ECONOMIC AND OPERATIONAL ANALYSIS OF MECHANIZED FOREST IMPLEMENTATION

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ABSTRACT – Mechanization in forestry implantation demands high energy, time, and high operational and production costs. Thus, studies related to the influence of variables on the efficiency of these activities are essential to reduce costs and optimize operations. The objective of this study was to evaluate the operational and cost performance of mechanized forest implantation operations in *Eucalyptus* sp. Data were collected from *eucalyptus* plantations located in the northern region of the state of Espírito Santo, Brazil. The analysis of operational performance determined the distribution of operating times, mechanical availability, degree of utilization, operational efficiency, and productivity of the machines. The cost analysis estimated the operating costs in forestry implantation activities. The forest planting operations were: waste removal, subsoiling, digging with fertilization, planting, chemical weeding, and covering fertilization. According to the results, planting (39.20%) and waste removal (15.99%) represented the longest operating cycle times, the shortest production times (51.48% and 53.64%), and finally the longest maintenance times (32.95% and 29%). Chemical weeding and subsoiling showed the lowest maintenance times (4.64% and 3.47%). The cover fertilization was the operation that presented the highest productivity (2.99 ha he^{-1}), and the removal of residues had the lowest (0.97 ha he^{-1}). The highest costs per effective hour (R$13.57 he^{-1}) and lowest production costs (R$81.59 ha^{-1}) occurred at planting. Subsoiling had the highest production cost (R$112.80 ha^{-1}). The lowest operating cost was obtained in the fertilizing operation. Operating costs had the greatest weight in labor, fuel, and maintenance and repairs.

Keywords: Forestry operations; Operational costs; Forest plantations.

ANÁLISE OPERACIONAL E DE CUSTOS DA IMPLANTAÇÃO MECANIZADA DE EUCALIPTO

RESUMO – A mecanização na implantação florestal exige elevada demanda por energia, tempo e altos custos operacionais e de produção. Assim, estudos relacionados à influência de variáveis sobre a eficiência dessas atividades são fundamentais, para reduzir custos e otimizar as operações. Objetivou-se, com este estudo avaliar o desempenho operacional e de custos das operações mecanizadas de implantação florestal em áreas de plantio de ***Eucalyptus*** *sp. Os dados foram coletados em plantios de eucalipto localizados na região norte do estado do Espírito Santo, Brasil. A análise do desempenho operacional determinou a distribuição dos tempos operacionais, disponibilidade mecânica, grau de utilização, eficiência operacional e produtividade das máquinas. A análise de custos estimou os custos operacionais nas atividades de implantação florestal. As operações de plantio florestal foram: afastamento de resíduos, subsolagem, coveamento com adubação, plantio, capina química e* *adubação de cobertura. De acordo com os resultados, o plantio (39,20%) e o afastamento dos resíduos (15,99%) representaram os maiores tempos do ciclo operacional, os menores tempos produtivos (51,48% e 53,64%) e, por fim, os maiores tempos em manutenção (32,95% e 29%). A capina química e subsolagem, apresentaram os menores tempos em manutenção (4,64% e 3,47%). A adubação de cobertura foi a operação que apresentou maior produtividade (2,99 ha he^{-1}) e o afastamento de resíduos a menor (0,97 ha he^{-1}). Os maiores custos por hora efetiva (13,57 R$ he^{-1}) e menores custos de produção (81,59 R$ ha^{-1}) ocorreram no plantio. A subsolagem apresentou maior custo de produção (112,80 R$ ha^{-1}). O menor custo operacional foi obtido na operação de adubação. Os custos operacionais tiveram como maiores pesos o custo de mão-de-obra, de combustível e de manutenção e reparos.*

Palavras-Chave: Operações florestais; Custos operacionais; Plantios florestais.

1.INTRODUCTION

The Brazilian planted forest sector is responsible for the production of 90% of all industrial wood in the country, representing 7.83 million hectares. Of this total, 5.7 million hectares are planted with species of the *Eucalyptus* genus, mainly located in the southeastern region of Brazil (IBÁ, 2019).

Despite the expressive numbers presented by the silvicultural sector, population growth and intensification of the rural exodus simultaneously led to an increase in demand for raw materials and a reduction in the availability of qualified labor (Minette et al., 2008). As a result, forestry entrepreneurs have been forced to intensify their efforts in planning forest implantation in order to guarantee the continuous and quality production of these products with a high yield index.

To this end, the entire production process from the implementation planning to the delivery of the final product must be carefully studied and executed in order to maximize productivity while minimizing costs (Silva et al., 2004). This is because in addition to the high initial investment, forestry enterprises require a long time for return on the invested capital and are subject to several risks (fires, pests, diseases, sales price variations) during the maturation period (Carmo et al., 2011).

Therefore, information related to the economic and operational viability of the stages of implementing a forestry investment is of paramount importance to ensure efficient resource maintenance during all execution phases.

One of the first steps to be evaluated in planning forest plantations is the stand establishment, which consists of operations ranging from soil preparation to the complete establishment of the crop. However, despite the soil preparation, fertilization and planting techniques being consolidated in the forestry sector, studies involving economic and operational analysis of these activities are scarce. Thus, studies related to the influence of variables on the efficiency of a forest implantation system are of fundamental importance, given that they enable acquiring information which makes it possible to reduce costs and optimize the performed operations (Diniz et al., 2018a).

In this case, a widely used technique is the study of times and movements which aims to define the best execution method of a given activity by measuring the time spent to carry it out by a qualified person at a normal work pace. This technique can be applied in several areas of the forestry sector, such as in the operational performance analysis of the subsoiling operation in implanting *eucalyptus* (Simões et al., 2011), in the analysis of seedling production, fertilization, planting and weeding of *eucalyptus* stands (Silva et al., 2004), clearing saws performance in delimbing (Leite et al., 2019), among others.

Due to the importance of evaluating the efficiency of forestry operations and the lack of studies related to the implementation phase, this study aimed to carry out an analysis on the operations and costs of mechanized forestry operations in *eucalyptus* plantation areas.

2.MATERIAL AND METHODS

2.1.Characterization of the study area

The study was carried out in *eucalyptus* plantations in the northern region of the state of Espírito Santo, Brazil, between the coordinates of 18º37'0" S and 39º51'30" W and altitude between 10 and 100 m. The climate of the study region is classified as Am according to the Köppen Classification, being tropical humid or sub-humid. The average annual temperature is 22.5 ºC and the annual precipitation varies from 1,350 to 1,500 mm, with the rainy period from October to December and the dry period from July to September (Alvares et al., 2013; Silva et al., 2018).

2.2.Description of operations and machinery

The experiment was carried out by monitoring six activities inherent to the forest implantation. The evaluated operations and the machines used were:

Waste removal (WR): Agricultural tractor with a nominal power of 78 hp equipped with a strovenga. This equipment was used to clear the planting line in a range of 0.8 meters to facilitate renovation operations;

Subsoiling (SB): Agricultural tractor with a nominal power of 180 hp equipped with a single-stem subsoiler. This equipment was used to remove the compacted layer (minimum 0.5 m deep) and perform phosphate fertilization;

Digging and fertilization (DF): Agricultural tractor with a nominal power of 78 hp equipped with a fertilizer digger. This equipment was used to mark the holes in the planting lines (3 m spacing) and to fertilize at a depth of 0.20 to 0.30 m;

Planting (PL): Agricultural tractor with nominal power of 75 hp equipped with kite tanks with 5 planters. This equipment was used to plant in the marked pits and deposit the seedling and the planting gel;

Chemical weeding (CW): Agricultural tractor with a nominal power of 75 hp equipped with a protected boom sprayer. This equipment was used to apply post-emergent herbicide in between lines;

Cover fertilization (CF): Agricultural tractor with nominal power of 75 hp equipped with a fertilizer. This equipment was used to distribute a continuous fertilizer fillet over the soil at an approximate distance of 0.30 m from the plant.

2.3.Data collection

Data collection was carried out between the months of March to June 2018, involving activities ranging from waste removal to fertilization after planting during an 8-hour work shift.

Data for the operational analysis were collected on maintenance times, scheduled work times and hours actually worked. The economic analysis was performed based on data on machinery costs (fixed and variable), management and labor in effective hours as provided by the company.

A study on the times and movements was used for the productivity analysis and to calculate the average time per stage of the operational cycle. The continuous timekeeping method was used for this purpose, in which time is measured without interrupting the stopwatch; the timing is started at the scheduled time for starting operations and is only interrupted at the end of the day. Digital chronometers and data recording forms were used for this purpose.

2.4.Operational cycles

The partial stages of the forest deployment operational cycle were determined as follows:

Accessory time (AcT): performance of mandatory functions, but not directly related to the operation;

Auxiliary time (AT): time for mandatory functions for operation continuity;

Unproductive time (UT): machine is available for operation, but is not being used, or idle time during maintenance activity;

Productive time (PT): effective performance of the analyzed operation;

Maintenance time (MT): preventive or corrective machine maintenance.

2.5.Sample procedure

A pilot sampling was performed to characterize the work cycles and determine the minimum number of samples required in order to provide a maximum sampling error of 5% (Equation 1), according Fiedler et al. (2008); Simões et al. (2014); Pereira et al. (2015) and Diniz et al. (2018a).

$$n \geq \frac{(t^2 \text{ x } s^2)}{e^2} \qquad \text{(Eq.1)}$$

Where, n = minimum number of cycles required; t = tabulated value at 5% probability level (Student's t distribution); S = standard deviation of the sample; and e = admissible error, in percentage (5%).

2.6.Operational analysis

2.6.1.Productivity

Productivity was determined based on marking the walking points of each machine in the field using GPS, then obtaining the distance in linear meters worked.

Thus, the total area worked was determined with the product of this distance by the working range. Next, the hours actually worked were determined by monitoring the machines.

As a result, productivity was calculated by the ratio between the area covered by the operation in question and the actual hours of work (total number of hours discounting mechanical and operational interruptions), according to Equation 2.

$$P=A/He \quad \text{(Eq.2)}$$

Where, P = productivity (ha h^{-1}); A = area covered (ha); and He = effective hours of work (hours).

2.6.2.Mechanical availability

Mechanical availability was calculated from the relationship between the time the machine was available for work and the total time scheduled to work, as expressed by Equation 3 (Guedes et al., 2017; Diniz et al., 2018a):

$$MA=\left(\frac{TT - MT}{TT}\right) X\ 100 \quad \text{(Eq.3)}$$

Where, MA = mechanical availability (%); TT = total scheduled work time (hours); and MT = maintenance time (hours).

2.6.3.Degree of use

The usage degree was defined as the percentage of time actually worked by the machine, expressed by Equation 4 (Diniz et al., 2018b):

$$DU= (Hex(TT - MT))X\ 100 \quad \text{(Eq.4)}$$

Where, DU = Degree of utilization (%); He = Effective hours of work (hours); TT = total scheduled work time (hours); and MT = maintenance time (hours).

2.6.4.Operational efficiency

Operational efficiency was calculated by the product of mechanical availability and the degree of use, as expressed in Equation 5 (Oliveira et al., 2009):

$$OE = \frac{MA\ x\ DU}{100} \quad \text{(Eq.5)}$$

Where, OE = operational efficiency (%); MA = Mechanical Availability (%); and DU = Degree of utilization (%).

2.7.Economic analysis

2.7.1.Total costs

The accounting method was used for the cost analysis, which uses values estimated in Reais (Brazilian currency). The machinery (fixed and variable), administration and labor in effective hours were used for the estimated cost values, using Equation 6 as proposed by FAO (Silva et al., 2014):

$$TC = FC + VC + ADC + LC \quad \text{(Eq.6)}$$

Where, TC = total costs (R \$ he^{-1}); FC = fixed costs (R \$ he^{-1}); VC = variable costs (R \$ he^{-1}); ADC = administration costs (R \$ he^{-1}); and LC = labor costs (R \$ he^{-1}).

2.7.2.Fixed costs

Fixed costs are those which do not change in relation to the hours worked, meaning they are independent of the machine operation (interest, depreciation).

Interest was calculated by applying an interest rate to the average annual investment (AAI) corresponding to the opportunity cost which would be applied to capital, as expressed by Equations 7 and 8. According to the local reality, an interest rate of 12% a.a. was adopted, which is the same as that adopted by Burla et al. (2012).

$$IN = (AAI\ X\ i)\ X\ He \quad \text{(Eq.7)}$$

Where, IN = interest (R\$ he^{-1}); i = annual simple interest rate (%); He = effective hours of annual work (h); and AAI = average annual investment (R \$) (Minette et al., 2008).

$$\text{Being,}\quad AAI = \frac{(PVx(UL+1))(RVx(UL^{-1}))}{2\ x\ UL} \quad \text{(Eq.8)}$$

Where, PV = purchase value of the machine (R \$); RV = residual value of the machine (R \$); and UL = useful life (years).

Depreciation is the effective reduction in the value of the asset, using it or not, resulting from wear and tear and technological obsolescence. Using the depreciation calculation, it is possible to estimate the amount to be saved in order to reestablish the equipment at the end of its useful life. Thus, depreciation was calculated using the straight-line method (Equation 9) (Moura et al., 2019).

$$D = \frac{PV - RV}{UL\ x\ He} \quad \text{(Eq.9)}$$

Where, D = depreciation (R\$ he^{-1}); PV = purchase value of the machine (R\$); RV = residual value of the machine (R\$); UL = useful life (years); and He = effective hours of annual work (h).

2.7.3.Variable costs

Variable costs are those which change proportionally with the quantity produced or with the use of the machine, such as: fuel costs, lubricants, hydraulic oil, tires, personnel remuneration, maintenance and repairs.

The fuel cost was determined by multiplying the average hourly consumption of the machines in the operation in question by the market price of diesel oil, as expressed by equation 10:

$$\text{FuC} = \text{Fcon (measured)} \times \text{cm} \qquad \text{(Eq.10)}$$

Where, FuC = fuel cost (R \$ he^{-1}); FCon = fuel consumption per effective hour of work (L he^{-1}); and cm = current market price (R \$ L^{-1}).

The estimation of the cost of lubricants and greases was performed according to the fuel cost using the coefficient for machines with a simple hydraulic system, meaning the agricultural tractors and crawler tractors, according to Equation 11:

$$\text{Clg} = \text{FuC} \times \text{cc} \qquad \text{(Eq.11)}$$

Where, Clg = Cost of lubricants and greases (R \$ he^{-1}); FuC = fuel cost (R \$ he^{-1}); and cc = consumption coefficient (0.2) (American Society of Agricultural Engineers, 2001).

Although a machine's maintenance costs increase with its use, they are determined based on a linear calculation in the same way as depreciation. Thus, the cost of maintenance and repairs was determined according to the linear calculation presented in Equation 12:

$$\text{MC} = \frac{\text{PV}}{\text{Ul} \times \text{He}} \qquad \text{(Eq.12)}$$

Where, MC = maintenance cost (R\$ he^{-1}); PV = purchase value of the machine (R\$); UL = useful life (years); e He = effective hours of annual work (h).

Labor costs are variables formed by direct costs, meaning the remuneration paid directly and indirectly (social charges) to workers, with the machine operator and assistants (Equation 13).

$$\text{LO} = \frac{12 \times (\text{Ms}\,(1 + \text{s}))}{\text{He}} \qquad \text{(Eq.13)}$$

Where, LC = labor cost (R\$ he^{-1}); Ms = monthly salary (R\$); Constant 12 represents the twelve months of the year; s = social charges factor; e He = effective hours of annual work (h).

The social charges factor of 120% in addition to the salary was adopted for calculation purposes, according to Burla et al. (2012).

The indirect costs related to the administration of labor and machinery were calculated using a coefficient of 10% on the costs of machinery and personnel, as expressed by Equation 14:

$$\text{CAD} = \text{CD} \times \text{K} \qquad \text{(Eq.14)}$$

Where, ADC = administration cost (R\$ he^{-1}); DC = direct costs of machinery and labor (R\$ he^{-1}); e K = coefficient of administration.

A value of k = 10% was adopted, which is the same adopted by Silva et al. (2014).

2.8.Statistical analysis

The results regarding the operational cycles of each operation were compared using an analysis of variance (ANOVA at 99% probability). The analysis of operating times and performance indicators of operations were analyzed as a completely randomized design (CRD) using the SISVAR 5.7 statistical software program. Thus, the data were processed through analysis of variance. Lastly, the Tukey means test was performed at 95% probability for means with significant differences.

Table 1 – Number of samples collected, minimum quantity required and standard deviation from the mean
Tabela 1 – *Número de amostras coletadas, quantidade mínima necessária e desvio padrão da média.*

Operations	N	S	n
Waste removal (WR)	239	0.106	238
Subsoiling with phosphate fertilizer (SB)	383	0.101	172
Digging and fertilization (DF)	837	0.010	53
Planting (PL)	49	0.114	47
Chemical weeding (CW)	936	0.097	110
Cover fertilization (CF)	241	0.097	174
TOTAL	2,685		794

N = sample population; n = minimum estimated population; and S = standard deviation of the sample.
N = população da amostra; n = população mínima estimada; S = desvio padrão da amostra.

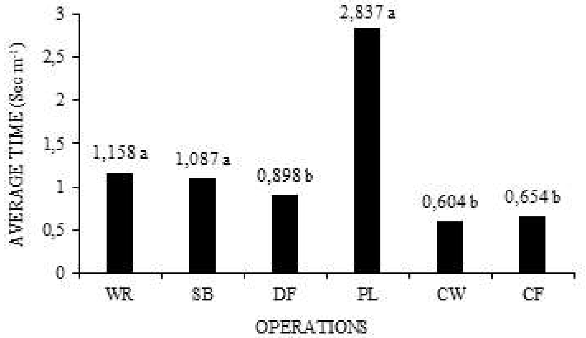

Figure 1 – Average time per operational cycle. Averages followed by the same letter do not differ statistically from each other, by the F test at 1% probability of error.
Figura 1 – *Tempo médio por ciclo operacional. Médias seguidas da mesma letra não diferem estatisticamente pelo teste F a 1% de probabilidade de erro.*

3.RESULTS

The performed sampling, the minimum number of cycles and the standard deviation of the mean are presented in Table 1.

The operational cycle of each operation was evaluated for the study of times and movements in order to obtain a sample within the one proposed by the methodology. Figure 1 shows the results obtained in the silvicultural operations. The sampling performed in the operations met the minimum number required at the 95% probability level for all operations.

According to the results presented in Figure 1, it was possible to verify that the activity which was the longest in the operational cycle was planting, which represented an average of 39.20%, followed by waste removal with 15.99%, and subsoiling with 15.01%.

Table 2 presents the results found for each of the times studied in each operation of the cycle.

The longest accessory and unproductive times were found in the subsoiling operation (17.84% and 14.82%, respectively). On the other hand, auxiliary (5.63%), maintenance (3.47%) and productive (58.24%) times in subsoiling stood out among the lowest of all activities.

Table 3 shows the values regarding the operational analysis of the activities studied.

The activities which required the longest maintenance times (WR and PL) also had lower percentages of productive times (53.64% and 51.48%, respectively) and operational efficiency (53.64% and 51.37%, respectively). On the other hand, chemical weeding and subsoiling activities had shorter maintenance times (4.64% and 3.47%, respectively). The accessory (17.84% and 16.91%) and unproductive (14.82% and 13.97%) times of subsoiling and chemical weeding were respectively the highest. Coverage fertilization was the operation which showed the highest productivity among those studied (2.99 ha he^{-1}). In contrast, waste removal showed the lowest productivity (0.97 ha he^{-1}).

The operating cost of the machines and operations was estimated using the calculation methodology developed by FAO. Table 4 shows the results obtained regarding the costs for each studied operation.

According to Table 3, the highest cost per effective hour (R$ he^{-1}) among operations occurred in planting (13.57 R$ he^{-1}). However, this operation also has a lower production cost (81.59 R$ ha^{-1}). In contrast, subsoiling was the operation with the highest production cost (112.80 R$ ha^{-1}). The lowest operating cost was obtained for the fertilizing operation.

Table 2 – Average values of accessory, auxiliary, unproductive, maintenance and productive times in percentage.
Tabela 2 – *Valores médios de tempos acessórios, auxiliares, improdutivos, em manutenção e produtivos em percentual.*

Operation	Accessory time	Auxiliary time	Unproductive time	Maintenance time	Productive time
WR	12.71 dC	7.32 bE	8.14 dD	18.19 aB	53.64 dA
SB	17.84 aB	5.63 dD	14.82 aC	3.47 eE	58.24 cA
DF	16.7 bcB	6.77 cD	11.78 cC	6.36 cE	58.39 cA
PL	12.19 eD	13.08 aC	7.24 fE	16.01 bB	51.48 eA
CW	16.91 bB	5.60 dD	13.97 bC	4.64 dE	58.88 bA
CF	16.53 cB	7.56 bD	7.59 eC	6.53 cE	61.85 aA
Average	15.48	7.66	10.59	9.20	57.08

Means followed by the same uppercase letter in the row and lowercase in the column, respectively, do not differ by Tukey's test, at 5% probability.
Médias seguidas pelas mesmas letras maiúsculas na linha e minúsculas na coluna, respectivamente, não diferem pelo teste de Tukey a 5% de probabilidade.

Table 3 – Average values of mechanical availability, degree of utilization and operational efficiency, in percentage and productivity in hectares per hour actually worked.
Tabela 3 – *Valores médios de disponibilidade mecânica, grau de utilização e eficiência operacional, em percentual e produtividade em hectares por hora efetivamente trabalhada.*

Operation	Mechanical availability (%)	Degree of use (%)	Operational efficiency (%)	Productivity (ha he^{-1})
WR	81.81 e	65.57 a	53.64 c	0.97 c
SB	96.53 a	60.34 d	58.24 b	1.06 c
DF	93.64 c	62.40 b	58.42 b	1.37 bc
PL	83.99 d	61.17 c	51.37 d	1.83 b
CW	95.36 b	61.75 bc	58.88 b	1.73 b
CF	93.47 c	66.18 a	61.85 a	2.99 a

Means followed by the same letter, in the column, do not differ by Tukey's test, at 5% probability.
Medias seguidas da mesma letra, na coluna, não diferem pelo teste de Tukey, a 5% de probabilidade.

4.DISCUSSION

The greater operational cycles found in planting, waste removal and subsoiling, respectively, are mainly justified by interruptions for maintenance in the case of planting and waste removal, and by unproductive times in subsoiling, as shown in Table 2. The maintenance required by subsoiling and stroving machines is due to the significant presence of grassy vegetation in part of the area which ended up obstructing visualization of materials at ground level and consequently the non-removal of cut wood in previous plantings. Thus, the obstructed view culminated in common incidences of impacts on the remaining stumps, thereby causing damage to the machines and implements and consequently longer maintenance times (Table 2).

As the time spent on maintenance directly influenced mechanical availability, the machines used for planting and waste removal showed lower percentages of the time mechanically available for carrying out the activities (Table 3). The maintenance time will always compose the operational times, however the more effective the preventive maintenance is, the less time will be spent to carry out the corrective maintenance.

Based on the principle that the productive times of the system depend on the times when the machine is able to carry out the activities, a trend was noticed between the times in maintenance, the productive times (Table 2) and operational efficiency (Table 3). In other words, the activities which require the longest maintenance times (WR and PL), also presented lower percentages of productive times (53.64% and 51.48%, respectively) and operational efficiency (53.64% and 51.37%, respectively).

Another factor which influenced the productive times of the planting operation to be considered low was due to replacing seedlings in the planter box to correct failures in planting, and to opening and closing the support structure of the hoses, thus resulting in a number large number of stoppages during operations and in turn increasing auxiliary times (Table 2).

Although maintenance times in the case of chemical weeding and subsoiling were the lowest (4.64% and 3.47%, respectively), the operational efficiency of these operations was not the best (Table 3). This can be explained by the influence of accessory times (16.91% in chemical weeding and 17.84% in subsoiling) (Table 2), which reduced the degree of use of the machines (61.75% and 60, 34%, respectively) because they are high (Table 3) and consequently increased unproductive times (13.97% and 14.82%) in these operations (Table 2).

Table 4 – Composition of costs per operation, in reais per hour (R\$ h^{-1}), actually worked.
Tabela 4 – *Composição de custos por operação, em reais por hora (R\$ h^{-1}), efetivamente trabalhada.*

Composição	WR	SB	DF	PL	CW	CF
Fixed cost	18.44	26.83	11.24	16.12	7.91	9.41
Variable cost	31.39	61.93	23.69	28.07	21.20	22.98
Labor cost	21.59	19.93	15.56	91.53	16.15	0.82
Administration cost	7.14	10.87	5.05	13.57	4.53	3.32
Total cost (R\$ he^{-1})	78.57	119.56	55.54	149.30	49.79	36.53
Production cost (R\$ ha^{-1})	81	112.80	40.54	81.59	28.78	12.22

The main components of accessory time in the analyzed operations were meal stoppages and snack breaks, as well as daily safety dialogue (DSD) for all operations, indicating that there was no time spent on activities outside the planning. The unproductive times were directly affected by the delay linked to the long distance between the exit point with the workers and the areas to be worked.

It is important to note that the ancillary time is composed of activities which must occur during the day, but they can be minimized with planning and compliance with the scheduled times for meals, rest and daily safety dialogue (DSD), thus avoiding interferences in productive time.

The 96.53% of mechanical availability found in the present study for subsoiling (Table 3) was close to that found by Simões et al. (2011). These authors found an average value of 96.96% of MA when measuring the operational and economic performance of the agricultural tractor in the subsoiling operation in areas of *eucalyptus* implantation with different slope classes. However, the operational efficiency found by the same authors (61.36%) for subsoiling, although close, was higher than that found in the present study (58.24%) (Table 3).

Coverage fertilization was the operation which showed the highest productivity among those studied (2.99 ha he^{-1}) (Table 3). This fact occurs due to the lesser operational requirement of the machine and the possibility of a faster travel speed in this activity, and also by fertilizing two planting lines in a single pass, effectively doubling the working range. On the other hand, waste removal presented the lowest productivity (0.97 ha he^{-1}) (Table 3), which is because there is a lot of time spent on maneuvers to avoid the remaining stumps, thus decreasing the ratio of area covered by effective hour.

Despite the planting operation having five lines in a single pass, the machine's travel speed in the area is lower so that workers are able to monitor and provide quality planting.

The higher production cost of the subsoiling operation is justified by the greater demand for power and the higher cost of purchasing large machines and implements, that is, translating into higher fixed costs. In addition, higher fuel consumption impacts the variable cost, which is one of the main components of this cost.

The lowest operating cost was obtained in the fertilizing operation (Table 4) due to the machines and devicces used having a low fixed cost, with the higher productivity reducing the operating cost.

Labor was the most influential factor in relation to the sum percentage of the total cost of operations, representing 36.05% of total costs, followed by fuel with 16.99%, and maintenance and repairs (12.67%). The variables with the least influence were lubricants and grease (3.40%), and tires (3.20%).

5.CONCLUSION

From the operational analysis, it was possible to notice that the activity which presents the best productivity is cover fertilization. It is also concluded that maintenance interruptions significantly influenced the productive and unproductive times;

The lack of planning regarding the time the workers travel from the exit point to the work area directly influenced the unproductive times of the activities;

The high fixed costs and high fuel consumption of the equipment used in the subsoiling operation resulted in higher production costs;

Coverage fertilization had the lowest operating cost, confirming that productivity is a determining factor for this type of cost;

Finally, the employed methodology has the potential to be implemented in any other area as well as other types of machines and/or forest plantations.

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