h^{-1}$); OE = Operational efficiency (%); Avg = Average; s^2 = Standard deviation. * Significant at 99% probability.

Source: compiled by the authors from data collected in the field.

Table 3. Operational results obtained during the study period for the fertilization activity.

Months	EH	DS	Ha	OI	OE
Apr/16	152	8	56,6	0,37	95,0
May/16	136	24	46,2	0,34	85,0

Months	EH	DS	Ha	OI	OE
Jun/16	132	28	40,4	0,31	82,5
Jul/16	116	44	31,8	0,27	72,5
Aug/16	116	44	28,3	0,24	72,5
Sep/16	112	48	35,0	0,31	70,0
Oct/16	160	0	49,0	0,31	100,0
Nov/16	158	2	48,3	0,31	98,8
Dec/16	144	16	43,2	0,30	90,0
Jan/17	124	36	30,3	0,24	77,5
Feb/17	68	92	27,9	0,41	42,5
Mar/17	48	112	8,2	0,17	30,0
Avg	**122**	**38**	**37,1**	**0,30**	**76,4**
s^2	34	34	13,0	0,06	0,2
p	0,0029				
T	3,3536*				

Observation: EH = Effective hours of work (h); DS = Daily stopped hours (h); Ha = Amount of hectares realized (ha); OI = Operating income ($ha.h^{-1}$); OE = Operational efficiency (%); Avg = Average; s^2 = Standard deviation. * Significant at 99% probability. Source: Compiled by the authors from data collected in the field.

Table 4. Operational results obtained during the study period for the pesticide application activity.

Months	EH	DS	Ha	OI	OE
Apr/16	120	40	53,5	0,45	75,0
May/16	136	24	37,1	0,27	85,0
Jun/16	148	12	41,7	0,28	92,5
Jul/16	160	0	52,8	0,33	100,0
Aug/16	160	0	49,1	0,31	100,0
Sep/16	124	36	31,0	0,25	77,5
Oct/16	108	52	33,8	0,31	67,5
Nov/16	156	4	40,0	0,26	97,5
Dec/16	116	44	32,7	0,28	72,5
Jan/17	108	52	33,2	0,31	67,5
Feb/17	64	96	16,2	0,25	40,0
Mar/17	96	64	21,5	0,22	60,0

Months	EH	DS	Ha	OI	OE
Avg	**125**	**35**	**36,9**	**0,29**	**77,9**
s²	29	29	11,5	0,06	0,2
p	0,0015				
T	3,6341*				

Observation: EH = Effective hours of work (h); DS = Daily stopped hours (h); Ha = Amount of hectares realized (ha); OI = Operating income (ha.h^{-1}); OE = Operational efficiency (%); Avg = Average; s² = standard deviation. * Significant at 99% probability.

Source: compiled by the authors from data collected in the field.

When considering the precipitation distribution periods (dry and rainy), the results of the actual hours worked, the hours stopped, the hectares realized, the productivity and the operational efficiency for each evaluated activity are presented in Table 5, as well as the results of the statistical analysis.

Table 5. Operational results obtained during the periods of precipitation distribution and statistical analysis by the Tukey test at 5% probability for the activities of irrigation, fertilization and application of pesticides, considering the dry and rainy periods.

Period	Effective Hours (hours/month)	Stopped Hours (hours/month)	Production (ha/month)	Operating Income (ha.h^{-1})	Operational Efficiency (%)
Irrigation					
Dry	133 a	27 a	39,5 a	0,30 a	83,2 a
Rainy	105 b	55 b	31,7 b	0,30 a	65,5 b
Average	121	39	36,2	0,30	75,8
Fertilization					
Dry	132 a	28 a	41,0 a	0,31 a	82,5 a
Rainy	108 b	52 b	31,6 b	0,29 a	67,8 b
Average	122	38	37,1	0,30	76,4
Application of pesticides					
Dry	137 a	23 a	42,7 a	0,31 a	85,4 a
Rainy	108 b	52 b	28,7 b	0,26 b	67,5 b
Average	125	35	36,9	0,29	77,9

Averages followed by the same letter, in the column and for the same activity, do not differ by the Tukey test at 95% probability.

Source: values compiled by the authors from data collected in the field.

IV. Discussion

The tractor is a main power unit used in most equipment and machinery in silvicultural activities, in those places where mechanization is possible [14]. On the other hand, the objective of machinery management is to increase the yields and profits of the activities through the selection and, mainly, the ideal management of tractors and equipment. The time consumption and productivity of mechanized silviculture systems depend on factors that characterize the conditions of the site, skills, work techniques and characteristics of the machines used. All of these factors, alone or jointly, directly contribute to the productivity levels of the machine-implement set and to the result of the forestry business [15].

Among these factors, considering only the pluviometric regime, the results show that there are significant differences between scheduled hours and hours actually worked when considering the rainy and dry periods throughout the year. The mechanization of silvicultural activities presupposes the movement of tractors and implements over the soil, which can present numerous surface and subsurface conditions with regard to texture, density, type of vegetation cover, water content, among others, capable of interfering in the handling capacity of the tractors.

From this perspective, the water content in the soil, a direct consequence of the rainfall throughout the year, offers different trafficability to the tractors used for silvicultural activities, reflecting in the skating index of these tractors and, consequently, in their traction capacity. According Compagnon et al. [16], when the soil is drier there tends to be greater friction with the tires, caused by the support of the soil, causing the tractor-implement set to move with greater speed than when the soil is more humid, keeping to same gear and working rotation.

Furthermore, Bianchini et al. [17] concluded that there was a tendency to increase the tractive force required from tractors as the soil moisture content increased. This result, according to the authors, is possibly associated with the fact that the moisture content is becoming close to the limit of the plasticity of the soil, which represents greater adhesion of the soil to the tractor used, offering greater resistance to displacement and, even, making its operation unfeasible.

As it is an operation with high costs involved, the mechanization of forest establishment activities needs to be planned and executed with great precision, so that unnecessary financial expenses and failures in operations are avoided. In the current globalized world, the lack of information is practically inadmissible and highly risky, especially within a business context [18].

In this way, assisting managers in making decisions with objective evidence, obtaining information at important moments, properly distributing it to those involved and promoting the storage of those useful for the company, using technological resources, intelligent processes and effective results it is the goal of any planner [19].

Under this light, there is an increasing demand for reliable and detailed information regarding the performance of agricultural tractors. This need for information is concentrated in the form of precise measures, with the main objective of optimizing the performance of the tractor to increase efficiency during the work [20], all factors that affect its efficiency must be considered, including those related to the pluviometric regime.

According to Donaldson [21], the low performance of tractors occurs due to several factors, including the type and moisture content of the soil and the vegetation cover, among others. Serrano [22], evaluating the performance of a tractor, concludes that an increase in skating rates decreases the efficiency of traction. Thus, the author reaffirms that traction is the result of the interaction between the wheelset and the surface. Another problem that affects the performance of the tractor is the sliding of the driving wheels, which are directly related to the reduction of the traction force, the increase in fuel consumption and the low operational efficiency and, e-

-ven, in some cases, the impossibility of execution of activities, with a consequent increase in operating costs.

From this perspective, Molin et al. [23] complement that the information about the performance and the work capacity of the agricultural machines are of great importance in the management of mechanized systems, helping in decision-making. According to the company's capacity, greater or lesser complexity in planning can be suggested [24]. However, little has been considered regarding the temporal optimization of activities, especially when there are limitations, such as the rainy season [25].

Any mechanized silvicultural activity, in order to be effective in the production system, must be carried out within the optimum period, provided for in the planning, and this is called punctuality of the operation [26]. For Balastreire [27], the inadequacy of the machines' capacity to carry out the operation on time is associated with the concept of punctuality. According to the author, punctuality is the ability to carry out operations at a time when the quality and, or, quantity of a product is optimized. Thus, punctuality in operations is achieved when you have an adequate selection of machines. Otherwise, the increase in the time of operation can generate delays in the forest implantation and, consequently, reduction in productivity, characterizing the increase in the indirect cost of mechanization. As the number, size and complexity of operations and machines increase, the more important is the impact of managing this system on the quality and profitability of the business.

Thus, the results presented in this study indicate the immense potential of including the pluviometric regime in the planning of mechanized forest establishment activities, in this case, more specifically for activities that require the traffic of the machines over the planted areas.

V. Conclusions

The pluviometric regime significantly affects the operational performance and efficiency of agricultural tractors in mechanized forestry activities.

Operational losses can be avoided by predicting lower operating income in the rainy season, which in this case ranged from November from one year to March of the following year.

The planning of mechanized forest establishment activities in a linear manner throughout all months of the year has not proved to be effective, leading to untimely operations.

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