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OPERATIONAL PERFORMANCE AND COSTS OF MECHANIZED STUMP EXTRACTION SETS

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ABSTRACT

Stump extraction can be carried out in different ways, among which the mechanized removal is the most usual in the forestry sector. Information regarding the operation with cutting implements is important in the context of decision taking, operational and economic optimization of the activity. The objective of this work was to evaluate the operational performance and mechanized costs of different stump extractors implements in an eucalyptus harvested area. The work was carried out in an *Eucalyptus urograndis* clones harvested area where the treatments adopted for removal were the following: agricultural tractor + shredder head (T1), excavator + shovel bucket (T2); excavator + shredder head (T3), excavator + stump shear (T4) and bulldozer mat + stump pullers (5). The experimental design was the completely randomized, with four replications per treatment, where it was evaluated the operational efficiency (Ef), operational field capacity (Ofc), extraction productivity (Ps), hourly fuel consumption (Fch), hourly cost (HC), operational (OC) and by extracted stump (SC). For the conditions of the work, the T5 was the one with the highest Ef, Ofc, and Ps, lowest OC and SC.

Palavras-chave:
Destoca
Eficiência operacional
Mecanização florestal
Tocos

DESEMPENHO OPERACIONAL E CUSTOS DE CONJUNTOS DESTOCADORES MECANIZADOS

RESUMO

A extração de tocos pode ser realizada de diversas formas, dentre as quais a mecanizada é a mais usual pelo setor florestal. Informações a respeito da operação com implementos destocadores são importantes ao contexto de tomadas de decisão, otimização operacional e econômica da atividade. O objetivo da pesquisa foi avaliar o desempenho operacional e de custos de diferentes implementos destocadores em área colhida de eucalipto. O trabalho foi realizado em área colhida de clones de *Eucalyptus urograndis*, onde para destoca foram adotados os tratamentos: trator agrícola + cabeçote triturador (T1), escavadora + caçamba destocadora (T2), escavadora + cabeçote triturador (T3), escavadora + stump shear (T4) e trator de esteira + stump pullers (T5). O delineamento experimental foi inteiramente casualizado, com quatro repetições por tratamento, sendo avaliadas a eficiência operacional (Ef), capacidade de campo operacional (Cco), produtividade de extração (Pt), consumo horário de combustível (Chc), consumo operacional de combustível (Coc), custo horário (CH), operacional (CO) e por toco extraído (CT). Para as condições de realização do trabalho, o T5 foi o que apresentou maior Ef, Cco e Pt, menor Chc, Coc, CO e CT.

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INTRODUCTION

According to Piacentini *et al.* (2012), the operating cost of an agricultural activity can be known through the sum of all fixed and variable costs resulting from the acquisition and operation of the machinery. Through cost analysis, Baio *et al.* (2013) describe that it is possible to improve planning and to make assertive decisions about an agricultural operation, making it more productive and economically advantageous. In addition to knowing the costs, Rabechini Junior *et al.* (2011) add that the managerial organization is fundamental for the viability of the operation or activity.

Regarding the perspective of forestry operations, Casselli *et al.* (2018) describe that the extraction of stumps is one of the most challenging to forestry, either by the economic or operational aspects. The operation is necessary to prepare the soil for a new forest planting or new agricultural activity in the area (CASSELLLI, 2016). Foelkel (2014) and Loconte (2018) clarify that the non-removal of stumps will result in limited mechanized operations around them, resulting in the loss of useful area.

The mechanized operation of stump extraction, stump harvesting or stump removal is carried out with stump grinders and implements, most of the time coupled to a hydraulic excavator or tractors (CASSELLI *et al*. 2018). Leite *et al*. (2014) and Freitas and Horta (2019), describe that the operation is heavy and financially costly, particular because of the density of stumps in the area, dimensions of the stumps, cleaning conditions of the surface and slope of the terrain, therefore demanding greater attention from managers for the selection of machines.

Almeida (2016) describes that the stump removal methods have been evolving and several types of cutters are available on the market, among them, shovel buckets, shreder head, drills, stump pullers and stump sphear. However, information about its efficiencies, productive capacities and operational costs is scarce, which according to Simões and Silva (2012), impair decision taking on which machine to be adopted, increasing the chances of na inefficient operational and financial planning.

Thus, the objective of this work was to evaluate the operational performance and mechanized costs of different implements of stump removal machines in an eucalyptus harvested área.

MATERIAL AND METHODS

The work was carried out in a harvest area of *Eucalyptus urograndis* clones, located in the municipality of Cristalina, State of Goias (GO), Brazil (17°12’19”S; 47°44’10” W, average altitude of 958 m and slope of less than 3%) . The soil in the area was classified as Red-Yellow Latosol.

The experimental area had 50 ha and a history of two log harvests for the production of chips, one carried out at 4.5 years after planting of the seedlings and the other at 5.4 years after sprouting conduction. The spatial arrangement of trees in the area was 3 m between rows and 2 m between plants and the trunks were harvested using with Feller Buncher Caterpillar, model CAT522, equipped with a cutting head model HF201.

The experimental design used was the completely randomized design with five treatments, which were different stump removal implements, identified in Table 1. Four replicates per treatment were carried out and the experimental plots defined with three stump parallel lines f stumps, 35 stumps each line, totaling 105 stumps per plot.

Table 2 shows the tractors and excavators used as power source and coupling of the stump grinders.

Table 1. Treatment identification and characterization

Treatment	Stump grinder type	Model/manufacturer	Power source	Coupling
T1	Grinding head	Tractor/Roder	Tractor with tires	SH
T2	Shovel bucket	CD30/Deltractor	Hydraulic excavator	HA
T3	Grinding head	Excavator/Roder	Hydraulic excavator	HA
T4	Stump shear	HDX/Thorco	Hydraulic excavator	HA
T5	Stump pullers	1720/Savannah	Track-type tractor	HA

SH: three-point hydraulic system and auxiliary plugs. HA: hydraulic arm. TB: Traction bar.

Table 2. Identification of tractors and hydraulic excavator

Machine	Model	Power (kW/cv)
Tractor with tires	MF7180 4 x 2 TDA	132.4/180
Bulldozer mat	DX61EX-23M0	126.7/172
Hydraulic excavator	CAT 336 D L	232/315

Before stump extraction, carried out in June 2019, shoots were desiccated and the litter of branches and leaves on the soil surface was treated. For dissection, a Jacto sprayer, model Jatão 600, capacity of 600 L was used. The rake used was Tatu Marchesan, model DE9, with 9 teeth spaced at 295 mm, 780 mm high, 2.5 m in total width. Both implements were coupled to a Massey Ferguson tractor, model MF4292 4 x 2 TDA, with 81.2 kW (110hp) of power at 2200 rpm.

To characterize the stumps in the area, 15 measurements of height, diameter and length were performed, using a 0.01 m precision measuring tape. The height corresponded to the measure between the surface of the soil and the surface of the stump, the diameter was the average of two perpendicular measures on the surface of the stump, and the length measured between the surface of the stump and the end of the pivoting root. To characterize the state of soil consistency in the area, its water content was determined at depths of 0.1 m; 0.3 m, and 0.5 m, using the standard oven method at 105°C for 24 hours, according to regulatory standard NBR6457 of the Brazilian Association of Technical Standards - ABNT (1986).

The average displacement speed used on the T1 tire tractor and on the T2, T3 and T4 hydraulic excavator was 1.8 km h^{-1}, and on the T5 bulldozer mat, it was 2.5 km h^{-1}. The data of operational efficiency (Ef) and operational field capacity (Ofc) were obtained using the methodology of times and movements by continuous timing, proposed by Simões and Fenner (2010). With the aid of digital stopwatches, the total operating time within the plot (Tt), and the productive time (Tp), required in the extraction of the stumps, were measured. The auxiliary time (Ta), spent with necessary maneuvers and movements between the extractions of the stumps was obtained by subtracting Tp from Tt. The productivity of the treatments was determined in stumps extracted per total hour of work, according to Santos *et al*. (2018).

Ef, Pfc and productivity (Ps) were calculated using Equations 1, 2 and 3, respectively.

$$Ef = \frac{Tp}{Tt} . 100 \quad (1)$$

$$Ofc = \frac{A}{Tp} \quad (2)$$

$$Ps = \frac{Nte}{Tt} \quad (3)$$

Where,

Ef = operational eficiency, %;
Tp = productive time, h;
Tt = total operation time within the plot, h;
Ofc = operational field capacity, ha h^{-1};
A = worked area, ha;
Ps = stump extraction yield, stumps h^{-1}; and
Nte = number of stumps extracted in the plot

The operating fuel consumption (Foc) data were obtained by adapting the test tube methodology described by Gomes *et al*. (2017). At the beginning of each plot, the fuel tank of the machine was rigorously filled to capacity. At the end of the plot, the machine was turned off and the tank completely refilled. The Foc was determined from the volume of fuel needed for refueling, using a graduated cylinder with an accuracy of 0.001 L. Depending on the size of the plot, the Coc was given in L ha^{-1}. The hourly fuel consumption (Fch) necessary for cost calculations was determined as a function of the total operation period in the plot, given in L h^{-1}.

To determine the hourly cost (HC), operating cost (OC) and cost per extracted stump (SC), the means obtained from Fch, Ofc and Ps were used. The costs were calculated according to the methodology proposed by Mialhe (1974) and ASABE (2011), using the equations indicated in Table 3 for the calculations.

The data considered as the initial acquisition value (Vi), final resale or scrap value (Vf), useful life in years (Vuy), useful life in hours (Vuh), hours of use per year (H) and accumulated hours of use (Ha), are listed in Table 4. The interest rate (Ri) adopted was 7.5% per year. The adjustment factor (Fa) for shelter and insurance was 0.75 and 0.25%, respectively, according to Simões *et al.* (2011), and the Fa for lubricants and grease was 15%, according to ASAE (2001). The fuel price (Pf) was R$ 3.85 L^{-1}, and the hourly wage (Rh) for the machine operator was R$ 9.76 according to information provided by the company that owns the machines. For social, labor and administrative burdens, (B) 25% was adopted (ASAE, 2001). The repair factor 1 and 2 (Fr1 and Fr2) were 0.007 and 2, respectively (ASAE, 2001).

Table 3. Equation used in the calculation of costs

Item	Costs
Depreciation (R$ h^{-1})	D = (Vi – Vf) / (Vuy × H)
Interests (R$ h^{-1})	I = [(Vi + Vf) / 2] x Ri x (1 / H)
Shelter (R$ h^{-1})	S = (Vi × Fa) / H
Insurance (R$ h^{-1})	In = (Vi × Fa) / H
Fixed costs (R$ h^{-1})	CF = D + I + S + In
Fuel (R$ h^{-1})	F = Fch × Pf
Lubricant/grease (R$ h^{-1})	LG = (Fa × Cc)
Labor (R$ h^{-1})	L = Rh × (1 + E)
Repair/maintenance (R$ h^{-1})	RM = [Vi × Fr1 (Ha + H/1000)^{Fr2}] - [Vi × Fr1 (ha/1000)^{Fr2}] / H
Variable costs	VC = RM + F + LG + L
HC (R$ h^{-1})	HC = FC + VC
OC (R$ ha^{-1})	OC = HC / Ofc
SC (R$ stump^{-1})	SC = HC / Ps

Vi: initial purchase value; Vf: final value of resale or scrap; Vuy: useful life in years; H: hours of use per year; Ri: annual interest rate; Fa: adjustment factor; Ha: accumulated hours of use; Fr1: repair factor 1; Fr2: repair factor 2; Fa: average hour consumption of fuel; Pf: price of the diesel; Rh = remuneration per hour; B = social, labor and administrative burdens; Ofc: average operation field capacity; Ps: Productivity of stumps extracted per hour.

Table 4. Information for cost calculation

Machine/implement	Vi	Vf	Vuy/Vuh	H	Ha
Tractor with tires	R$160,000.00	30%	12/12000	1000	6,800
Bulldozer mat	R$414,200.00	15%	9/18000	2000	8,250
Hydraulic excavator	R$412,500.00	20%	5/10000	2000	5,850
Grinding head T1	R$152,000.00	5%	4/4500	1125	350
Shovel bucket T2	R$11,750.00	5%	3/6000	2000	1000
Grinding head T3	R$135,000.00	5%	4/4500	1125	350
Stump shear T4	R$94,200.00	5%	3/4500	1500	500
Stump pullers T5	R$964,955.00*	5%	5/7500	1250	1500

Vi: purchase value of a machine model in 2020, as specified in Table 1 and 2. Vf: residue value (%). *value with import tariffs included.

Data on efficiency, operational field capacity, productivity and hourly fuel consumption were subjected to analysis of variance and, when significant, the means were compared using the test of Tukey at the 5% probability level. The costs were compared descriptively, considering any difference in the obtained value.

RESULTS AND DISCUSSION

The soil water content in the stump extraction area was characterized by 9.1; 16.4 and 21.6% at the depths of 0.0-0.1 m; 0.1-0.3 m and 0.3-0.5 m respectively, and the extracted stumps characterized by dimensions of 11.5 cm in height, 23.1 cm in diameter and 65 cm in length. The characterization is important because the status of soil consistency (dry, friable, plastic or liquid) determined by the water content can affect its trafficability and operationalization (FOLLE *et al.* 2001). It was observed that the water content did not limit the mechanized removal operation, without excessive adherence of soil to the machinery and to the roots of the stumps, just as the dimensions of the stumps had not influenced their identification by the machine operators neither their displacement and mechanical availability in the area. The dimensions of the stumps were compatible with the species of eucalyptus harvested and to the management carried out in the area. The diameter and length are similar to the results observed by Casselli (2013), 21 and 70 cm, respectively, in *Eucalyptus urograndis* stumps. The height of the stumps corroborates the maximum recommended for eucalyptus culture in a budding conduction system by Foelkel (2014) and Zanella *et al*. (2018), which is 15 cm. Thus, the results of water content and stump dimensions characterize the field frequent condition of an eucalyptus forest in the second harvest.

The results of efficiency (Ef), operational field capacity (Ofc), hourly fuel consumption (Fch) and stump extraction productivity per hour (Ps) are shown in Table 5.

The highest operational efficiency was obtained by the T5 (Stump pullers), 83.7%, which means that most of the total operation time was used in the extraction of stumps, and a smaller part (16.3%) demanded with other auxiliary movements and times. As an example, the obtained efficiency indicates that in one hour of work, the stump puller extracts stumps for 50.2 minutes. The operational efficiency of Stump pullers is significantly higher than that of T1, whose efficiency was 69.2%, the lowest obtained. The operational efficiency of the T5 was 17.3; 11.4; 12.6 and 12.1% higher than T1, T2, T3 and T4, respectively. Because the stump pullers are coupled to the drawbar and centered on the stump line, it almost does not require auxiliary times with operational interventions for positioning or maneuvers, operating predominantly with constant speed and without clogging.

The other stump grinders under study showed lower displacement speed and greater time demand for movements and short maneuvers, necessary for the better positioning of the equipment on the stumps, justifying the reduction of operational efficiency. The operational efficiency of the T1 (tractor crushing head) is even lower than that of the stump grinders coupled to hydraulic excavators (T2, T3 and T4), since the operation occurs with the tractor moving in reverse over the stump line, with lower displacement speed and longer time with maneuvers.T2, T3 and T4 did not differ in relation to operational efficiency.

The highest operational field capacity was obtained in T5, 0.93 ha h^{-1}. T1 and T2 did not differ from each other and had an operational capacity of less than 0.2 ha h^{-1}. The difference in operational capacity from T5 to T1, T2, T3 and T4 was 84.9; 81.7; 78.4 and 75.2%, respectively. The result is possible to be understood because the treatment has also shown greater operational efficiency.

Correlating the results of the operational capacity of the work with others in the literature, the superiority of the T5 corroborates Freitas and Horta (2019), who using Stump pullers in stump lines spaced at three meters and operational speeds of 3 and 4.5 km h^{-1}, obtained 0.74 and 1.1 ha h^{-1} respectively, proving the greater operational capacity of the Stump pullers. The reduced operational capacity of T1 and T2 are similar to that verified by Saarinen *et al*. (2006), of 0.1 ha h^{-1} with a tractor crushing head and a shovel bucket.

In terms of productivity, treatment 5 showed the highest result, 1541 stumps h^{-1}, which was 84.5; 81.5; 78.8 and 75.2% more productive when

Table 5. Operational efficiency (Ef), operational field capacity (Ofc), stump extraction productivity per hour (Ps) and hourly fuel consumption (Fhc) and operational fuel consumption (Foc)

Treatment	Ef (%)	Ofc (ha h^{-1})	Ps (Stumps h^{-1})	Fch (L h^{-1})	Foc (L ha^{-1})
T1	69.2 c	0.14 d	238 d	17.17 c	122.69 b
T2	74.1 b	0.17 cd	284 cd	31.69 a	186.45 a
T3	73.1 b	0.20 bc	326 bc	35.00 a	175.30 a
T4	73.5 b	0.23 b	382 b	31.99 a	139.11 b
T5	83.7 a	0.93 a	1541 a	25.00 b	26.89 c
ANOVA					
CV (%)	1.29	5.87	5.87	9.80	10.09
MSD	0.021	0.040	67.45	6.03	28.68
SE	0.004	0.009	15.00	1.38	6.56
SD	0.009	0.018	30.018	2.763	13.135
F test	126.38*	1143.79*	1142.99*	26.88*	92.76*

Means followed by the same letters in the column do not differ by the test of Tukey ($P \leq 0.05$). CV: coefficient of variation; MSD: minimum significant difference; SE: standard error; SD: standard deviation; DF: degree of freedom. * Significant at the level of 5% of error probability compared to T1, T2, T3 and T4 respectively. The result is justified because T5 does not demand time by mobilizing soil to shake the stump and weaken the roots, actions necessary to facilitate the extraction of the stump by T2 and T4. In addition, although T1 and T3 do not need to shake the stump, the time for the drill to penetrate by grinding the stump is relatively long, especially in larger stumps, reducing the productivity of stump grinders.

Even at a low displacement speed of 2.5 km h^{-1}, the T5 kept its displacement and extraction constant without needing stops for interventions, suffering only small speed reductions when greater traction force is required, especially for stumps with deeper root system and/or drier soil with greater resistance to penetration. Thus, greater efficiency, operational capacity and uninterrupted extraction enabled greater productivity to the T5.

Casselli *et al*. (2018) clarify that implements for stump removal such as tubular saw, hydraulic bucket, crushing heads and grapples, have a tendency to present lower efficiency, operational field capacity and productivity, consequently, due to the speed of descent and excavation in the stump, resistance to penetration of the soil and cut of the root system. The authors stressed that even with a hydraulic excavator, and considering the extraction as a light operation for them, and the machine's hydraulic system automatically compensating for greater efforts when necessary, auxiliary movements hinder efficiency and productivity and times required for soil mobilization and maneuvers positioning of the machine to work, corroborating the results found in this work.

Comparing the productivity results of T1 and T2 to those obtained by Casselli *et al*. (2018) showed that they were greater. Using a tubular saw crusher cutter coupled to an agricultural tractor, an implement similar to T1, and a cutter bucket coupled to a hydraulic excavator, similar to T2, the authors found productivity of 30.6 and 166.8 stumps h^{-1} respectively. The differences in productivity between the works can be associated with the dimensions of the extracted stumps, as Casselli *et al*. (2018) worked with extraction of larger stumps, which demanded more extraction time per stump, thus reducing productivity.

The productivity and operational efficiency in T4 compared to that obtained by Almeida (2016) was 11.2% higher and 16.4% lower, respectively, as their evaluation on the eucalyptus stump removal using Stump shear in a population of 1515 stumps ha^{-1} resulted in a productivity of 339 stumps h^{-1} and efficiency of 88%. The differences in the results between the works are likely to have occurred because the authors evaluated the machine in a condition with a smaller population of stumps, but stumps with larger dimensions, so the efficiency is increased because more time is used per stump, but the productivity is reduced by extracting less number of stumps per hour.

Spinelli *et al*. (2005) using a rotary drill set on a 132 kW agricultural tractor, obtained productivity of 97 stumps h^{-1}, which is lower than that found in T1, possibly because the authors worked with stumps of larger diameter, 50 cm. Saarinen *et al*. (2006) obtained productivity of 475 stumps h^{-1} with an implement similar to the shovel bucket coupled to a hydraulic excavator, a greater productivity than T2 due to the fact that stumps with smaller dimensions were removed. Karha (2012) found productivity of 100 and 74 h^{-1} stumps using a stump lifting on stumps with 30 and 40 cm in diameter respectively, and reported that the 10 cm increase in the stump diameter reduces the productivity of the cutter machine by 26%.

Regarding the results of hourly fuel consumption, T1 had the lowest value, 17.17 L h^{-1}, being 54.1; 49; 53.6 and 31.3% less than T2, T3, T4 and T5, respectively. It is likely that the differences are associated with the fact that the machines used to drive the stump cutters are different, because there was no difference between the three treatments that used the hydraulic excavator (T2, T3 and T4). Therefore, the differences occur between hydraulic excavator, bulldozer mat and tire tractor.

The fuel consumption result in T1 is higher than that found by Casselli *et al*. (2018), which for a set of agricultural tractor + tubular saw shredder crusher (drill) obtained 14.3 L h^{-1}. The difference might have been caused by the rotation regime of the engine for each stump removal model. It is clear that the hourly fuel consumption of the tractor crushing stump remover is not the villain of mechanization in eucalyptus culture, being lower than that used in soil tillage operations. Machado *et al*. (2015), with an 89-kW (121hp) agricultural tractor, pulling a subsoiler with five rods at 35 cm depth, identified Fch of 22.19 L h^{-1} due to the average power of 42190 N required in the drawbar. Barbosa *et al*. (2015), using a 104-kW (141hp) agricultural tractor and 1900 rpm in the harrowing and subsoiling operations in the soil tillage for forest planting found Fch of 35.46 and 43.64 L h^{-1}, respectively.

The hourly fuel consumption did not differ significantly between T2, T3 and T4, since a hydraulic excavator was used in the three treatments and operating at a similar engine speed, around 1800 rpm. Casselli *et al*. (2018) found a fuel consumption of 30.6 L h^{-1} for a mechanized set consisting of excavator + shovel bucket. Using a hydraulic excavator + Stump shear, Almeida (2016) obtained fuel consumption of 28 L h^{-1}. The fuel consumption of the excavator was similar when used for forest harvesting with a cutting head by Vieira *et al*. (2016), who found a consumption of 32.8 L h^{-1}.

The operational fuel consumption (Foc) was lower at T5, 26.89 L ha^{-1}, and higher at T2 and T3, 186.45 and 175.30 L ha^{-1}, respectively. The difference in Foc from T5 to T1, T2, T3 and T4 was 21.9; 14.4; 15.3 and 19.3%, respectively. The Foc is variable according to the operational field capacity and hourly fuel consumption, thus the lower Foc of T5 is understood due to the higher operational capacity and lower hourly fuel consumption shown in Table 5, meaning that it is possible to remove more consuming less fuel.

The results of the hour cost (HC), operating cost (OC) and cost per extracted stump (SC), are shown in Table 6.

Table 6. Hourly cost (HC), operating cost (OC) and cost per extracted stump (SC)

Treatment	HC (R$ h^{-1})	OC (R$ ha^{-1})	SC (R$ $stump^{-1}$)
T1	175.96	1256.86	0.74
T2	214.11	1259.47	0.75
T3	286.86	1434.30	0.88
T4	256.35	1114.57	0.67
T5	397.06	426.95	0.26

The highest HC was obtained at T5, R$ 439.17 h^{-1}, and the lowest at T1, R$ 214.47 h^{-1}. The HC at T1 was 27.5; 35.9; 26.5 and 51.1% less than T2, T3, T4 and T5 respectively. The lowest HC of the treatment was possible particularly because of the lower Fch, as the input is responsible for most of the hourly costs, as shown in Table 7 of the composition of the HC of the treatments, in which it is observed that the lowest fuel cost is in T1, R$ 66.13 h^{-1}.

Despite presenting a higher HC, T5 obtained a lower OC, R$ 472.23 ha^{-1}. The value was 69.1; 72.8; 71.8 and 62.8% less than T1, T2, T3 and T4 respectively, which occurred because T5 had a larger removed area per hour of work, as shown in the Foc result in Table 5. If the area worked is greater per unit of time, it means that the operational capacity is greater and therefore the operational cost is lower, even if the cost per hour is higher.

The lowest cost per extracted stump (SC) was obtained in T5, which was R$ 0.28 $stump^{-1}$. The result was 64.8; 65.3; 70.4 and 61.1% lower than T1, T2, T3 and T4 respectively, possible due to the higher productivity of the treatment (Table 5). The higher number of stumps extracted per hour allows optimization of the HC, substantially reducing the SC.

In the work carried out by Almeida (2016), in which the Stump shear + hydraulic excavator was used for the removal of eucalyptus, an hourly cost of R$ 305.35 h^{-1} was obtained, an operating cost of R$ 1374.09 ha^{-1} and a stump of R$ 0.91. In comparison to the T5 costs, the reference values were higher, possibly due to lower operational capacity and productivity.

Spinelli *et al*. (2005) using a tractor-drill deducted a cost of €72.00 h^{-1} and €300.00 ha^{-1}, adopting the currency costing R$ 5.74 (average value in March 2020), the hourly and operational cost of stump removal was equivalent to R$ 413.28 h^{-1} and R$ 1722.00 ha^{-1}, values higher than those found in this work, due to the low productivity of the set. In the same way, the low productivity reflected the costs calculated by Karha (2012), of €1.00 $stump^{-1}$, the equivalent to R$ 5.74 $stump^{-1}$ in March 2020, and Janoselli *et al*. (2016), of R$ 1500.00 ha^{-1}, with a cutter coupled to the tractor. Considering the aforementioned references, the cost values of this work are lower and the main explanation is the higher productivity of stump removal.

Table 7 shows the expenditures that make up the hourly cost (HC) of each treatment. Costs with fuel, depreciation, repairs and maintenance were those that most affected the HC.

Table 7. Hourly cost composition

Treatment	Fixed Costs (R$ h^{-1})				Variable cost (R$ h^{-1})			
	D	I	S	In	F	LG	RM	L
T1	41.42	13.12	2.21	0.74	66.13	1.30	38.35	12.69
T2	34.86	9.51	1.59	0.53	122.00	1.36	31.57	12.69
T3	61.50	14.01	2.45	0.82	134.98	1.35	59.06	12.69
T4	52.89	11.75	2.02	0.68	123.18	1.33	51.81	12.69
T5	141.79	14.00	6.37	2.13	96.29	1.30	122.49	12.69

D: depreciation. I: interests. S: shelter. In: insurance. F: fuel. LG: lubricant and grease. RM: repairs and maintenance. L: labor.

Fuel costs made up most of the HC in T1, T2, T3 and T4, because the T1 tractor had low fixed costs and T2, T3 and T4 used a hydraulic excavator that had higher hourly fuel consumption (Table 5).

Although T5 had had an hourly fuel consumption greater than T1 (Table 5), the lower participation of input in the HC in T5 was possible due to the higher costs with depreciation, repairs and maintenance respectively. The depreciation of the T5 was greater due to the mechanized set, especially the stump pullers, having a high initial purchase value, as the implement is imported and is expensive due to high exchange and import tariffs. Considering the commercial dollar costing R$ 5.00, as occurred in the first term of 2020 in Brazil, the implement arrives in the country costing approximately one million reals, a value significantly higher than that of the domestic implements (Table 4). In addition to the tied value, there is practically no market for resale of the implement in Brazil, so the final value is admitted as scrap, which considerably raises the depreciation. In terms of repairs and maintenance, the cost of the T5 is higher due to the almost nonexistent availability of parts, components, dealers and skilled labor in Brazil, increasing the costs with import and/or design and manufacturing in Brazil, in addition to the machine idle for a longer time awaiting repair. The discussion corroborates with Freitas and Horta (2019), when describing that machines and implements with relatively low investment, less power and simplified designs tend to have low costs, characteristics opposite to that observed in the T5.

T2 was found to have a lower cost of repairs and maintenance, which is possible because it is a set with a little complex implement in terms of parts and components, in addition to being easily repaired, replaceable, of low cost and commonly available in the Brazilian market. T1, T3 and T4 have a repair and maintenance cost between 20 and 22%. The results refer to the importance of this component in decision-taking by machines and implements whose technical assistance for services, parts and components are easily available and affordable in the region and profile of the producer, at risk of unavailability for a long or undetermined period of the machine work due to their absence.

When the components considered fixed costs (depreciation, interest, accommodation and insurance) and variable costs (fuel, repairs and maintenance, labor, lubricants and grease) are separeately added shows that the variable cost makes up most of the OC of the stump removal operation , representing 67; 78; 72; 73 and 58% of the OC of T1, T2, T3, T4 and T5 respectively. The result confirms the importance of decision taking for a set that balances operational capacity, productivity and economy through the greater efficiency, the lower hourly fuel consumption, and the depreciation, repair and maintenance costs, observed in the T5 treatment.

CONCLUSIONS

- For the conditions in which the work was carried out, the T5, composed of Stump pullers, was the one that showed the highest efficiency and operational capacity, the highest productivity, and the lowest operating cost per stump extracted.

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