EVALUATING THE EFFECTIVENESS PRODUCTIVITY OF MOTOR-MANUAL FELLING WITH A CATALYTIC CHAINSAW

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Abstract

The evolution and constant development of chainsaws aims at the increase of their productivity, their ergonomic improvement as well as their eco-friendliness. The use of catalytic chainsaws in timber harvesting operations is in line with this eco-friendly approach. In the present paper an attempt is made to assess the productivity of a Stihl MS 170D catalytic chainsaw compared with a conventional Stihl MS 181 saw. The aim of the present research was to perform a time study of timber harvesting operations with a view to comparing the productivity of a catalytic and a conventional chainsaw. According to the results of the research, the hourly production of the catalytic chainsaw with and without delays was 3.35 cubic meters per hour (12 trees/hour) and 3.48 cubic meters per hour (13 trees/hour), respectively. The hourly production of the conventional saw with and without delays was 3.42 cubic meters per hour (14 trees/hour) and 3.91 cubic meters per hour (16 trees/hour), respectively. Finally, the average time in minutes required for the production of a cubic meter of timber was 28.27 min/cub.m. and 24.21 min/cub.m. for the catalytic and the conventional saw respectively. The results showed that there is nearly no difference between Stihl MS 170D and Stihl MS 181.

Keywords: *chainsaw, catalytic, timber harvesting, time study*

1. INTRODUCTION

The evolution of chainsaws is a continuous and necessary process since saws are used in contexts that are extremely demanding and tiresome for the worker and highly detrimental to the environment. The development of these machines that are operated in the forest concerns both their ergonomic improvement and their ecological acceptance. From this viewpoint, as 'developed' can be considered the catalytic saws which are marked, so that they can be easily identifiable, with the letter D by Stihl, the manufacturing firm that produces both the saws examined in the present paper.

The basic principle in the creation of such saws was the reduction in the emission into the atmosphere of harmful gases such as hydrocarbons. The catalytic converter is an exhaust emission control device that converts toxic gases and pollutants in exhaust gas from an internal combustion engine into less-toxic pollutants by catalyzing a redox reaction (an oxidation and a reduction reaction).

In a research paper by Dimou et al. [1] it was shown that catalytic saws have reduced NO emissions in comparison with conventional saws under all operation conditions investigated in the study, namely under normal conditions (frequent accelerator, poor-quality oils and impure filter), whereas when used with poor-quality oils and impure filters they had reduced emissions of CH_4.

Another recent major development in the chainsaw sector is that of battery powered chainsaws that ultimately eliminate the impact of exhaust gases on humans and the environment

Nowadays, the battery saws represent a large share of the chain saw market. Their advantages include, in addition to eliminating exhaust gases, their lower weight as well as less vibrations and noise in operation compared to conventional saws.

Specifically α light-weight conventional catalytic saw with a 33cm-long blade filled with fuel weighs approximately 6 Kg, whereas a battery saw of the same category weighs about 2 Kg. In addition, other

advantages of battery saws include on one hand the limited need for maintenance and, on the other, the lower levels of vibrations generated when they are in operation as well as the production of less noise [2].

At present, battery chainsaws available on the market are only those intended for pruning activities. In the paper by Colantoni et al. [2] it was found that battery chainsaws achieved good results in the absolute sense, and in some cases were able to achieve a higher cutting performance than the reference model with internal combustion engine. Their main disadvantage, however, was found to be the need for frequent battery recharging.

In this work the working productivity of a catalytic chain saw was evaluated compared to a conventional chain saw. The term 'effectiveness' in timber harvesting contexts has a dual meaning: on one hand, it comprises the timber volume produced, and, on the other, the time that is necessary for the harvesting operations to be accomplished. Time, in association with factors like fuel consumption and carbon dioxide emissions, has been investigated by Tomas Gałęzia, who used an electronic timer with an accuracy of 1 second [3]. Galezia's paper is extremely interesting as it incorporates ecological parameters, too, but it is not grounded in the approach of the time study method, as is the present paper. Behjou et al. [4], also examined productivity and cost of manual felling, but made no differentiation between conventional and catalytic saws [4]. Owusu et al. [5], on the other hand, focused on the assessment of efficiency of two different types of blades to be used for sawing in the Ghana forests and not in mills [5]. Wójchik and Petrów [6], based on the time study approach, examined the efficiency of an experienced and a beginner logger [6]. Finally, Wang et al. [7], also applied the time study method in order to assess productivity and costs of timber harvesting systems [7]. In Greece, there have been similar studies of efficiency and cost [8]. However, there has been no research focusing on productivity comparisons between different work equipment like the chainsaw.

1.2 Aim of research

The aim of the present study was the evaluation of work productivity of a catalytic Stihl MS 170D saw in comparison with a conventional saw (a Stihl MS 181).

The present study constitutes the second part of a research project investigating the use of catalytic chainsaws [8]. The first part of the study had focused on the gases generated by catalytic saws which are detrimental to the saw operator as well as those that are harmful for the environment.

1.3 Study areas

The data from the present study have been obtained from harvesting operations carried out in the peri-urban forest of Xanthi (41º 09´ 27.33´´ N - 24º 54´ 09.80´´ E) which is located northern of Xanthi city, in northeastern Greece, and it covers an area of 2.366,137 ha [9].

The topography of the area varies, due to many hills, gorges and streams. Slopes vary from 5% to 80%, while the minimum altitude is 100 and the maximum 630 m above the sea level.

In 1936, planting activities began and took place periodically up to 2007, even though most of them were had been performed till 1973. In 2006, the forest was designated as 'protected forest'. The species that were used for reforestation were mainly *Pinus brutia*, and secondarily *Pinus pinaster*, *Pinus pinea*, *Pinus nigra*, and *Cupressus spp*. A few broadleaves such as *Robinia pseudoacakia* were used as well [9].

According to data from the nearest meteorological station (located in the city of Xanthi), the mean annual temperature is 15.5ºC and the mean annual precipitation is 675 mm. The xerothermic period lasts from July till the middle of October [10]. The soil is classified as alkaline with poor humus [9].



Fig. 1. Demonstrative plots

Measurements were performed in the frame of the research project FoResMit (EU Life Program) [11]. Felling tasks were carried of the demonstrative plots (Fig1.), the total area where harvesting and measurement work was done was 2.2 ha. Stand age was about 70 years old, the average volume of trees felled with the catalytic chain saw was 0.10 m^3 and with the conventional 0.19 m^3 respectively. The receiving area was at an altitude 300 to 440m and the average slope was classified as *steep* varying from 38% to 55%. Rock type was gneiss and soil depth varied from moderately deep (30-60cm) to deep (60-120 cm). Soil species was sand–clay. (Management plan of Public Forest of "Gerakas-Xanthi-Kimmeria" [online 12].

2. MATERIALS AND METHODS

In total, felling, processing and walk-to-tree times of 84 *Pinus brutia* trees were measured, 42 trees for each saw. In addition, delays were taken into consideration, too. 193 task measurements were performed with the catalytic Stihl MS 170D (hereinafter referred to as Cat S MS 170D), and 198 measurements were performed with the conventional Stihl MS 181 (hereinafter referred to as S MS 181). Time measurements were carried out under actual conditions of felling and processing small-length *Pinus brutia* logs (below 4m).

Time measurements of harvesting tasks were carried out in accordance with the time study method in order to compare the productivity of a catalytic saw, namely a Stihl MS 170D, with a conventional, saw, a Stihl MS 181. Both the conventional and the catalytic saws (S MS 181 and Cat S MS 170D) are light-weight, have a 33cm blade and engine capacity varying between 35 - 45 cm^3.

For every tree that was felled, its characteristics (breast height diameter and volume) were recorded in a special document. The products yielded through logging were mainly in the form of stacked timber 1.00-1.20m long.

From the measurements that were performed, the trunk volume was determined for each tree separately based on the breast height diameter and with the help of a volume table [13]. The equation for the determination of the volume was as follows:

$$y = 0.201 - 0.032x + 0.001x^2, \quad R^2 = 0.792$$

Site conditions that were taken into consideration included the existence and the form of obstacles that hinder felling works (understory vegetation, rocks etc.) as well as the distance in minutes that the worker covers walking from tree to tree.

For carrying out the time study research in the specific *Pinus brutia* forest, a skilled forest laborer aged 30-35 was used. Before the onset of the time studies, the purpose of the research was explained to the laborer and he was properly informed and trained. The laborer completed on his own all felling and

processing tasks (delimbing, measurements and bucking). The equipment that he used for these tasks was the chainsaw (Cat S 170D or S MS 181).

The crew that took the time elements consisted of two persons: the timer, who followed the worker and recorded his actions and moves, and his assistant, who followed and recorded information about the trees.

Björheden et al. [14], who dealt with the classification of time in forest work, defined Workplace Time (WP) as the portion of the total time that a production system or part of a production system is engaged in a specific work task.

Workplace Time includes Main Work Time (MW) plus delays such as Refuel Time (RF) and Rest and Personal Time (RP) [14]. Main Work Time (MW) according to Björheden et al. [14], means the portion of the productive work time used to change the work object with regard to form, position, or state within the definition of the work task; this includes tasks such as felling, de-limbing, bucking, skidding, loading, etc. Delays in the present study include Refuel Time (RF) and Rest and Personal Time (RP).

Before the start of the research, the following suboperations were delineated: a) walk to tree, b) preparation for felling (in this stage breast height diameter was measured, too), c) felling, d) processing, and e) delays (avoidable and unavoidable).

The method that was followed was continuous timing. According to this method, the stopwatch is in continuous operation and at the beginning of each phase or phase change as well as at the end, the time shown by the time indicator is recorded, so the duration of each stage is calculated on the basis of the time difference between a specific work stage and the previous one. All these were recorded in the special table.

Additionally, for each tree and work phase separately the worker's efficiency coefficient was applied that was calculated as a percentage of the coefficient of normal efficiency (100%), which characterizes the sufficiently capable trained worker, who works with proper methods, utilizes suitable means and works with satisfactory intensity and productivity, making use of necessary breaks for preparation or rest. The efficiency coefficient cannot be the same during the day and it may also differ from worker to worker. Its calculation is mainly done on the basis of the laborer's work intensity and productivity.

From the time differences that were recorded in the time studies tables, main work times were calculated for each phase and, separately, for unavoidable delays.

Based on the time elements recorded, for each *Pinus brutia* tree calculated were: main working times of felling, main working times of processing (measuring, bucking and delimbing), total main working times of harvesting (the sum of felling and processing times) as well as unavoidable delays as percentage (%) of main working times.

Subsequently, the above times were correlated with the tree volume and the covariance equations of the partial working times (namely the main working times of felling and processing) and the total harvesting time were computed.

For the determination of the statistical equations (1) the following formula was used:

$$y = a + bx \quad (1)$$

Where, Y = the time of suboperations (workplace time of felling and processing) and the total time (total workplace harvesting time), x= volume and a and b = coefficients.

Reliability check of the equations was done with Pearson correlation coefficient R^2.

In most published papers, delays are reported as a percent of the total scheduled time or Workplace Time. SMH can be calculated from Equation (2) [15].

$$SMH = PMH + H_{mech} + H_{op} + H_{oth} \quad (2)$$

Where:

$SMH =$ scheduled machine hours,

$PMH =$ productive machine hours,

$H_{mech} =$ hours of mechanical delay (Refuel Time),

H_{op} = hours of operator delay (Rest and Personal Time), and

$H_{oth} =$ hours of other delay.

Mechanical delays (MechD), have been calculated [15] from equation (3).

$$MechD = \frac{H_{mech}}{SMH} \quad (3)$$

Where:

$MechD =$ mechanical delay (%) (Delay of Refuel Time),

and operator delays have been calculated from the following equation (4)

$$OpD = \frac{H_{oph}}{SMH} \quad (4)$$

Where:

$OpD =$ operator delay (%) (Delay of Rest and Personal Time),

The other delays (OthD) were not taken into consideration in the present study. OthD included walk-to-tree times, since time studies were performed on two plots, delays due to hanging trees and delays incurred by breast height diameter measurements on each tree that was felled.

3. RESULTS

Table 1. ANOVA model for Cat S MS 170D

Source	Sum of Squares	df	Mean of Spuare	F-value	P-value.
Regression	10.784	1	10.784	106.796	0.00
Residual	4.039	40	0.101		
Total	14.824	41			
Regression	55.335	1	55.335	73.385	0.00
Residual	30.161	40	0.754		
Total	85.496	41			
Regression	114.977	1	114.977	112.886	0.00
Residual	40.741	40	1.019		
Total	155.717	41			

In order to make comparisons regarding the productivity of the two chain saws, the harvest time was measured in relation to the volume of the trees.

The significance level of the ANOVA (Table 1 and 2) shows that the models are significant at a=0.01. The volume and the interaction between felling time, processing time and harvesting time are shown in figure 2 and 3 for the Cat S MS 170D and Stihl MS 181 saws, respectively.

Table 2. ANOVA model for Stihl MS 181

Source	Sum of Squares	df	Mean of Spuare	F-value	P-value.
Regression	10.274	1	10.274	110.513	0.00
Residual	3.719	40	0.093		
Total	13.992	41			
Regression	63.665	1	63.665	83.0.54	0.00
Residual	30.662	40	0.767		
Total	94.328	41			
Regression	125.067	1	125.067	145.963	0.00
Residual	34.274	40	0.857		
Total	159.341	41			

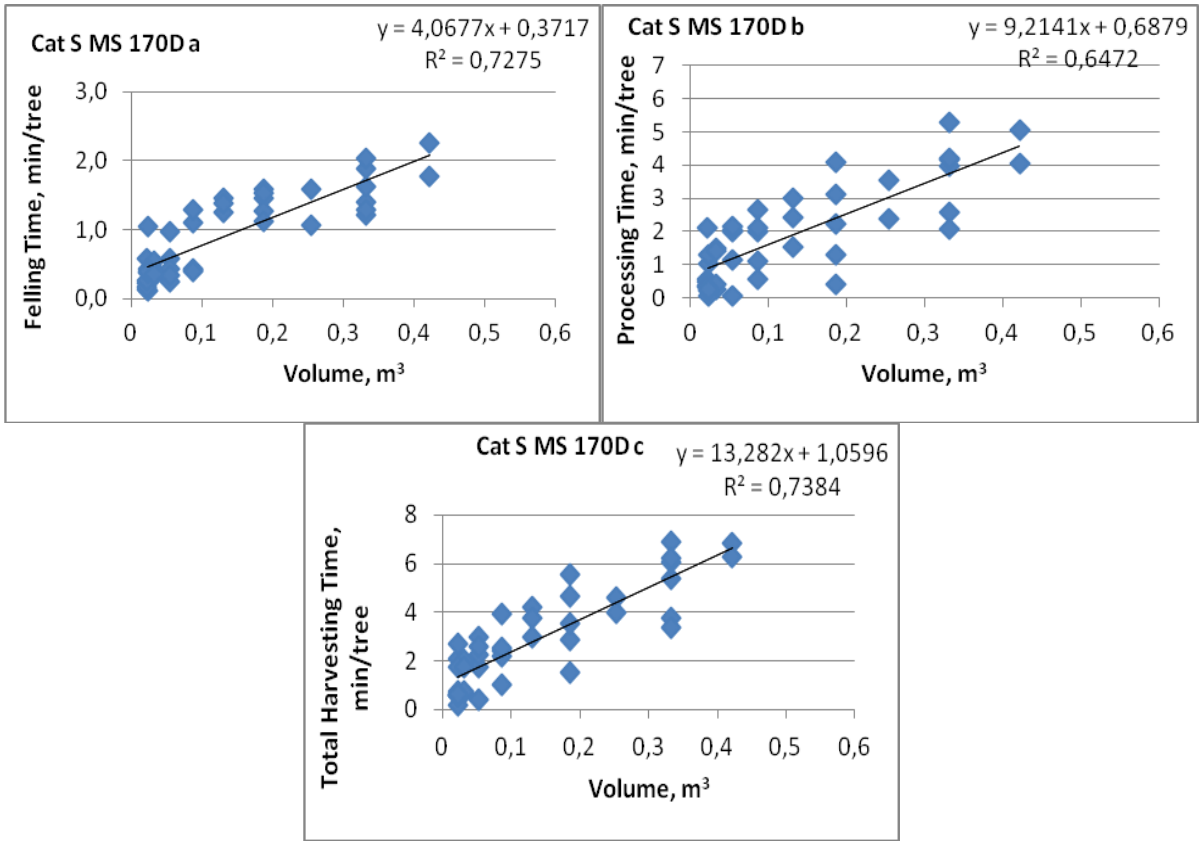


Fig. 2 a, b, c. Relationships between the volume and basic working time for each sub-operation and the total harvesting time for Cat S MS 170D

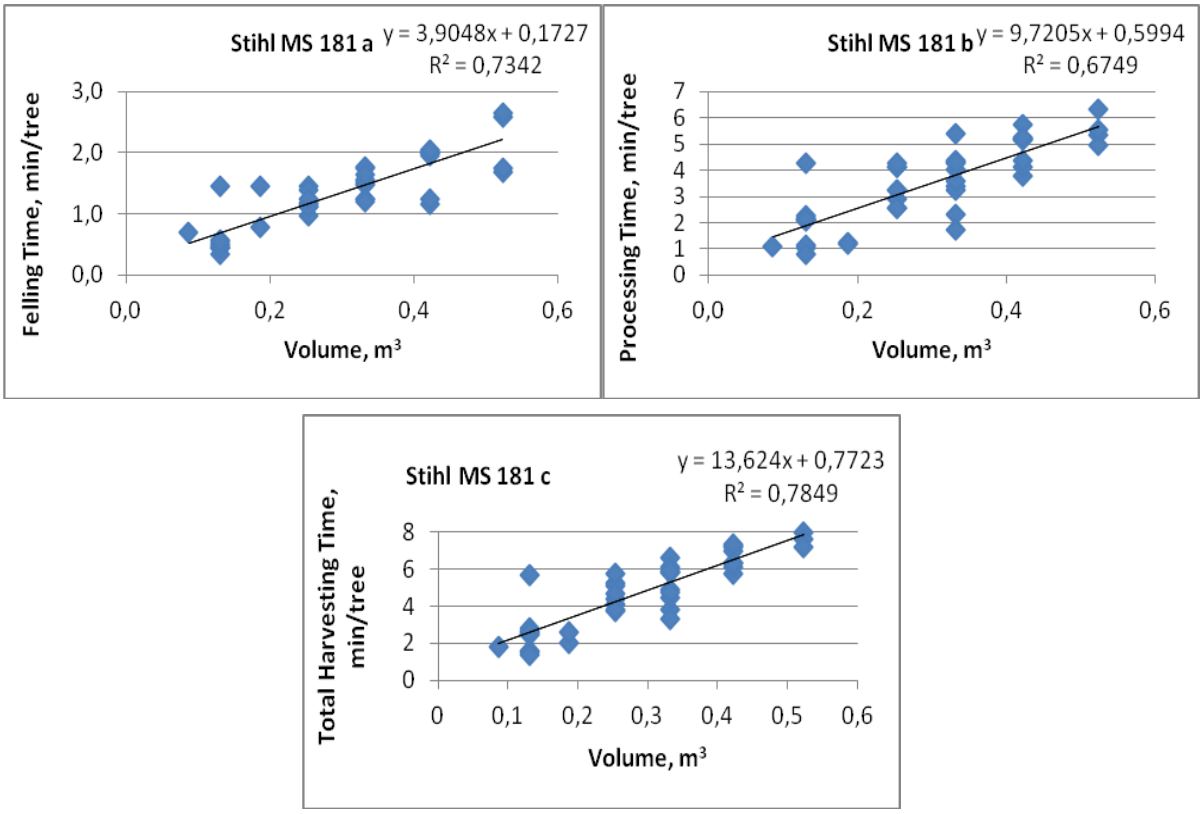


Fig. 3 a, b, c. Relationships between the volume and basic working time for each sub-operation and the total harvesting time for Stihl MS 181

From regression equations as well as mechanical delay and operator delay equations (3) and (4), the following equations can be derived, which were used for the calculation of the total harvesting time with delays in minutes per log (Tables 2 and 3, column 8).

Column 9 shows the results with delays in min/cubic meter, which are derived by multiplying Workplace time WP (column 8) with pieces of logs/cubic meter (column 2) (Tables 1 and 2).

Cat Stihl MS 170D $$y = 13.282x + 1.0596 + 0.15MechD + 0.24OpD \quad (5)$$

Stihl MS 181 $$y = 13.624x + 0.7723 + 0.15MechD + 0.14OpD \quad (6)$$

Table 3. Workplace time (Total harvesting time) with delays in min/cub.m for Cat S MS170D

Cat S MS 170D		**Workplace Time (WT)**						
cub.. /logs	piece of logs /cub.m.	Work Time (WT) Main Work Time (MW)			Refuel Time (RF)	Non-Work Time (NT) Work-Related Delay Time (WD)	Workplace Time (WP) MW+RF+RP min/logs	Workplace Time (WP) MW+RF+RP min/cub.m.
		cut	delimb.	Sum (MW)		Rest and Personal Time (RP)		
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
<0.2	10.00	0.78	1.61	2.39	0.36	0.57	3.32	33.19
>0.2-0.4	3.33	1.59	3.45	5.04	0.76	1.21	7.01	23.35
Average								28.27

Table 4. Workplace time (Total harvesting time) with delays in min/cub.m for Stihl MS 181

Stihl MS 181		**Workplace Time (WT)**						
cub.. /logs	piece of logs /cub.m.	Work Time (WT) Main Work Time (MW)			Refuel Time (RF)	Non-Work Time (NT) Work-Related Delay Time (WD)	Workplace Time (WP) MW+RF+RP min/logs	Workplace Time (WP) MW+RF+RP min/cub.m.
		cut	delimb.	Sum (MW)		Rest and Personal Time (RP)		
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
<0.2	*10.00*	*0.56*	*1.57*	*2.13*	*0.32*	*0.30*	*2.75*	*27.54*
>0.2-0.4	3.33	1.34	3.52	4.86	0.73	0.68	6.27	20.88
Average								24.21

The productivity of chainsaw harvesting can be obtained by using the production and time data as follows [16]:

$$Production = \frac{TFV}{TFT} (7)$$

Where:

$TFV = total\ felling\ volume, m^3$

$TFT = total\ felling\ time, hour$

Table 5 presents the statistics of time studies in minutes for the 84 trees felled (42 trees for each type of saw: Cat S170 D and S 181).

Table 5. Statistics of operational variables of chainsaws

Variable	Mean		Standard deviation		Minimum		Maximum	
	Cat. SMS 170D	SMS 181	Cat. SMS 170D	SMS 181	Cat. SMS 170D	SMS 181	Cat. SMS 170D	SMS 181
Harvest conditions								
DBH	18.2	24.5	5.69	3.56	10	18	28	30
Volume per tree (m^3)	0.13	0.29	0.12	0.12	0.02	0.09	0.42	0.52
Elemental times (min)								
Walk to tree	0.86	1.06	0.02	1.47	0.08	0.11	4.24	9.01
Cut	0.93	1.33	0.60	0.58	0.12	0.35	2.26	2.65
delimb./process	1.94	3.48	1.44	1.24	0.08	1.46	5.29	5.72
Total harvesting time[a]	2.87	4.81	1.95	1.77	0.20	2.15	6.92	8.37
Productivity (m^3/PMH)[b]	3.35 Cat. SMS 170D 3.42 SMS 181							

[a] Total harvesting time per tree include delays.

[b] PMH = productive machine hour, between 0.1-0.4 m^3/tree

4. DISCUSSION

From equations (3) and (4) it was made possible to calculate the mechanical delays and operator delays for the two saws. For the catalytic saw, mechanical delays equal 15% and operator delays equal 24.08%, whereas for the conventional saw the equivalent delays were 14.78% and 14.27% respectively.

Spinelli et al. [15] in a research of 34 time studies on harvester where labor productivity in relation to manual felling is clearly higher nonetheless the productivity found that mechanical delays equaled 7.1% and operator delays 4.7%. Besides, Borz et al. [17] in a study on time consumption of round wood skidding found that mechanical delays corresponded to 5.62%.

From Tables 3 and 4 it is easy to see that the difference between the two saws in min/cub.m. is very small (column 9). For trees below 0.2 m^3 Cat Stihl MS 170D takes 33.19 min/cub.m and Stihl MS 181 27.54 min/cub.m. For trees from 0.2 to 0.4 m^3 the equivalent times are 23.35 min/cub.m and 20.88 min/cub.m. respectively for Cat Stihl MS 170D and Stihl MS 181.

From equation (7) it is clear that the productive machine hour without delays for Cat. S170 D was 3.48 m^3/PMH and with delays 3.35 m^3/PMH (Table 5).

The measured production for motor-manual harvesting without delays was 3.91 m^3/PMH and with delays 3.42 m^3/PMH (Table 3) for S 181.

The comparisons between the two saws were performed in the range between 0.1 and 0.4 m^3/tree, which was the common range of volume per tree.

Jourgholami et al. [16] in their assessment of saw productivity quote corresponding values of 56.4 m^3/PMH and 80.7 m^3/PMH with and without delays respectively. The big difference between their measurements and the results of the present study is attributed to the difference in tree volumes.

In the paper by Jourgholami et al. [16] the volume per felled tree was between 0.2 to 29.7 cubic meters with an average of 4.27 cubic meters, whereas in the present paper comparisons were made between trees ranging from 0.1 to 0.4 cubic meters with an average of 0.24 cubic meters. In another paper by

Wang et al. [7] it was found that chainsaw productivity was 10.14 cubic meters (362 ft^3/PMH) per productive machine hour (PMH).

Also, the hourly production of Cat. S MS 170D harvesting with delay was 12 trees per hour and without delay 13 trees hour, respectively. The hourly production of S 181 chainsaw harvesting with and without delay was 16 trees per hour and 14 trees hour, respectively. Jourgholami et al. [16] found 13 tree per hour with delay and 19 trees hour, without delay, respectively.

However, productivity of felling may be influenced by the operator skills, silvicultural method, tree species, stand composition, undergrowth trees and seedlings, weather condition, coldness of weather, age and brands of chainsaws, chain condition, and lean of the tree as well as slops [18]; [19]; [20].

All the factors mentioned above were not taken into consideration in the present study since the focus here is mostly on the brand of the saws.

5. CONCLUSIONS

The findings of the present research can be summarized as follows:

Based on the harvesting times that were calculated for the two chainsaws under study, the output in min/cub.m. has been assessed and it has been nearly the same that is as productive as the catalytic saw. The difference found 28.27 min/cub.m. in average for Cat MS 170D (for trees below 0.2 m^3 take 33.19 min/cub.m and for trees from 0.2 to 0.4 m^3 take 23.35 min/cub.m) and 24.21 min/m^3 in average for S MS 181 (for trees below 0.2 m3 take 27.54 min/cub.m and for trees from 0.2 to 0.4 m^3 take 20.88 min/cub.m).

The productive machine hour with delay was 3.35 m^3/PMH and 3.42 m^3/PMH for Cat MS 170D and S MS 181, respectively. The results show that there is almost no difference. The construction of larger chain saws, ie higher horsepower and blade length, could fit them in place of conventional chain saws and capable of all woodworking regardless of the volume of the trees because they have considerable advantages as reference to pollutant exhaust gases by reducing the carcinogenic risk to forest workers.

Further developments in this technology would lead to the cleanliness of chainsaws by eliminating the carcinogenic risk of forest workers after removing the combustion of the mixture. In addition, electric motors do not develop (inside themselves) alternating movements thanks to the rotation of the rotor, the vibrations are significantly reduced, as well as noise, much lower than the endothermic motors.

Although no temperature measurements have been made frequent interruptions in the use of a chain saw adversely affect the productivity of a catalytic saw. This is because the operation of a saw in idle mode inevitably leads to drops in engine temperature, resulting in a reduction in overall performance. In order to regain its normal productivity, the saw must be returned to a temperature of 350-400 ° C.

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