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STUDY ON MILLING TECHNOLOGY UNIT PERFORMANCEFOR SITE PREPARATION FOR AFFORESTATION

Velika Jordanova* and Konstantin Marinov

Faculty of Forestry, University of Forestry, 10 St. Kliment Ohridski blvd., 1797 Sofia, Bulgaria. E-mails: veli_jordanova@abv.bg*; kmarinov_ltu@abv.bg

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Abstract

Contemporary technologies for afforestation of forest areas, based on the use of specialized milling units for soil preparation, mulching, shredding of stumps and other typical forest operations, are characterized by relatively high environmental and quality indicators, lower cost of labor and a smaller number of used technical means. These indicators are due to the use of specialized milling machines, which can operate in wide range of strength and type of deformation and interaction of the cultivated object. To achieve good results and low technology speeds, more energy and powerful tractors are needed. This article presents results of some basic performance of forest milling aggregate PT-400, with multi-purpose forest tiller FAE 300/S. The survey has been carried out on experimental poplar sites and slashes along the Danube river valley in the north-west region Bulgaria. For the purpose of the study the following parameters were determined: fuel consumption, operating speed and operational performance of the milling unit under certain conditions: 1) crushing stumps with diameters up to d_{av} = 65 cm, mulching False indigo-bush (*Amorfha fruticosa*) with height of 2.5–3.0 m and clearing debris; 2) milling of the soil to a depth of 0.5 m. The obtained results will be useful for better determination and establishment of technological capacities and performance of the studied specialized milling unit.

Key words: fuel consumption, operating speed, poplar plantations, productivity.

Introduction

The cultivation of intensive poplar plantations in Bulgaria has already extensive experience. The first specialized experimental station and poplar farm were established in Bulgaria in the early 1960's. They were used to conduct research and development activities in the field of growing, cultivating and production of reproductive material of different poplar species. Since then a significant part of Bulgarian forest areas along the biggest rivers were used for establishment and cultivation of intensive poplar plantations for accelerated timber production, and energy plantations.

Physical and mechanical characteristics of the soil are important factors for the soil resistance to processing with tillage machines and directly affect the energy consumption. Such factors are the mechanical structure, hardness and soil moisture of the arable area. The structural distribution of the soil after its treatment is a qualitative factor affecting the soil fertility, development of erosion and growth of the planted poplar cultures.

Afforestation and cultivation of poplar plantations is a well-studied process in Bulgarian forestry (Kolarov 1988, 1996; Kalmukov and Alexandrova 1999, 2003; Tzanov et al. 2001; Vasev et al. 2003; Kalmukov 2008; Vasev 2009, 2013). Very few international studies have examined wood production potential in poplar plantations and site preparation (Anonymous 2007; Anonymous 2009; Böhlenius 2015; Christersson 2008, 2010; Hansen et al. 1984, 1993; Keča and Pajić 2015; Löf 2012). Afforestation and cultivation of poplar plantations are very dynamic processes demanding constant development and application of newer production technologies. The afforestation through establishment of intensive poplar plantations is a laborious and complex activity as it covers most labor-intensive processes, such as soil preparation, weeding and pushing the stumps, and planting. Therefore, it is necessary to introduce innovative mechanized technologies and systems of machines in an attempt to achieve full mechanization of the main technological processes. This will allow to increase the percentage of mechanization in silvicultural activities and thereby to enlarge timber output, to decrease the labor costs and the cost per unit area new forest plantation. Such machines must fulfill all agricultural, forestry and environmental requirements of modern forest management. In countries with well-developed intensive poplar plantations specialized machines with high quality and technical-economic indicators are more frequently used.

The main technological schemes currently applied for soil preparation of poplar clearings in Bulgaria are based entirely on the use of tooth and rotor eradicator. One of the major disadvantages of older but still widely used technology based on frontal tooth eradicators is the removal of a significant part of the upper and fertile soil. As a result, the physical, mechanical properties and the fertility of the soil deteriorate with each subsequent production rotation. Also, while using this technology some additional operations such as removal of stumps, and leveling the area are required. These operations necessitate the use of relatively heavy and energy-intensive bulldozer aggregates. On the other hand, the second and newer technological scheme uses rotary eradicators with positional action for the grinding of stumps. The main disadvantages are minimized in it, but it has a limited area application. It can be used only on clean slashes without wood residues and woody and shrub vegetation, rocks-free and very deep soils.

Recently, forest managements in many countries, including Bulgaria, apply innovative specialized milling machines for soil preparation for afforestation of forest lands. According to its purpose and technological capabilities, these machines can be used for shredding and mulching stumps, roots and wood resides, and primary tillage.

In the past several years three types of milling machines were used for soil preparation of non-renewable forest areas within the North-east Regional Forestry Enterprise „Shumen” – forestry mulcher FAE UMH/S-200, ameliorative tiller SSH 200 and milling machine for crushing stumps AHWI SF 100. The first studies of the work of these machines conducted in Bulgaria showed that under certain operating conditions they show good performance and their wider use in Bulgarian afforestation practice is recommended (Marinov 2014). In 2013 new specialized milling unit – Prime Mover PT-400 was introduced to the territory of North-west Regional Forestry Enterprise „Vratza”. It is used in soil preparation for establishment intensive poplar plantations. The operating body of the milling unit is multifunctional forest cutter FAE 300/S-225, and the energetic machine is crawler PT-400.

The initial studies (Jordanova and Marinov 2014) on the operational work of the milling aggregate have shown that it has broad technological capacities. These surveys have found that the multifunctional milling unit can shatter stumps with diameters up to 0.8 – 1.0 m, it can shred standing trees and shrubs with height up to 10–12 m and wood residues with a weight of 0.8 m. Simultaneously, it performs basic soil processing in depth of 0.55 m, while the crushed wood chips are evenly mixed with the soil at full depth. The introduction of such aggregates leads to rationalization of shredding and grubbing technology due to dropping out of operations like stumps and roots pushing out of the area and leveling the terrain. During the working process strong crushing, mixing and aeration of the soil layers and debris occur, while the field is perfectly aligned. The treated soil is already suitable for planting without the need of subsequent pre-sowing treatment. The introduction of such specialized milling machines would facilitate our forestry practice to develop intensive poplar plantations establishment and to apply more efficient and high-performance technologies.

The purpose of this study is to present the work of forest milling unit PT-400 with multifunctional forest tiller FAE 300/S-225, with nominal motor power 310 kW (415 hp) (Anonymous 2014). The aim is achieved by studying the following parameters: operating fuel consumption, productivity and grain structural composition of the treated soil and wood chips under predefined conditions.

Materials and Methods

The experiments were carried out on two experimental poplar sites along the Danube river valley in the region of Northwest State Forestry Enterprise „Vratza", within the territory of State Forestry Service (SFS) „Lom" and State Forestry Service (SFS) „Oryahovo" (Fig. 1).

Operational site conditions

The study was performed over two plots situated in fresh poplar clearings, at aver-

Fig. 1. Map of the site for afforestation in SFS „Oryahovo".

age altitude up to 30 m. According to the forest management plans of SFS „Lom“ and SFS „Oryahovo“ the sites would have been prepared for afforestation with 1-year old poplar saplings (*Populus × euramericana* cv. Agathe-F), in 4 × 4 m scheme (Anonymous 2006a; Anonymous 2006b). The two operational sites belong to the subbelt of floodplain and riparian forests type, and the landscape consists of flat or inclined terrains with northern exposure. The soil depth is up to 1.0 m, which favors deeper soil preparation. Location of the experimental plots at Danube River is a prerequisite for the systematic flooding of the area, leading to water logging of soil and in many cases hinders and delays afforestation work. To prevent formation of erosion and to protect the workers and the unit while processing the soil, the working moves were performed from the coast inwards perpendicular to the river. Timing observations were done in the two working sections – one in SFS „Lom” and another in SFS „Oryahovo”. Representative samples of soil and crushed wood chips were taken from the two clearings. They were used to determine the texture composition distribution of the soil and the structural composition distribution of shattered wood residues.

First operational site (OS-1, coordinates 43°50’28.24” N and 23°15’45.87”E, 30 m a.s.l.), is located along the Danube River, in subsection 53^d within SFS „Lom”. The total area is 10.4 ha with an average slope up to 2˚. The soil is alluvial, sandy loam, very deep and free of stone particles. The contour of the terrain has rectangular shape. The stumps scheme was 4 × 4 m. The land is non-renewable clearing, after 100 % felling. About 70 % of the terrain was invaded by False indigobush (*Amorpha fruticosa* L.) and inferior vegetation with height of 2.0–2.5 m. The average density of stumps was 75 pcs per 1 dka, with average diameter d_{av} = 50.1 cm, while d_{max} = 68 cm and d_{min} = 41 cm. The land preparation for afforestation includes mulching the stumps and other clearing debris, and deep loosening up to 50 cm. The average length of the working area is 121.4 m. Samples of wood chips were taken to determine the struc tural composition, soil sample to determine grain-mechanical composition and the moisture. Two timing observations were made during two operators’ shifts.

Fig. 2. Specialized milling unit Prime Mover PT-400 with multifunctional forest tiller FAE 300/S, subsection 13^e in State Forestry Service „Oryahovo”.

Second operational site (OS-2, coordinates 43°44’28.45” N and 23°56’23.08” E, 30 m a.s.l.), is located along the Danube River, subsection 13^e of SFS „Oryahovo” (Fig. 2) with an average slope up to 2 °. The soil is alluvial, sandy – loam, very deep and free of stones. The contour of the terrain has a rectangular shape with total area of 9.5 ha. The average length of operational site is 44.7 m. The area is renewable clearing, after 100 % felling and scheme of the stumps 4.5 × 2 m. Average density is 101 pcs per 1 dka, with average diameter at the base of the stumps d_{av} = 40.8 cm, as d_{max} = 47 cm and d_{min} = 35 cm. Preliminary preparation includes crushing stumps and deep loosening of the soil up to 50 cm. The hardness of the soil was measured. Samples of crushed chips and soil to determine the size distribution and humidity were taken.

Tasks and parameters

For the purpose of the present study the following tasks have been fulfilled:

- assessment of the timing of operations;
- determination of the fuel consumption;
- determination/assessment of the structural composition of treated soil;
- determination/assessment of the structural composition of the wood chips residues after treatment.

The parameters as slope of terrain; diameter and density of stumps; density and height of trees and shrubs; depth of processing; length of the work area; type, mechanical composition, humidity and hardness of the soil were set constant. During the study they were maintained at the same level.

Demanded parameters of the study as duration of observed operations; volume of work performed (productivity); structural texture composition of wood chips; soil moisture, grain and texture, and fuel consumption are measurable quantities. They were obtained during the process of the study.

Methods and equipment

The time spent for individual operations and processes was determined by composing a workday route picture. For the purpose the estimated analytical methods for standardization of processes for monitoring of the fieldwork was used. Time within one working day was measured with an accuracy of 1 min. Operating time was determined by performing full Timing observations with an accuracy of 1 s (Stoyanov and Stoyanova 2005). The grain structure of the treated soil and the texture composition of the wood residues were determined by sieve method. The equipment for the survey consistsed of:

- Stopwatch with accuracy up to 1 s;
- Tape measure with accuracy up to 1 cm;
- Electronic scale model „Sartorius" and „Radwag", accuracy up to 0.1 g;
- GPS system model „Garmin Montana 650 T", for the field work;
- Penetrometer „Dickey-John Corporation", Auburn, Illinois, USA;
- Electric laboratory dryer – MK „Opticoelectron" Plant 7 – Velingrad;
- Screens sizes: 30 mm, 25 mm, 20 mm, 11 mm, 5 mm, 2.5 mm, 2.0 mm, 1.6 mm, 1.0 mm, 0.5 mm, 0.25 mm, and 0.10 mm.

The samples used to determine the texture distribution, soil moisture and structural composition of shredded wood residues were tested at the laboratory „Mechanization of forestry activity", Department "Technology and mechanization of Forestry", University of Forestry in Sofia.

Initially, the average diameters of the stumps, planting scheme and existing vegetation were determined onsite. Soil hardness was measured with a penetrometer. For the purpose of the study 20 soil samples at depths up to 30 cm were taken and the average hardness was defined by statistical methods. The moisture of the soil samples was obtained by gravimetric method, as percentage of field soil samples with humidity to absolute dry soil mass. The workday photo and the timing of the operations were scored by chronometric measurements. To determine the grain mechanical structure of the soil and the soil moisture were taken samples from the two OS.

For the purpose of the study two timing observations were carried out. The total duration of a recording timing observation was six hours. The way of movement of the studied aggregate in the sample area was defined at the beginning of the working day by selecting the most rational scheme.

The rate of use of milling unit within one shift was expressed by the coefficient of use of work time in one shift – τ_{cm}. This coefficient was defined as the ratio between the time spent on operational work and the total duration of one shift – $\tau_{cm} = T_{stroke} \cdot T_{shift}^{-1}$. Due to the specific workflow workday was divided into two shifts by six hours. The coefficients of the use of the working time for both OS were ascertained based on the data obtained from the timing and route images. Route pictures were done within two working days.

Measurements of timing included strokes and idle state of the machine were noted down in a special timing-form. Within a shift the duration of all times were measured and they were recorded in tabular form. After that a workday-route picture was composed. The performance of one shift was determined by measuring of the processed area at the end of the shift. For Timing of all operations 20 to 30 experimental observations were done. Comparative method which measures the impact of various factors on the processes studied was used.

The survey was conducted from 24th of November, 2014 until 25th of April, 2015. Three soil samples from both areas were taken and the texture composition of the soil was established by sieve method. Two samples were taken to define the percentage distribution of structural composition from shattered wood residues. Three soil samples were taken to specify the soil moisture by using gravimetric method.

Results and Discussion

The soil is alluvial, with sandy – loam mechanical composition. The average hardness of the soil for the OS-1 is 792 kN/m^2 (8.1 kg/cm²), and in the OS-2 – 1380 kN/m^2 (14 kg/cm²). The measurement in the second operational site where flood waters had retired earlier and the soil was drier showed higher hardness. The results show that the type of the soil has lesser impact on its hardness than the time of withdrawal of flood waters and its current humidity.

Soil moisture for the first working site was 40.8 % and for the second – 22.2 %. Soil moisture for the OS-1 is more favorable for the mechanical processing of alluvial soils, while for the OS-2 it is dry and hard, which effects on the higher costs of energy.

The moisture of the treated soils show that the soil from the first studied OS-1 is W_{av} = 40.8 %, as for the second OS-2 is W_{av} = 22.2 %.

Figures 3 and 4 represent the percentage distribution of the texture composition of the soil samples from the two studied operational sites.

Based on the results obtained, we can assume that after processing the drier soil from the OS-2, the structure of the soil is relatively even measured, and the participation of large aggregates with a size above 20 mm is negligible. Coarse

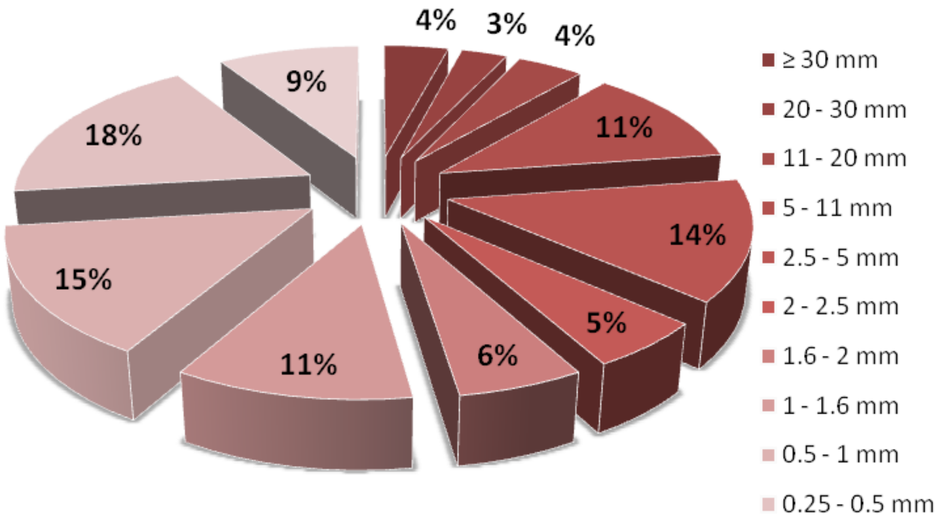

Fig. 3. Texture composition distribution of the soil from the OS-1.

soil aggregates from the first soil sample are about 7 %. Both samples show that the milling unit crushed and loosened soil very good, while leaving the soil aggregates within the sizes larger than the levels of dusting (>0.25 mm).

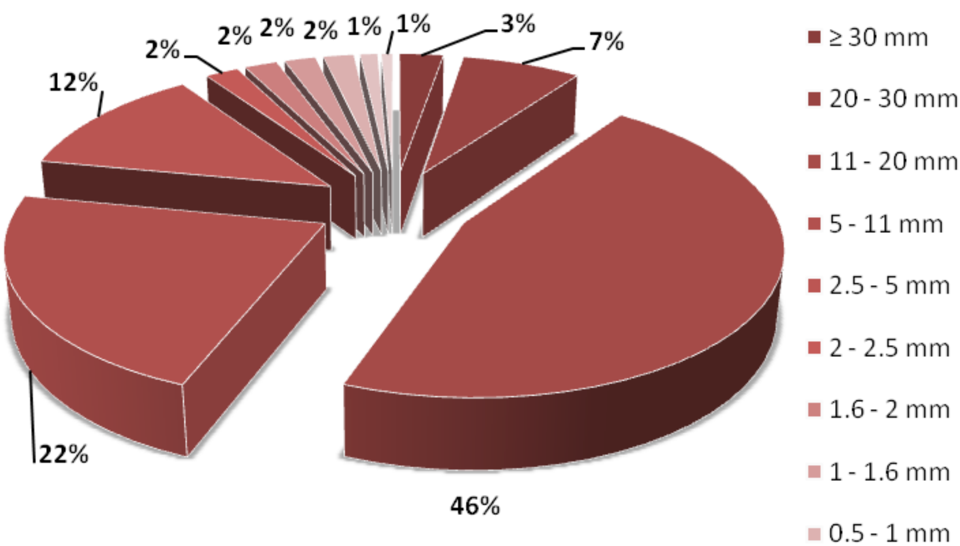

Fig. 4. Texture composition distribution of the soil from the OS-2.

In agriculture a valuable agronomic soil is considered the one containing soil aggregates with size between 0.25 mm and 10 mm. The beginning of wind erosion in agricultural areas is reckoned (Gyurov and Artinova 2015) to occur when there is presence of at least 30 % soil aggregates with size below 1 mm in the total soil volume. Thereby the erosion risk is about 50%. Therefore the application of the specialized unit preserves the soil fertility and minimizes the development of wind erosion.

Characteristics of splintered wood into the soil

Figure 5 and Figure 6 show the percentage distribution of the shattered wood chips. Figure 5 shows the percentage distribution of the wood chips, after the PT-400 has moved forward i.e. after the process of mulching. Figure 6 shows the percentage distribution after the milling unit has moved in reverse i.e. after the process of tilling. There is a tendency that after the unit move in reverse the wood chips become more shattered and the highest percentage of the wood chips bigger than 30 mm after the forward stroke transfers to wood chips with size between 11–20 mm after the reverse stoke.

The size of wood chips is an important factor for the rapid absorption of splintered wood into the soil and for the reduction of the total resistance, which they perform upon the machine working body during the followed operations (additional tillage and cultivating). The structural composition of chips was defined in two different technological operations: 1) after mulching (grinding of stumps and standing ground woody shrubs) – after the first run of the unit forward gear the tractor (Fig. 5), and 2) after basic processing (deep milling) – after subsequent passage of the unit in the same trace reverse gear of the tractor (Fig. 6). Samples of the two OS showed similar re-

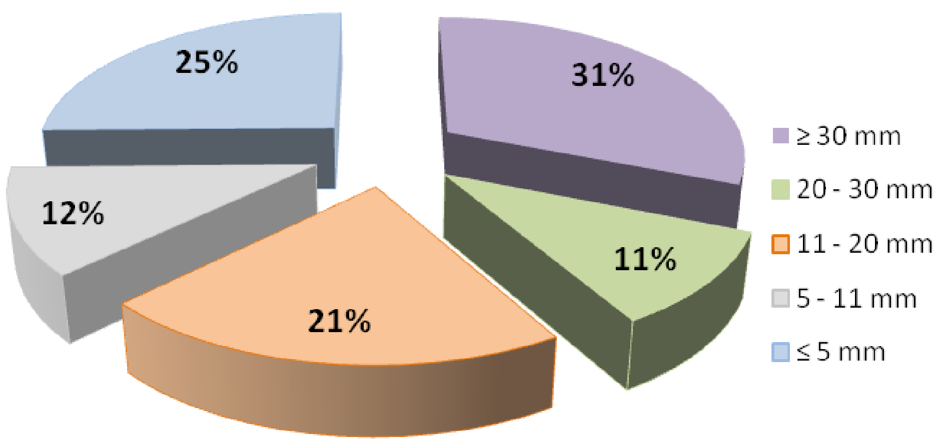

Fig. 5. Structural composition distribution of shattered wood residues after the first pass of the unit.

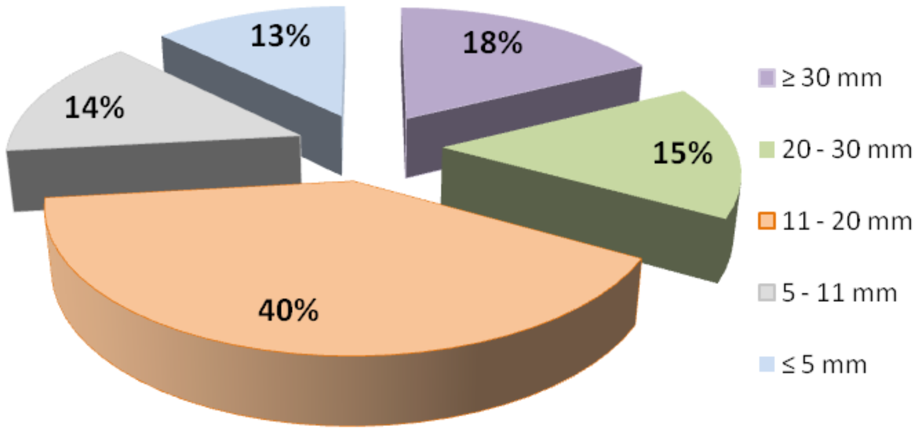

Fig. 6. Structural composition distribution of shattered wood residues after the second pass of the unit.

sults. Chip distribution after milling were relatively uniform, predominantly consisting of particles between 11–20 mm. The grinding of the particles and their mixing with soil layers helps to facilitate their decomposition.

Determination of performance and fuel consumption

Timing observations of the working day were performed to determine the operating performance of engine tests. Average timing is given in Table 1. The coefficient of basis time – τ_{cm}, is higher for the first site, because the service (repair) and idle time are shorter.

The characteristic of the production conditions in the two OS which affect these

Table 1. Timings of milling unit PT-400 operations.

Observed time, min	First experimental site, SFS „Lom“		Second experimental site, SFS „Oryahovo“	
	1^{st} shift	2^{nd} shift	1^{st} shift	2^{nd} shift
T_{stroke}	284	277	268	269
T_{idle}	17	18	22	20
$T_{op.t}$	267	259	246	249
$T_{prep.fin.t}$	30	30	35	32
$T_{serv.t}$	13	14	18	20
$T_{rest.t}$	14	18	15	16
T_{org}	2	3	2	3
$T_{notw.t}$	59	65	70	71
T_{shift}	360	360	360	360
$T_{cm}=T_{stroke}/T_{shift}$	0.789	0.769	0.744	0.747

Note: The duration of one shift is six hours. The indications of time spent in the table are: T_{stroke} – time stroke unit; T_{idle} – time to maneuver and idle units; $T_{op.t}$ – operating time; $T_{prep.fin.t}$ – time for preparatory-final work; $T_{serv.t}$ – time maintenance of machinery (includes greasing); $T_{rest.t}$ – time for vacations and natural needs of workers; T_{org} – downtime due to organizational reasons; $T_{notw.t}$ – time during which technological activities were not carried out directly; T_{shift} – hours of work in one shift.

Table 2. Data of performance of milling unit PT-400 for soil preparation.

Technical performance	First experimental site SFS „Lom“	Second experimental site SFS „Oryahovo“
Productivity, dka per shift	3.35	2.53
Hourly output, dka·h^{-1}		
- Mulching	-	0.664
- Deep milling	-	0.468
- Average for the soil preparation	0.715	0.566
Operating speed, km·h^{-1}		
- Mulching	-	0.51
- Deep milling	-	0.56
- Idle stroke	2.36	1.95
Relative fuel consumption, l·dka^{-1}		
- Mulching	30.2	54.7
- Deep milling	66.3	113.8
- Idle stroke	-	1.6
- Total for the soil preparation	96.5	170.1

parameters is presented in paragraph 2.1 „Operational site conditions”. Productivity of mobile machine-tractor unit is directly dependent on the technological parameters of the machines: working speed, working width and coefficient for using working time. The obtained results in the form of averages for different operations are presented in Table 2. The results show the main performance of the research milling unit at predefined production conditions.

The results of the study showed a higher operating performance of the unit in the OS-1 – W_h = 0.715 dka·h^{-1}, compared to W_h = 0.566 dka·h^{-1} in the OS-2. To a large extent this is due to the lower density of stumps – 56 pcs per 1 dka to 101 pcs per 1dka in the OS-2, regardless of stumps that have larger average diameter – 51 cm to 41 cm. The results about fuel consumption showed that the greater density of stumps is reflected more strongly in the relative cost per unit area. For example, for the OS-2 relative fuel consumption of one decare area prepared for afforestation is 170.1 liters and for the OS-1 is – 96.5 liters, which is nearly 77 % more.

Despite of the higher fuel consumption the specialized milling unit Prime Mover PT-400, shattered completely the stumps, roots and competitive vegetation to chips, and simultaneously mixed intensively and aerated the crushed biomass into the soil. Thereby conditions for improvement the soil fertility and reduction of the risk of spreading diseases and pests were created. The main deep milling process of heavy clay forest soils allows stabilization, airing and raise the fertilization of the soil, meanwhile to level the terrain without subsequent further processing, such as disking and harrowing.

Conclusions

The use of the studied specialized forest milling machine PT-400 with multi-purpose forestry tiller FAE 300/S for mulching, stump grinding and deep soil preparation leads to increasing the productivity and improvement the quality of the work. Such innovative aggregates will lead to soil enrichment and will reduce almost twice the time for the soil preparation for afforestation by shortening the number of operations. At the same time, they are expected to reduce the total cost of the final production. The treated soil has ecologically suitable grain-mechanical structure and there is no need for further processing of preparation. Organic residues from the crushed wood debris (wood chips), mix with the rest of the soil, and during their degradation they enrich the soil with minerals and other nutrients.

The conducted study on specialized forest milling unit Prime Mover PT-400 for soil preparation of poplar clearings under predefined conditions resulted in established operating fuel consumption, productivity and the grain structural composition of the processed soil and shattered wood chips. The obtained results can be used to determine productivity and labor costs for land preparation with forest milling unit PT-400 equipped with multifunctional cutter FAE 300/S for afforestation with poplar cultivars.

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