

ANALYSIS OF ENERGETIC INDICATORS OF FORESTRY MILLING MACHINES FOR SITE PREPARATION

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ABSTRACT

In this paper is performed experimental study to determine energy intensity of self-propelled milling unit PT-400 equipped with multifunctional forestry tiller FAE 300/S-225 for site preparation, for poplar plantation establishment. For the purpose of the study the following processes are investigated: grinding stumps and roots, mulching shrubs and slash, and primary tilling. The study is conducted in riparian and partially flooded areas along the Danube River. As a result of the survey are established the fuel consumption and the operational productivity of the forestry unit under certain working conditions and predefined variable modes of operation of the unit. For all the operations are found the energy intensity and the relative fuel consumption per unit area. With the obtained data are built functional graphical relationships, expressing the energy intensity of the milling unit depending on the speed modes and working conditions. As a final result are determined the optimal operational modes for the tilling aggregate where energy cost for land preparation for the establishment of poplar plantations is minimal.

Key words: poplar clearings, mulching, milling, energy intensity.

1. INTRODUCTION

The management of poplar plantations for accelerated timber production requires periodically and in a relatively short periods of 12–18 years timbering areas to be reimbursed (Dimitrov and Panov 1982, Isebrands 2007, Christersson 2008). Forest site preparation for afforestation is among the most labor-intensive and expensive activities, especially for intensive poplar cultures establishment. (Dilov 1992, Gönna and Marc 1992, Hallbrook 2006, Löf et al. 2012, Marinov 2013 *a*). In order to increase the productivity of these cultures it is essential to apply intensive cultivation practices (Dimitrov and Panov 1982, Christersson 2010, Böhlenius and Övergaard 2015). Such agro-technics is possible only for when the competitive standing vegetation, trees, brushes and all stumps are completely removed from the clearings and. This requires a significant portion of the capital expenditure to be in-

vested in the first year of the creation of the culture. The introduction of modern technologies and machinery for site preparation for afforestation is the key for reducing labor costs (Fight and Barbour 2004, Marinov 2013 *b*, Keča and Pajić 2015). According to the applied technology and operating conditions, such costs can range between 120 and 350 €/dka (Keča at al., 2011, Marinov and Yordanova 2016). All technologies for site preparation are based on a certain system of machines (Vasilev and Dimitrov 1978, Hansenetal 1984, Gönna and Marc 1992, Marinov 2013a). Recently, in many countries increasingly is introducing the use of specialized forestry tillers and mulchers. According to their purpose, these machinery can be used for stumps grinding, to fell down trees and shrubs, to mill the standing vegetation and wood chips, and for soil tillage. Technologies for site preparation, built on such forestry milling machines have the

following major advantages (Marinov 2014):

- To decrease labor costs;
- To rationalize the whole process – to shorten some of the applied operations and reduce the agrarian period for soil preparation;
- To reduce the risk of forest fires in the area of clearings;
- To support full utilization of biomass and land area for afforestation;
- To ensure higher quality of soil preparation and etc.

Lately in the Northwestern Enterprise Vratca was introduced into operation a new milling aggregate for site and site preparation of clearings for poplar plantations establishment. The milling aggregate is assembled from tracked carrier PT-400 and multifunctional forestry tiller FAE-300/S-225. The aggregate is powered by a Caterpillar CAT C-13 engine with a rated power of 310 kW. The tracked carrier module is equipped with 800 mm width track, which ensures the machine a higher negotiability and traction force of 275 kN, a low level of soil compaction – 0.35 kg/cm^2 and the opportunity to work on humidified and waterlogged terrains. For more flexibility of the milling process and to be able to operate at severe conditions, the machine is equipped with a hydrostatic drive system and transmission management of the cutter. Through adjustable piston-axial pumps and hydromotors ensures smooth change of the speed of the tiller, and the working speed and the traction of the unit. The teeth of the cutter are 92 chisel-shaped knives with a diameter of 0.80 m and a width of 2.35 m, staggered along the periphery of the milling drum. For even load the teeth they are staggered equi-

distantly over an unfolding four-threaded screw with left and right sweep.

The forestry milling unit PT-400 with multifunctional tiller FAE-300/S can perform three different technological operations and operate as 1/ forestry brush cutter – mulcher; 2/ tractor milling machine for grinding stumps and roots up to 50 cm; 3/ tiller for deep primary tillage. The first two operations, mulching of standing and lying vegetation and crushing stumps and roots, are performed during the first stroke of the unit. The main tillage can be performed as a second stroke or after full completion of the first two operations. During the third operation, the received wood chips by the grinding process are mixed with the soil and subsequently digest into the ground in the form of valuable organic substances. Thus, they help to improve the food base and increase the productivity of future poplar culture. The soil enriched with such organic substances has a high degree of loosening and aeration, and is ready for planting large-sized poplar saplings. The first results of this machine showed high quality of soil preparation and shortening the agricultural terms for afforestation (Marinov and Jordanova 2015, Jordanova and Marinov 2015). On the other hand, milling machines for soil preparation are also distinguished with higher energy intensity. Compared with the previous technologies for soil preparation for afforestation in our the country, this new one may adversely affect on the cost per unit area. To reduce these costs while keeping higher quality and environmental performance of soil preparation is necessary to establish such technological modes with which the relative energy costs will be lowest. From the annual summary for 2015 in Forestry Enterprise Vratsa, it was calculated that the average price for an acre area treated with milling unit PT-400 is between

140÷150 € / dka, and nearly half of these costs are for fuel. Therefore, it is important to determine the optimal operational conditions under which the energy intensity of the milling unit will be minimal.

Purposes of the study: To determine the energy consumption of milling unit PT-400 with multifunctional forestry tiller FAE 300/S for site preparation of poplar clearings and to optimize the technological process.

Objectives of the study: 1/ To determine fuel consumption and productivity of the studied unit during its performance of different technological operations from the process of soil preparation; 2/ To establish the optimal operating speed of the milling

aggregate by optimizing the power consumption per unit area.

2. METHODS AND MATERIALS

2.1. The object and subject of study

The subject of the study is a machine-tractor unit PT-400 with multifunctional forestry tiller FAE 300/S-225 for site preparation of poplar clearings. The subject of the study is the power consumption of the milling unit during performance of different technological operations. In order to determine the energy consumption it is required first to determine the fuel consumption and the productivity of the milling aggregate, which operates under certain working conditions.



Figure 1: Site preparation of a poplar clearing with tracked self-propelled unit PT-400 equipped with multifunctional forestry tiller FAE 300/S-225

2.2 Optimization of process the soil preparation

To determination of optimal operational regimes of the process the soil preparation at certain engine power and operational width, is necessary to determine in advance the most efficient operating speeds and loading of the machine. In forestry to optimize the technological processes and to reduce the production costs different methods and tools are applied. One of the main methods when exploit mobile forestry machines is the eco-

nomie method, with which we aim to minimize direct costs. Different optimization criterias can be used for this purpose. Such optimization criterions, mainly used in the process of acquisition of forestry mobile machine-tractor aggregates is the “technical criterion” (Marinov 2013, a).

The operation modes of the milling unit PT-400 with forestry tiller can be controlled by the speed gear of the drive unit and the forestry mulcher revolutions. To optimize the operational technological process by

using the “technical criterion” we are looking for the minimum of the specific power consumption, using the following formula:

$$E_p = \frac{N_{E\phi} \cdot \eta_{DB}}{B_p \cdot v_p} \rightarrow \min, \quad (1)$$

where v_p is the working speed of the unit, km.h^{-1} ;

$N_{E\phi}$ – effective engine power, kW;

η_{DB} – the coefficient of power usage of the engine;

B_p – working width of the tiller, m.

The power consumption of the unit E_p in the formula (1) is determined by the working width, the working speed of the unit, and the coefficient of power usage of the engine. The last is established experimentally. The power consumption can be determined by summarizing the direct operational costs. Another way of finding the power consumption is by direct measurement of the fuel consumption and the treated area per unit of time. The “technical criterion” can be replaced with equivalent “operating criterion”. The “operating criterion” to find the minimum of power consumption is as follows:

$$E_p = \frac{G_h}{W_h} \rightarrow \min, \quad (2)$$

where G_h is operational fuel consumption per hour, l.h^{-1} .

$W_h = B_{\text{work}} \cdot v_{\text{work}}$ – operational productivity per hour, dka.h^{-1} .

The optimization of power consumption by using “operating criterion” (2) will allow to establish operating speeds at which the fuel consumption per unit area will remain minimized while the productivity will be maintained highest.

2.3. Parameters of the study

To determination of fuel consumption and operational productivity of the milling unit PT-400 for different operations, as

mulching, grinding stumps and roots, and deep milling is carried out experimental observations with established input and output parameters.

Input parameters of the study. These parameters, also known as input factors, affecting directly the process, can be controllable and uncontrollable.

Input controllable factors. To monitor the process are selected two factors – gear speed of the unit and speed of the milling drum. At constant operating width of the machine, these two factors express most correctly the needed power capacity and energy intensity of the process. The speed of the unit and the speed of the milling drum can be controllable and maintained at the same level during the experiments. They are independent, controllable and compatible, and therefore are suitable to be input controllable factors. These parameters are the basis for choosing the appropriate mode of each milling machine as directly influence the cutting speed and feed of processed material. Thus it is possible to use multi-criteria optimization of the technological processes. The speed of submitting the material (the movement of the unit) and the speed of cutting directly affect on the necessary power for propulsion and the energy usage for cutting and deformation of soil and wood.

1. *Transmission gear.* The first three gears of the reciprocating movement of unit PT-400 are suitable for soil preparation. Both, the frequency of rotation of the milling drum and the transmission gear, affect on the step of cutting and the degree of deformation of the soil and wood chips. For this purpose it can be selected: 1st gear for lower level of variation; 2nd gear – for average level and 3rd gear – for upper level of variation.

2. *Milling drum revolutions.* The frequency of rotation of the milling drum af-

fects directly on the speed of cutting and the needed power for milling, the deformation and the fragmentation of the soil and the vegetation. The frequency of rotation can be managed between 0–500 min^{-1} . Based on the prior information and to be able to explore the research process in details, it was found that the range of variation of this factor must be between 250 min^{-1} ÷ 500 min^{-1} . The lower frequency leads to overload of the machine and decrease the quality of work. Three basic levels of the frequency of rotation of the milling drum are chosen in this range. These levels would help to limit the number of attempts and to facilitate the tracking of the alteration of the output parameters. The levels are: lower level – 250 min^{-1} ; average level – 375 min^{-1} and upper level – 500 min^{-1} .

Input uncontrollable factors. These factors are related to certain production conditions. They can not be managed on the field, but during the experiments can be maintained at a certain level. These factors are:

- slope – до 2÷3°;
- depth of tillage –50cm;
- mechanical structure and category soil: sandy loam, moderate;
- soil moisture – 48÷52 %;
- soil hardness – 1.8-2.0 MPa.

These production conditions are typical for floodplain areas and forest areas along Danube river. They are best suited for establishment of poplar plantations.

Output parameters of the study. Output parameters are those, that can be measured and used to determine the energy cost and productivity of the milling unit. They are:

1. Quantity of fuel consumption, l;
2. Duration of the operations, h;
3. Volume of the production, dka.

The volume of the production is measured immediately at the end of each obser-

vation. To measure the performing time for every operation are made motion-time studies. The minimum duration of these motion-time studies is determined by pre-approved methods for standardization of productivity of mobile machine-tractor units for afforestation activities in Bulgaria (Stojanov 1994).

2.4. Place, conditions and equipment of the study

The study was conducted in poplar clearings along the Danube River, in the period between 2014 and 2016. In these areas is made 100% clear felling and is forthcoming planting with poplar trees. To conduct the experiments were differentiated experimental sites with size between 30 and 52 dka. These experimental sites are located within several Forestry States – Forestry State “Vidin”, Forestry State “Lom” and Forestry State “Oryahovo”. The average diameter of the remaining stumps in the cutting areas varies between 22 cm and 60 cm. The soil is alluvial, partially floodplain, very deep and non-rocky. The terrain is flat with altitude 250 m. The habitats are type M-I-2, D_{2,3}. The clearings and the experimental sites are rectangular-shape, which facilitates the productivity of the unit. To differentiate the production conditions in order to perform the first technological operation – mulching of standing trees and coppice vegetation, shrubs and slash, it is used earlier introduced categorization of poplar clearings (Marinov and Yordanova, 2016).

1st category – they are cleaned of standing trees and coppice vegetation, also of wood chips, may consist low shrubs with height up to 2 m; *2nd category* – cleaned from standing trees and wood chips, but with high vegetation, consisting of coppice, Amorpha and other bushes with height

above 2.5 m; 3rd category – not cleaned from standing trees and wood waste, with low shrubs with height up to 2 m; 4th category – not cleaned from standing trees and wood waste, with high vegetation, consisting of coppice, Amorpha and bushes with height above 2.5 m.

The measuring equipment includes – tape, GPS „Speed Data TT-43” to measure the fields; stopwatch to determine the duration of the operations; spring penetrometer "Dickey-John" to determine the hardness of the soil; electronic scale "Sartorius ME235S" with accurate to 0.01 g to weigh the soil and wood chips samples. Soil moisture is determined by weighting method, by drying the soil samples in a desiccator at a temperature $T=103 \pm 2^{\circ}\text{C}$.

3. RESULTS AND ANALYSIS

The study was conducted on the territory of the Northwestern Forest Enterprise Vratsa in the region of several Forest States. The milling aggregate PT-400 was studied under real working conditions. Experimental observations for every operation of the unit

were carried out. The operations include – mulching of coppice vegetation, shrubs and wood waste in the clearings; grinding of poplar stumps and roots; deep primary tillage.

3.1. Mulching of shrubs, coppice vegetation, and wood waste in poplar clearings

The experimental observations are conducted on the territory of Forest State “Oryahovo”, Forest State “Lom” and Forest State “Vidin” in the period between 2014 and 2016. The research is conducted on four category clearings. For the observations are used 12 differentiated experimental sites, by 3 for every category clearings. The experimental sites are between 52 and 65 dka. According the accepted methodology, in each experimental site are carried out by nine experiments, by three for every transmission speed gear and by three for the accepted three levels of the frequency of rotation of the milling (mulcher) drum – revolutions. The values obtained are provided in Table 1.

Table 1: Relative fuel consumption (energy intensity) for mulching 1 dka poplar clearing

Mulcher (milling) drum revolutions [min ⁻¹]	Relative fuel consumption [l.dka ⁻¹]					
	1 st category slash			2 nd category slash		
	1 gear	2 gear	3 gear	1 gear	2 gear	3 gear
250	37.33	28.53	24.95	41.22	30.71	28.06
375	25.05	22.07	21.06	29.09	24.07	24.02
500	19.47	18.40	17.35	22.36	19.46	20.30
Mulcher revolutions [min ⁻¹]	3 rd category slash			4 th category slash		
	1 gear	2 gear	3 gear	1 gear	2 gear	3 gear
250	44.88	37.02	35.69	51.91	43.40	43.83
375	32.70	29.87	33.45	37.45	34.04	39.57
500	27.00	25.49	29.89	30.21	29.36	35.32

Based on the obtained results are build graphical relationships representing the alteration of the energy consumption of the research unit depending on the speed gear of the unit and the milling drum revolutions.

To expres these dependencies for all four categories cutting areas were built separate graphics that are presented in figures № 2, 3, 4 and 5.

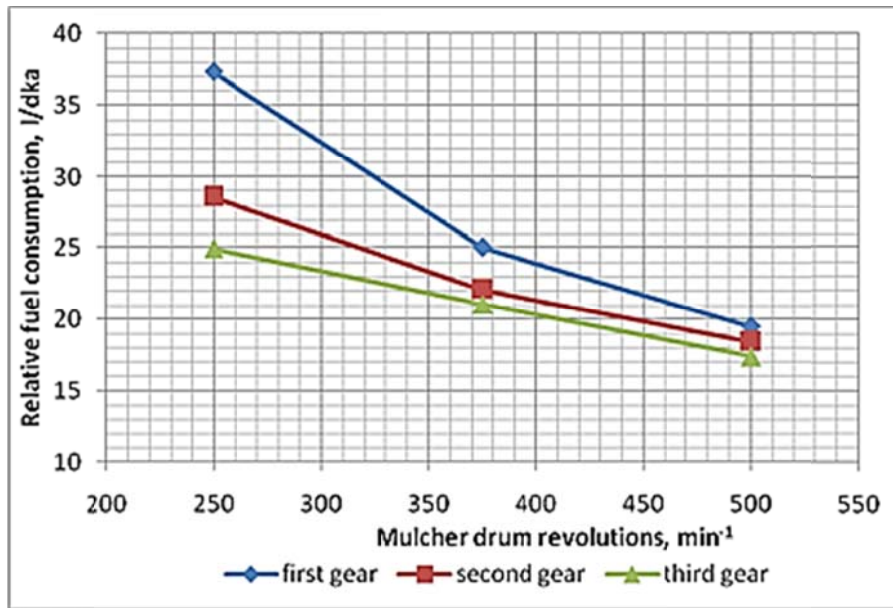


Figure 2: Variation of power consumption for mulching in 1st category clearings

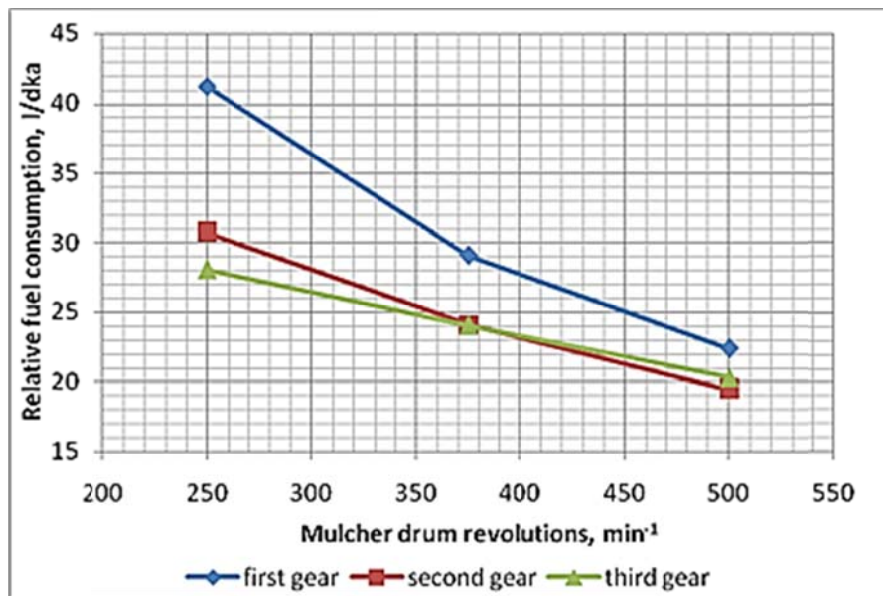


Figure 3: Variation of power consumption for mulching in 2nd category clearings

The graph in Figure 2 shows that in the advantageous conditions of work in the clearings of the first category, low power consumption is obtained when operating at third speed gear and at highest cutter revolution of 500 min⁻¹ – 17.35 l/dka. Slightly higher is the power consumption when operating at second gear and at the same cutter revolution – 18.4 l/dka. When the unit operates in 2nd category clearings, wherein the standing vegetation has a larger volume and

weight, most economical is to operate at second speed gear, but only at the maximum frequency of rotation of the cutter. By reducing this rate to 375 min⁻¹, power consumption equalize, and then again third gear has priority. The power consumption is 19.46 l/dka, which is 0.84 l/dka less compared to operation at third gear. It can be seen for both category clearings that the relative power consumption at average revolution of the cutter are higher with 3.5÷4.0

l/dka, compared with those at maximum frequency of rotation of the milling drum.

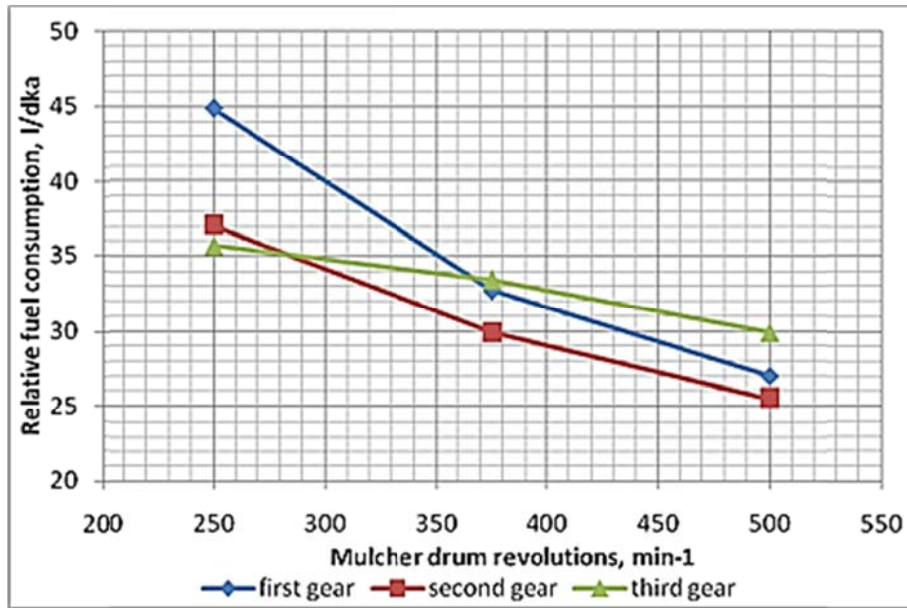


Figure 4: Variation of power consumption for mulching in 3rd category clearings

Mulching in 3rd category clearings, where there is a large amount of wood waste, the power consumption are less when using 2nd transmission gear and operating with mulcher revolution between 375 min⁻¹ and 500 min⁻¹. At maximum frequency of rotation of the milling drum, the minimum power consumption of the aggregate at 2nd speed gear is 25.5 l/dka, which is 4.5 l/dka less, compared to operating at 3rd speed gear. Here it should pay attention to the

comparatively lower power consumption when operating at 1st gear, which is only 1.5 l/dka higher compared at 2nd gear. These results are valid only for maximum milling drum revolution. By reducing the revolution to 350 min⁻¹, his mode is no longer as economical and again prevail takes 2nd and 3rd transmission gears. But at revolution lower than 285 min⁻¹, again lower energy consumption has operating at third gear.

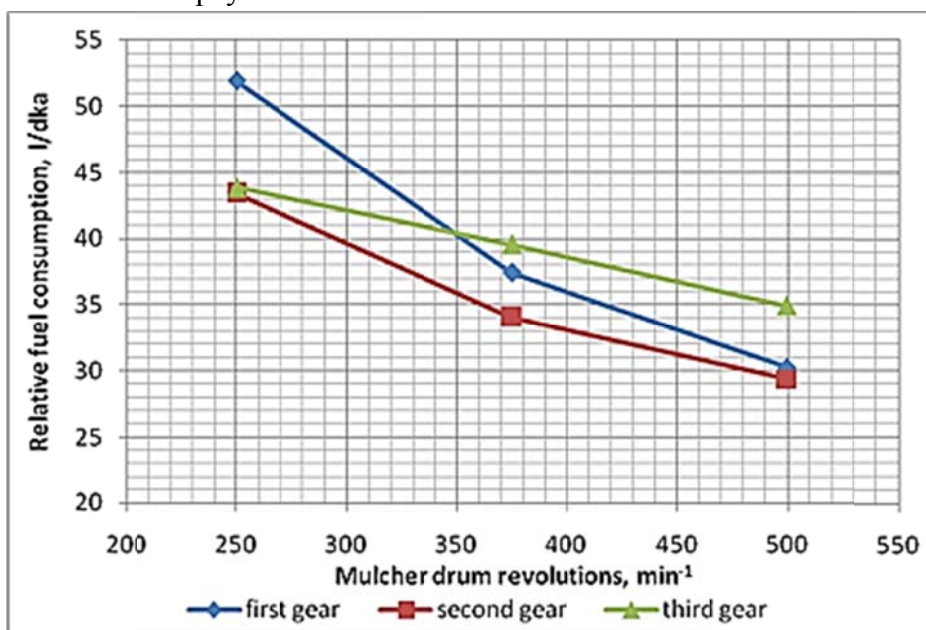


Figure 5: Variation of power consumption for mulching in 4th category clearings

Operating at the most severe field conditions, in the fourth category clearings, lowest power consumption is at second speed gear. It should be noted here that when using higher mulcher revolution significantly improves the performance, even when using first gear. For example, it can be seen from the graphs in Figure 5 that when move at first speed gear and at maximum revolution of the milling drum, the energy consumption is only 0.85 l/dka higher compared when using second speed gear, which is 29.36 l/dka.

From the results for the operation of mulching it can be seen that the lowest power consumption at maximum frequency of rotation of the milling drum – 500 min⁻¹. By reducing the frequency power consumption gradually increases, as at the beginning it increases slightly, but at revolution below 375 min⁻¹ it becomes considerably higher. Considering the different category clearings, the highest energy consumption is expected at mulching clearings from fourth category. For example, at the most economical modes of operation of the unit at 1st and 2nd transmission gears and maximum milling drum revolution, the power consumption in 4th category clearings is respectively – 29.4 l/dka and 30.2 l/dka. This is 65% higher, compared with operating in 1st category clearings, where the most economical modes are using 3rd and 2nd speed gears, respectively with 17.35 l/dka and 18.40 l/dka average energy consumption. By reducing the speed of the milling unit, this difference decreases, but power consumption remains larger in any case.

In conclusion it can be noted that for the operation "mulching", the energy consumption of the milling aggregate decreases with the increment of the revolution of the

milling drum. This means that to perform the operation mulching, the frequency of the mill should be maintained at a maximum level of 500 min⁻¹. By the displayed graphical relationships can be seen that can be used higher revolution of the milling drum, whereby the energy consumption will be reduced even more. However, this may lead to destruction of soil aggregates, which will degrade the fertile quality of the soil and may provoke wind erosion. Regarding the transmission gears of the tractive unit it was concluded that for operation mulching in different category clearings, different speed gears can be used. For example, mulching in 1st category, lowest power consumption is received at 3rd speed – 17.35 l/dka. Second transmission gear is more appropriate for mulching in clearings from 2nd, 3rd and 4th category, where the energy consumption is respectively– 19.46 l/dka; 25 l/dka and 25,49 l/dka. For mulching in 4th category clearings most suitable speed gear is 1st, where the power consumption at maximum milling drum revolution is 30.21 l/dka.

3.2. Grinding of poplar stumps and roots

The experimental observations for grinding of poplar stumps and roots with forestry tiller FAE 300/S are conducted on the territory of Forest State "Oryahovo" and "Lom" in the period of 2015/2016 year. For the purpose every stump is grinding with three operating strokes of the milling aggregate. During the first stroke is frittered the terrestrial part of the log. After that at reversing stroke of the unit the roots at depth up to 25÷30 cm are shattered and at the end again with forward stroke, finally are crushed the deepest roots to a depth of 50÷60 cm. Due to the high energy intensity of the studied operation, it can be performed

only at 1st speed gear of the tractive unit. To determine the power consumption at different revolutions of the milling drum are made experimental observation over 285 stumps. Depending on the average diameter of the logs, they are grouped in 19 size classes. Every class has step of 2 cm, and the complete scale is between 22 cm and 58 cm. To

determine the fuel consumption for crushing each stump of a given size class were conducted by five experimental observations. The average values for fuel consumption for fragmentation of every stump are defined. The results obtained are presented in Table 2.

Table 2: Average fuel consumption for grinding 1 stump in depth to 50cm, in liters diesel.

Mulcher revolutions [min ⁻¹]	Size classes [cm]									
	22	24	26	28	30	32	34	36	38	40
250	1.30	1.32	1.33	1.36	1.39	1.44	1.5	1.6	1.69	1.79
375	1.22	1.24	1.25	1.27	1.28	1.33	1.37	1.44	1.52	1.61
500	1.22	1.23	1.25	1.26	1.29	1.31	1.33	1.39	1.46	1.55
Size classes [cm]	42	44	46	48	50	52	54	56	58	
250	1.91	2.08	2.26	2.47	2.69	2.97	3.26	3.59	3.95	
375	1.73	1.87	2.03	2.22	2.41	2.65	2.9	3.19	3.52	
500	1.64	1.74	1.88	2.04	2.2	2.39	2.62	2.86	3.18	

Based on the obtained data are built graphical relationships expressing the amendment of the fuel consumption for

crushing stumps, depending on the average diameter and the frequency of rotation of the milling drum (Figure 6).

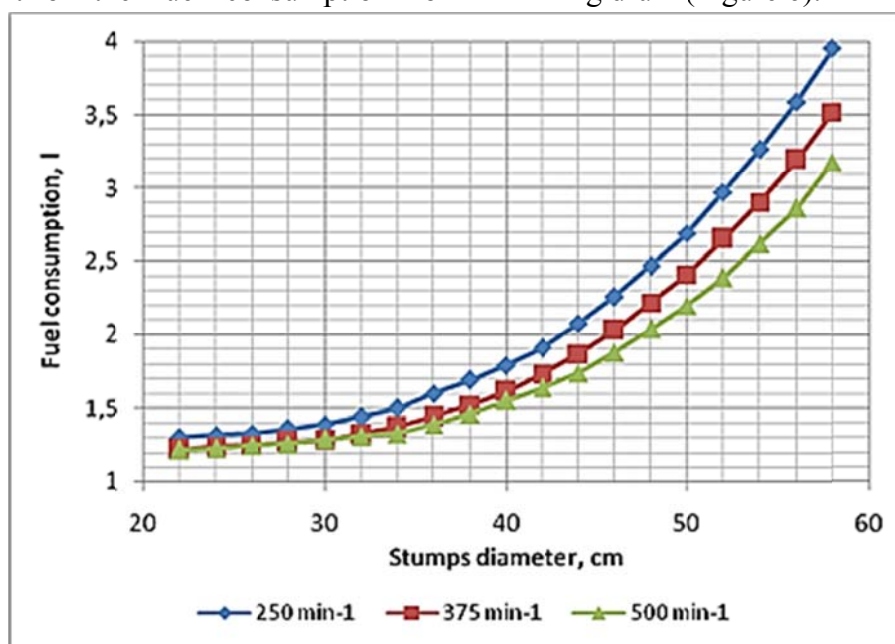


Figure 6: Variation of the fuel consumption for grinding poplar stumps, depending on the milling drum revolutions and the average stump diameter

The energy consumption to eradicate one acre poplar clearing depends on the density of the stumps and their average diameter. The density of the remaining stumps after felling can be determined by afforestation scheme. The afforestation of intensive

poplar plantations for the production of technological and structural timber in Forest State "Oryahovo" and "Lom" is done mostly by planting schemes of 4x4 and 5x3. After conducting intermediate thinnings, they can be reduced to scheme at 6x6. After complete

felling of the culture in these clearings will remain stumps with an average density of 25 pc/dka to 66 pc/dka. From the obtained results for fuel consumption for crushing stumps and the density of the logs, it can be determined the fuel consumption for eradicating poplar clearings with different characteristics of stumps. For frittering stumps

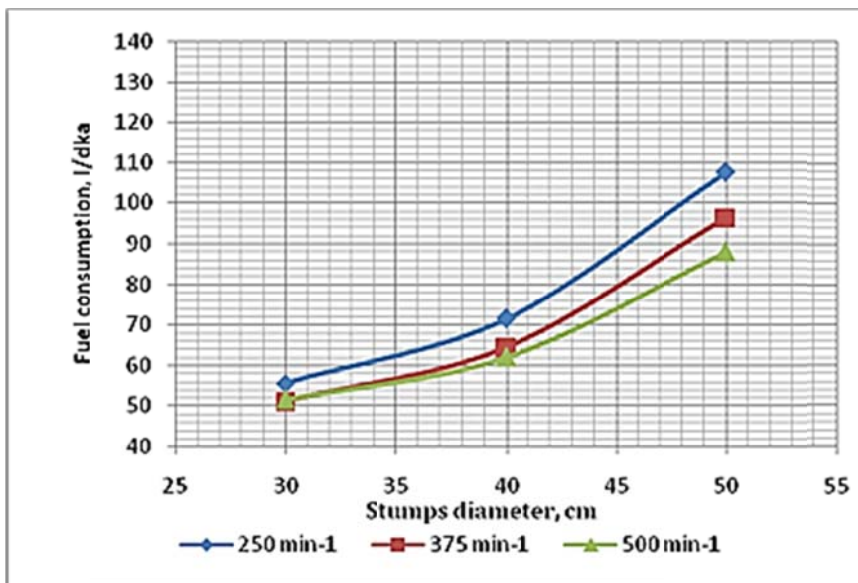
with diameter between 30 ÷ 50 cm in 1 acre is established the energy consumption of the milling unit for three different densities of the stumps in the clearings – at 40 pc/dka, 50 pc/dka and 60 pc/dka. These characteristics of the stumps are most common in poplar logging. The obtained results are presented in Table 3.

Table 3: Energy consumption per unit area, depending on the milling drum revolution, the average diameter and the density of the stumps

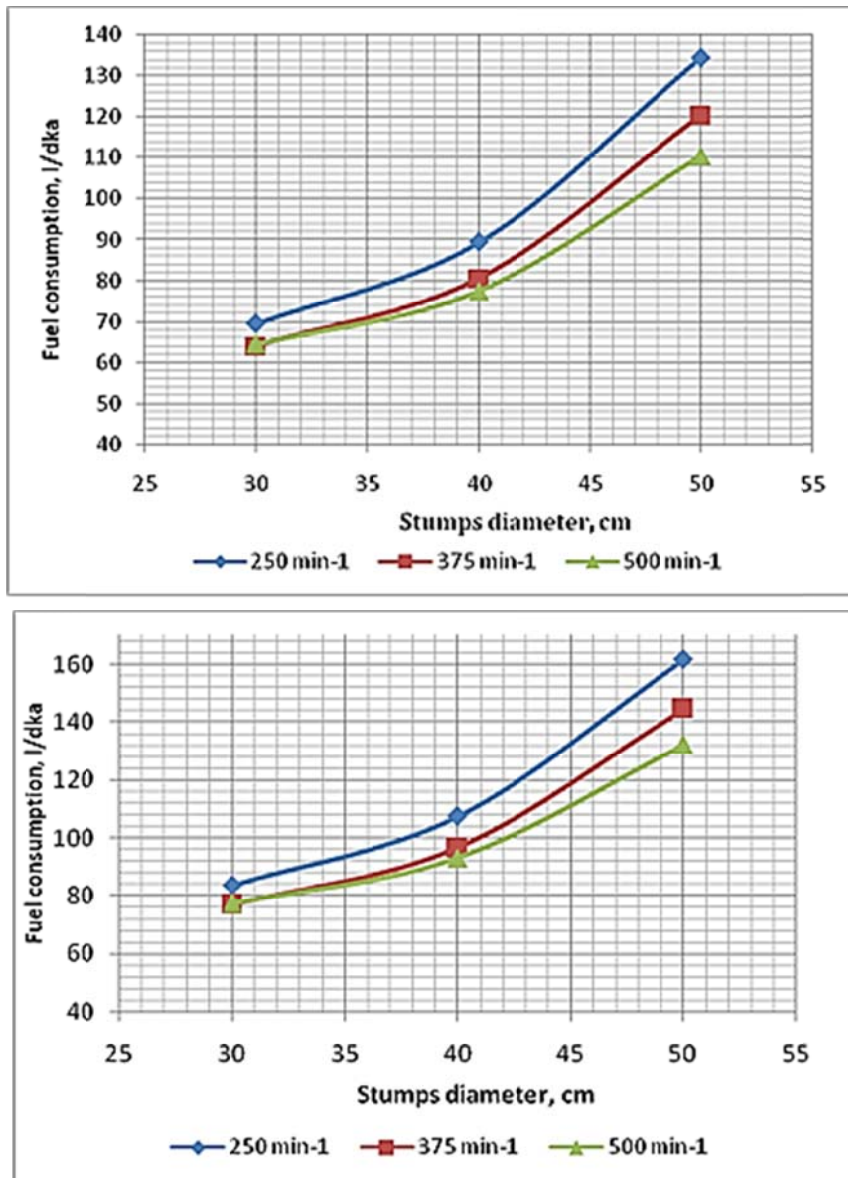
Indicators	Relative fuel consumption [l.dka ⁻¹]								
	Mulcher drum revolutions [min ⁻¹]								
	40 [pcs.dka ⁻¹]			50 [pcs.dka ⁻¹]			60 [pcs.dka ⁻¹]		
Stumps density	250	375	500	250	375	500	250	375	500
Stumps diameter [cm]	250	375	500	250	375	500	250	375	500
30	55.5	51.2	51.6	69.3	64.0	64.2	83.7	77.0	77.5
40	71.4	64.4	62.0	89.5	80.5	77.5	107.5	96.5	93.1
50	107.5	96.4	88.0	134.6	120.7	110.4	161.5	144.8	132.2

Based on the obtained values are built graphical dependencies, which could help to determine the energy consumption of the forestry tiller FAE 300/S for grinding poplar stumps with diameter between 30 cm and

50 cm, and density between 40 pcs/dka and 60 pcs/dka (Figure 7). From these graphs, by approximating the data can be determined the power consumption for other densities of the stumps.



a) stumps density – 40 pcs.dka⁻¹



б) stumps density –
50 pcs.dka⁻¹

в) stumps density –
60 pcs.dka⁻¹

Figure 7: Variation of fuel consumption for grinding stumps with different density and diameter, depending on the milling drum revolutions

From graphs above it can be seen that the energy consumption for grinding stumps with a diameter bigger than 40 cm, the unit should operate at maximum revolutions – 500 min⁻¹. From graphs above it can be seen that the energy consumption for grinding stumps with a smaller diameter up to 28÷30 cm and at different revolutions of the milling drum is approximately equal. With increasing the diameter of over 30 cm, the power consumption starts to increase at lower revolutions. The received values shows that to decrease the power consumption of the milling aggregate PT-400, and respectively to reduce the price per unit treated area, the frequency of the rotation of the milling drum should be maintained above 375 min⁻¹.

For grinding stumps with diameter bigger than 40 cm, the unit should operate at maximum revolutions – 500 min⁻¹.

3.3. Primary tillage of the soil

Compared to trenching ploughs, tooth and disc rippers, the forestry rotary tillers for deep tillage of the soil are more energy-intensive. This is due to the technological features of the process of milling. On the other hand, forestry tillers mix more evenly the organic and mineral soil substrate and provide better loosening and aerating the earth, also very well aligned the topsoil.

Thus no further pre-sowing tillage is required and there is no need to use other machinery for soil preparation. An experimental research on island “Masata” in Danube River is conducted, nearby to city of Oryahovo. It support us to establish the technological regimes, at which the energy consumption of the milling aggregate for primary tillage up to 50 cm is minimal. For the purpose was performed preliminary preparation of the area, with the same unit PT-400, which included complete stumps

grinding, followed by mulching of the coppice vegetation, shrubs and wood cutting waste. The soil is sandy loam, moderate, hardness 1.95 MPa and relative humidity during the experiments – $W_a = 52\%$. In accordance with the adopted methodology was made two-factor experiment. The received results for the power consumption, expressed as a relative fuel consumption for primary tillage of the soil with milling unit FAE 300 / S, are presented in Table 4.

Table 4: Fuel consumption of the milling unit at primary tillage up to 50 cm

Milling drum revolutions [min^{-1}]	Relative fuel consumption [l.dka^{-1}]		
	1 st gear	2 nd gear	3 rd gear
250	47.24	37.53	40.9
375	29.28	26.77	31
500	22.54	21.26	24.68

Functional graphical dependencies are built based on the obtain results. These graphics show the amendment of the energy consumption of forest milling aggregate PT-

400 with multifunctional cutter FAE 300/S for deep tillage of the soil up to 50 cm, depending on the transmission gear and the milling drum revolutions (Figure 8).

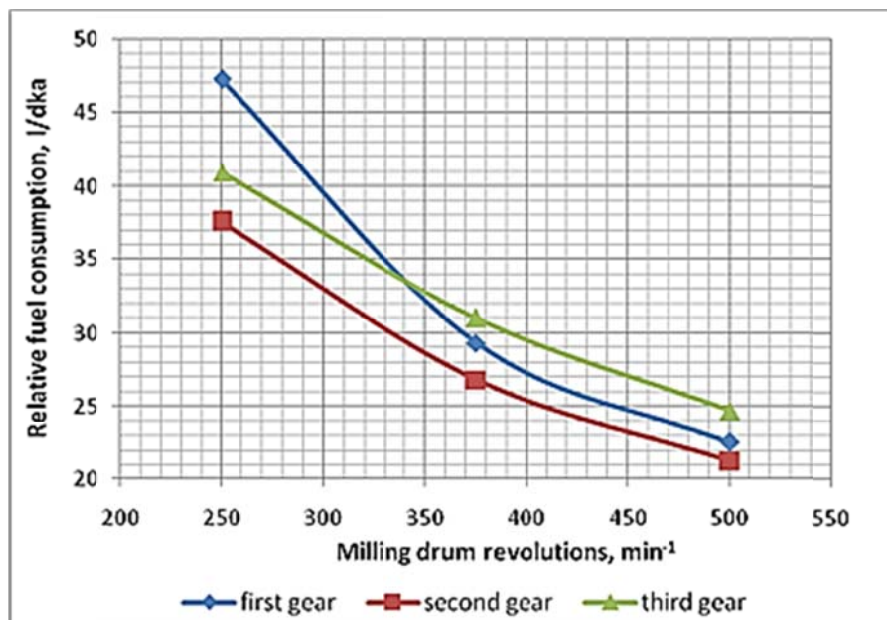


Figure 8: Variation of the power consumption for primary tillage of the soil, up to 50 cm with forest milling aggregate PT-400 with cutter FAE 300/S, depending on the gear and the milling drum revolutions

From the obtained results it is found that for primary tillage of the soil with mul-

tifunctional cutter FAE 300/S, the minimal level of the power consumption is 21.2

l/dka. It is received when the unit is operating at 2nd speed gear and maximum milling drum revolution. These values should be considered for optimal when determine the direct costs per unit area. When operating in heavier and more humidity soil we should expect lower power consumption at 1st speed gear.

CONCLUSION

Intensive poplar plantations are an alternative source to relieve pressure on forest resources and receive valuable timber for industrial and construction needs. A significant portion of the capital costs for afforestation and growing poplar plantations are concentrated in the first year, the majority of them (60 ÷ 80%) are invested for soil preparation. In modern forestry is introducing more increasingly specialized machinery for soil preparation for the establishment of poplar plantations. The application of new technologies based on such innovative machines is an important factor for improving the quality of work and productivity. The implementation of modern equipment is essential for reducing costs and shortening the terms for soil preparation. The introduction of such milling unit for soil preparation in Northwestern State Enterprise – Vratsa significantly improve the quality of soil preparation. The outcome of inventories at the end of the first growing season of some cultures, created with this machine, showed high rate of interception and survival of saplings (over 98%). The established labor costs for complete soil preparation per 1 acre clearing, treated by the new forest milling aggregate were within 2.76 ÷ 2.93 h / dka, which is 2.5 to 4 times less compared to the costs for previous technological schemes. The price per 1 acre full soil preparation with this machine is within 148÷157 €/dka. A main component in the pricing of

the soil preparation is fuel consumption. It is nearly 50% of the total price of the product.

As a result of the survey can be provided the following basic conclusions and recommendations:

1. An experimental study was conducted to determine the operating fuel consumption and productivity of specialized milling unit PT-400 with multifunctional forest cutter FAE 300 / S for full soil preparation of poplar clearings.
2. A method for optimization of the technological processes for the operations of specialized milling unit for soil preparation is developed.
3. The power consumption of the milling aggregate for soil preparation is determined under different production conditions.
4. The operation modes of the machine for the following operational processes are optimized:
 - mulching standing trees, coppice vegetation, shrubs and wood waste.
 - shattering stumps and roots
 - primary tillage up to 50 cm.

The obtained results have scientific and applied science contribution to mechanized land preparation for afforestation of intensive poplar cultures. They can be used in the design of special forest cutters. These results can be used to determine the energy consumption and to rate the fuel consumption when working with forest milling machines for mulching, eradicating and soil preparation.

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