EVALUATION OF FOREST MILLING MACHINE PERFORMANCES FOR SITE PREPARATION

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ABSTRACT

This article represents analysis of the technical capabilities of the specialized forest milling machine PT-400 with multi-purpose forestry tiller FAE-300/S for mulching, stump grinding and for deep soil preparation for establishment of intensive forest poplar cultures. The operating productivity, the optimal ways of movement, production capacity and some basic quality indicators of the machine have been determined under specific working conditions. The survey has been conducted on poplar sites and slashes along the Danube river valley.

Key words: forest tiller, productivity, soil preparation.

INTRODUCTION

One significant part of the Bulgarian forest areas is located along our biggest rivers. These sites are used for cultivation of intensive plantations for timber production, energy plantations and other. The forests are mainly from poplars (Populus) and willows (Salix). They have short rotations - between 12 and 15 years. This requires performing of eradication, clearing and soil preparation to be done in very brief productive intervals. Therefore, afforestation is an essential part of the sustainable development of forestry.

Establishment of forest plantations is a laborious and complex process. Silvicultural operations are characterized to be one of the most labor-intensive. This determines the introduction of innovative technologies and systems of machines for complex mechanization of the processes. This can be realized through the use of appropriate machines and units – that possess higher performance, more efficiency, and therefore they are more economical. Increasing the degree of mechanization in afforestation work would lead to enlarge productivity, to reduce labor costs and the cost of afforestation by an acre, providing better interception of saplings, more environmentally friendly forestry management and others.

In the classic technology using front eradicators along with the eradication of timber significant part of the fertile humus layer is exported. In many countries the last few years the use of specialized milling units for crushing stumps and soil preparation is increased. That helps to void the main disadvantages of the classic technology and reduces the labor cost.

1. APPLICATION OF INNOVATIVE SPECIALIZED MILLING UNITS (PRIME MOVERS) FOR AFFFORESTATION OF FOREST AREAS

In many countries there is a more widespread use of innovative technological schemes based on milling units for crushing stumps and soil preparation for afforestation. These machines are characterized with great diversity in terms of their function, technological capabilities and characteristics. Since the autumn of 2013 in our country was introduced and put into operation the first specialized milling machine for crushing stumps and deep soil preparation – Prime Mover – PT-400, with energetic machine Caterpillar CAT-C13 and technological machine multi-purpose forestry tiller FAE-300/S. The initial observations on this newly implemented machine in Bulgaria, operating in the Northwest Forestry Enterprise, have showed that it has good technological performances. Specialized forest milling machine PT-400 is used for cleaning clearings and areas with standing trees, shrubs and clearing debris, as they are cut into chips (wood mulching). Parallel to this is carried out deep loosening of the soil into a depth of 450-550 mm, thus organic residues are ground and mixed with treated soil. Due to such specialized aggregates the processes of eradicating, pushing the stumps and roots, and leveling the terrain are dropped out. Simultaneously is performed strongly crushing, aeration and mixing the soil layers and biological debris, and the soil is aligned. Thus treated soil is ready for planting without the need for further pre sowing treatment.

Implementation of specialized milling machines would allow some of our State Forestry to implement more efficient and modern technologies.

Conducting this research will give us new knowledge about the performance of specialized milling units such Prime Movers for preparation of forest land for afforestation.

1.1. THE PURPOSE OF THIS PAPER is to establish the performance of a specialized milling machine Prime Mover PT-400, for predefined condi-tions.

1.2. THE OBJECT OF THE STUDY is forest milling unit PT-400 with multifunctional forestry tiller FAE-300 / S. The specialized unit cut down standing and lying vegetation and clearing debris with thickness up to 800 mm, and loosens the soil of a depth up to 550 mm in beds with a width of 250 mm.

1.3 THE SUBJECT OF THE RESEARCH are the technical performance of the milling unit, the productivity, the structural composition of processed clearing debris and the grain structural composition of the treated soil.

1.4. THE PLACE OF THE EXPERIMENTS. The experiments were carried out in the region of Northwest Forestry Enterprise in Vratza city, within the State Forestry „Lom“ and State Forestry “Oryahovo“. The sites were a barren area in the village of Dolni Tzibar village, Lom and clearings along the river Danube, near the town of Lom and within the NPP “Kozloduy” (Fig. 1).

Figure 1: Map of Regional Directorate of Forests „Berkovitza“ – State Forestry „Lom“ and State Forestry „Oryahovo“

2. EXPERIMENTAL METHODS

2.1. PURPOSE AND TASKS OF THE STUDY

The study aims to establish operational performance in the preparation of land for afforestation and primary tillage under certain operating conditions. Its purpose is also to determine the structural composition of treated stumps and plant residues/the wood chips/ and to determine the grading of treated soil. For this goal, the following tasks would be performed:

2.1.1. Timing of operations;
2.1.2. Composition of timing-picture for a shift;
2.1.3. Determining grain-mechanical composition of the treated soil;
2.1.4. Determining the structural composition of treated wood chips.

2.2. INPUT PARAMETERS

Input parameters are constants and during the experiments were maintained at the constant level. They characterize the production conditions and are:

2.2.1. Slope of terrain;
2.2.2. Diameter and density of stumps;
2.2.3. Density and height of trees and shrubs;
2.2.4. Depth of processing;
2.2.5. Length of the work area;
2.2.6. Type, mechanical compo-sition and density of soil.

2.3. OUTPUT PARAMETERS

The output parameters of the experiment are the duration of the studied processes, the productivity and the grain composition of the tilled soil and the structure of the crushed wood chips. They are measurable quantities and will be used to perform the assigned tasks of the study. Output parameters are:

2.3.1. Duration of the observed operations;
2.3.2. Operational productivity – the volume of the performed work;
2.3.3. Grain mechanical composition of the treated soil;
2.3.4. Structural composition of the crushed wood chips.

2.4. PLACE AND CONDITIONS OF THE STUDY

The place and the conditions of the study are presented in 3. CONDITIONS OF THE STUDY.

2.5. METHODS AND MEANS FOR THE STUDY

The time spent for every operation and process is determined by composing a picture of a route of the working day. For the purpose the estimated analytical methods for standardization of processes to monitor the fieldwork is used. Times within one working day are measured with an accuracy of 1 min. Operating time is determined by performing full timing observations in the test areas with an accuracy of 1 s. The grading structure of the treated soil and the structural composition of the wood chips are determined by sieve method. Equipment for the survey consists of:

2.5.1. Stopwatch accurate to 1 s;
2.5.2. Tape measure to the nearest 1 cm;
2.5.3. Electronic scale “Santorius”, accurate to 1 g;
2.5.4. GPS system model "Garmin Montana 650 T", to determine the field work;
2.5.5. Penetrometer "Dickey-John Corporation", Auburn, Illinois, USA;
2.5.6. Electrical laboratory dryer - MK „Opticoelectron“ Plant 7 – Velingrad;
2.5.7. 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.

2.6. DURATION AND PROCEDURE FOR CONDUCTING RESEARCH

Timing observations are four. The total duration of one shift (respectively an observation) is six hours. At the beginning of the working day is determined the manner of movement of the units in the sites by selecting the most rational scheme of work. Timing observations include strokes and empty moves of the milling machine. For this purpose Timing sheet for every technological process and change is filled. Within a shift is measured duration of all operations. They are recorded in tabular form, after that is composed a route photo of working day. Production (performance) for one shift is determined at the end of the shift by measuring the treated area.

2.7. NUMBER OF MEASUREMENTS AND OBSERVATIONS

The timing observations are performed in two test areas (two sections of State Forestry "Lom"). Timing of operations is made as 20 and 30 experimental observations are made. Route pictures are composed within two working days. Four samples of treated chips are taken to determine the structural composition. Three samples of treated soil are taken to determine the structural distribution and other six to determine the humidity of the soil. Soil samples and samples of chips are tested in laboratory conditions.

2.8. METHODS FOR DATA PROCESSING AND ANALYSIS OF RESULTS

The data obtained from experimental observations are processed using statistical methods. To analyze the results is used the comparative method, which measures the impact of various factors over the studied processes.

3. CONDITIONS OF STUDY

The sites in which the survey is conducted are one barren area and two non-renewable clearings, after 100 % felling is carried through. According to forest management plans „State Forestry "Lom" and "Oryahovo" these areas should be planted with annuals saplings of poplar (Populus), by 4x4 m scheme. The average altitude is 30 m. The terrain is along the river. The fields are flat, and the type of the habitats is M-I-1. Soil horizon has a large capacity to 100 cm, which favors deeper soil preparation. The exposure is north. The location of the sites is a prerequisite for systematic flooding from the river Danube, leading to waterlogging of the soil and in many cases creates difficulties and hinders afforestation works. To prevent erosion and protect workers and the milling unit, during the primary tillage, swept to gamble from the coast to the interior.

Timing observations were made in two operational sections of State Forestry "Lom" and are pursuant with the production conditions. Soil samples were taken from the three working sites. Samples of wood chips were taken from the two clearings.

3.1. FIRST OPERATIONAL SITE. It is situated along the river Danube within the NPP "Kozloduy" in State Forestry "Oryahovo" (Fig. 2), with an average slope to 2 °. The soil is alluvial, sandy–loam, very deep and not stony. The contour of the terrain has a rectangular shape. The land is non-renewable clearing, after 100 % clear felling. About 90 % of the field is overgrown with amorphous (Amorpha fruticosa) and inferior vegetation to a height of 2,0–3,0 m. The measured average diameter of the stumps is d_{av}=65,7 cm (d_{max}=80 cm and d_{min}=51cm). Preconditioning of the area includes shredding of stumps and other debris clearing, and deep loosening in depth to 550 mm. Samples were taken from the crushed wood chips and soil samples to determine the grain mechanical structure.

Figure 2: Stroke of specialized milling unit Prime Mover PT-400 with multifunctional forest cutter FAE-300 / S, in the first working section, State Forestry "Oryahovo"

3.2. SECOND OPERATIONAL SITE. This site is located near the Tsibar village, in the section 59, subsection 'r' within the State Forestry "Lom" (Fig. 3). The field is a non-renewable clearing, since a fire in the winter of 2012. The terrain has an average slope of 2 °. The contour of the terrain has a rectangular shape, which facilitates the movement of the machine and reduces non-operating moves. The soil is heavy, meadow-marsh, clay and not stony, with powerful horizon. The total area for afforestation is 3,6 ha, most of which is covered with reeds and low woody shrubs to a height of 2,5–3,0 m. The preparation includes the removal of entire vegetation and deep tillage in depth to 450 mm. The average length of stroke is 150 m. Soil samples were taken to determine the moisture and grain-mechanical structure of the soil. Two timing observations were made during two working shifts.

Figure 3: Section 59, subsection 'r', State Forestry „Lom"

3.3. THIRD OPERATIONAL SITE. The site is located along the Danube, in section 53, subsection 'e' within State Forestry "Lom". The total area is 10.4 ha with an average slope up to 2 °. The soil is alluvial, sandy loam, very deep and not stony. The contour of the terrain has a rectangular shape. The land is non-renewable clearing, after 100% felling. About 70 % of the terrain is overgrown with amorphous (Amorpha fruticosa) and inferior vegetation to a height of 2,0–2,5 m. The average density of stumps is

75 pcs / dka, and the average diameter d_{av} = 50.1 cm, as d_{max} = 68 cm and d_{min} = 41cm (Fig.4). The land preparation includes mulching of stumps and other debris clearing, and deep loosening up to 550 mm. Average length of the working area is 121.4 m. Samples of wood chips were taken to determine the structural composition, soil sample to determine grain-mechanical composition and the moisture. Two timing observations were made during two shifts.

Figure 4: Measuring of the average diameter of the stumps

4. RESULTS AND DISCUSSION

The study is conducted between 06/08/2014 and 22/10/2014, according the developed methodology.

Three soil samples were taken from all test sites and by sieve method is established grain-mechanical composition of the soil. The ratio of grain mechanical composition of the treated soil and crushed chips are determined (Fig. 5). By three soil samples were taken from the second and third working sites and by gravimetric method is defined the soil moisture. To determine the structural composition of treated wood chips were taken two samples – one from the first and one from the third working site. Sieve method is also used to define the structural composition of wood chips (Fig. 6).

Figure 5: Determination of grain mechanical composition of soil samples

Figure 6: Determining the structural composition of treated wood chips

4.1. SOIL SAMPLES. The following indicators were determined: density, humidity and grain mechanical composition.

Soil density is determined by a penetrometer. By 20 field samples were made and by statistical methods is defined the average density of the soil for each site. For the first working site it is 241,5 kg/cm² or 23788 kPa. For the second site soil density is 185,5 kg/cm² or 18 272 kPa, and for the third is 158,2 kg/cm² or 15583 kPa. With the lowest density is heavy alluvial soil with high flood waters in the third working site. Heavy clay soil in the second test area has less density than the alluvial soil in the first site, but there the flood waters have the highest level. The first working site shows highest density of the soil, as there the flood waters have had withdrawn. The results show that the type of soil has less impact over the density of the soil than flood waters.

The moisture of soil samples was determined by gravimetric method as p the ratio between the soil samples with field humidity and the absolute dry soil mass. The moisture is determined only for the second and third working sites, and are as follows: the second site has moisture of 40.90 %, and the third – 40.33 %.

The percentage distribution of the grain mechanical composition of the soil samples is given at Fig. 7, Fig. 8 and Fig. 9. The results show that, at the heavy clay soil of the second operational site the sample has biggest part of particles between 11–20 mm, but the smaller particles are unsubstantial. While at alluvial soil samples from the first and third operational sections, the structure is distributed relatively evenly - from large particles to microscopic clay. However, the milling unit shows very good loosening of the soil, making the soil particles big enough to allow keeping the fertility of the soil.

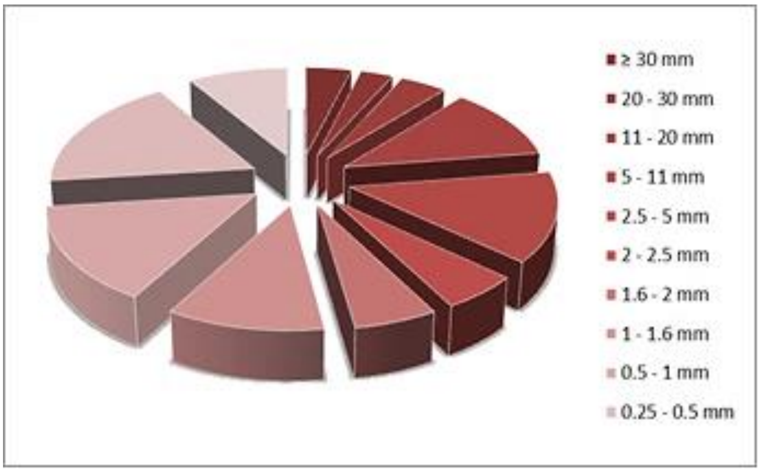

Figure 7: Structural distribution of the treated soil from the first working site, [%]

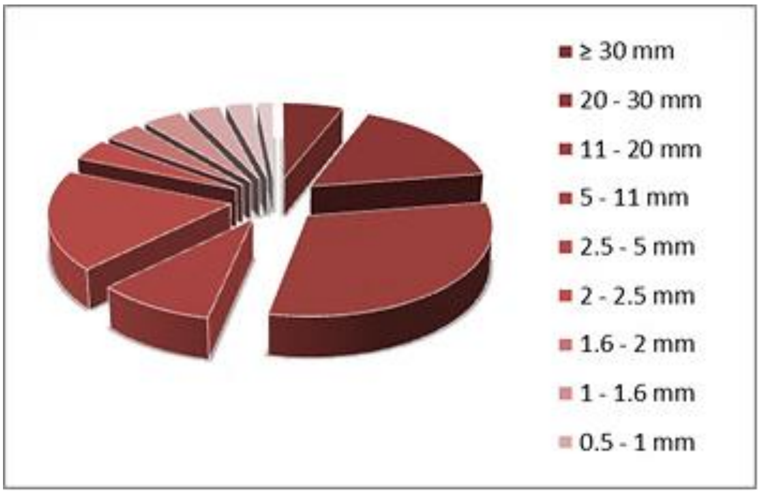

Figure 8: Structural distribution of the treated soil from the second working site, [%]

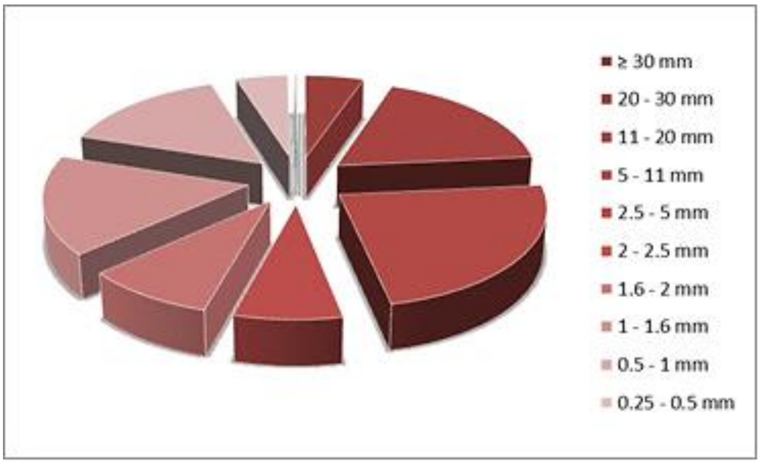

Figure 9: Structural distribution of the treated soil from the third working site, [%]

4.2. CRUSHED WOOD CHIPS SAMPLES. For them is determined the structural compositions in two states - after the first stroke of the milling unit (mulching) at forward gear (Fig. 10 and Fig. 12) and then re-pass (tilling), at reverse gear (Fig. 11 and Fig. 13). Samples of the two operational sections show similar results. The percentage distribution of the crushed wood chips after the operation of tilling is relatively even. The particles between 11–20 mm prevail. Grinding particles and mixing them with soil layers helps to facilitate their decomposition.

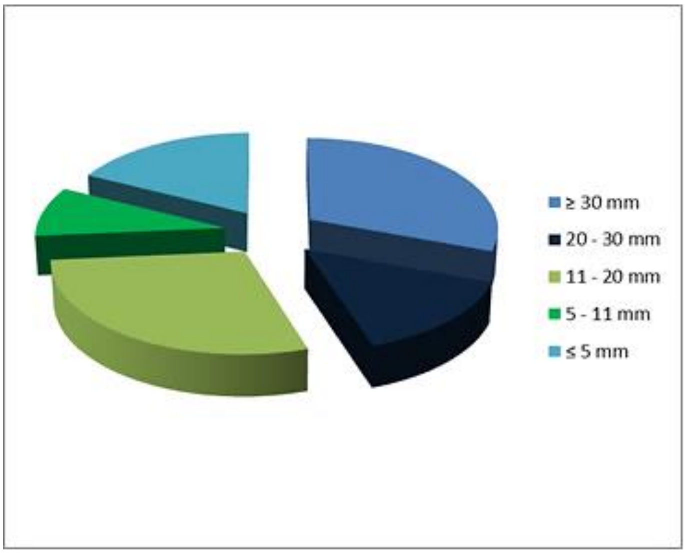

Figure 10: Structural composition of wood chips after first pass of the unit (mulching), first working section, [%]

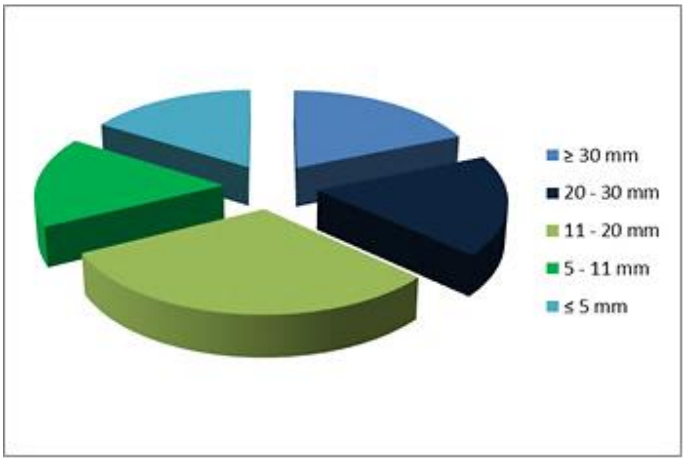

Figure 11: Structural composition of wood chips after second pass of the unit (tilling), first working section, [%]

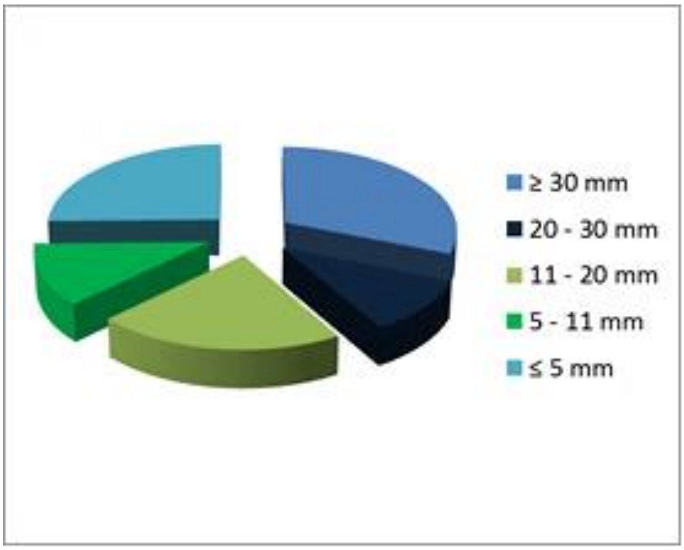

Figure 12: Structural composition of wood chips after first pass of the unit (mulching), third working section, [%]

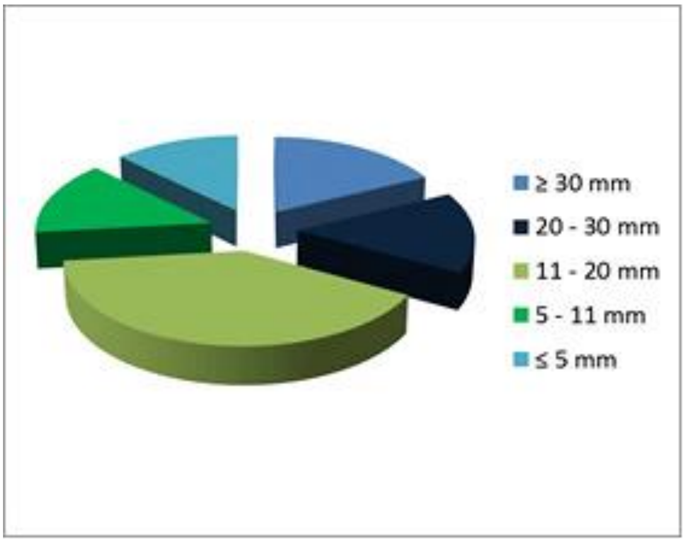

Figure 13: Structural composition of wood chips after second pass of the unit (tilling), third working section, [%]

4.3. TIMING OBSERVATIONS. The average values for the results obtained from the timing observations are given in a summary Table 1. The indications of the times in the table are:

4.1.1. Tstroke – time stroke of the unit;
4.1.2. Tidle – time to maneuver and idle units;
4.1.3. Top.t. – operating time;
4.1.4. Tprep.fin.t. – Time for preparatory-final works;
4.1.5. Tserv.t. – Time for maintenance of the machinery / includes greasing /;
4.1.6. T rest.t. – Time for workers' breaks and natural needs;
4.1.7. T org. – Downtime due to organizational reasons;
4.1.8. Tnotw.t. – Time during which no technological activities are carried out;
4.1.9. Tshift – duration of the shift.

Table 1: Route photo of the working day of milling unit PT-400

Observed times, [min]	**Subsection 59-r, [13/09/2014]**		**Subsection 53-d, [22/10/2014]**	
	1-st shift	**2-nd shift**	**1-st shift**	**2-nd shift**
Tstroke	271	268	284	277
Tidle	22	20	17	18
Top.t.	249	248	267	259
Tprep.fin.t.	31	32	30	30
Tserv.t.	18	20	13	14
T rest.t.	15	16	14	18
T org.	3	4	2	3
Tnotw.t.	67	72	59	65
Tshift	360	360	360	360
τshift = Tstroke/Tshift	0.753	0.744	0.789	0.769

*Note: * The time for one shift is six hours*

The extent of the use of the milling unit within one shift is expressed by the coefficient of use of work time in one shift - τ_{sh}. This coefficient is defined as the ratio between the time spent for operational work and the total duration of one shift - $\tau_{sh} = T_{stroke} / T_{shift}$. In this case the shifts are normalized six hours, due to the specific work and depending on the production conditions and the operators' requirements. The coefficient of use of working time is defined for two shifts by the both operational sections based on the data of timing observations and the route photos of the working days.

The coefficients of use of work time of the milling unit in one shift for full soil preparation are as follows: for the first shift in the 2nd operational section: $\tau_{sh} = 0.753$, and $\tau_{sh} = 0.744$ for the second shift; for the first shift in the third operational section: $\tau_{sh} = 0.789$, and $\tau_{sh} = 0.769$ for the second shift;

The results of working time showed a higher degree of use of working time in the third operational section. This is due to the more favorable field conditions. Time during which was not carried out direct technological activity in the second operational site is higher due to the combination of high flood waters and heavy clay soil adhering to the working body, as well as its easier obstruction from the high and difficult to tear cane. This leads to higher service time of the machine.

The performance of the specialized milling unit is set in accordance with the approved methodology. The characteristic of the production conditions for the two operational sections which affect these parameters is presented in 3. CONDITIONS OF STUDY. The operational performance of milling aggregates is directly dependent on the technological parameters of the machines: working speed, working width and extent of use of work time. After the timing observation of every operation and after establishing the actual production by measuring the treated area, the operating speed, the timing operational performance and shift operational performance in the production conditions are defined. The results obtained as averages for all operations are presented in Table 2. The established values for the productivity express the basic performance for the studied specialized milling unit in specific production conditions.

Table 2: Performance of milling unit Prime Mover PT-400

Technical performance	Subsection 59-r, [13/09/2014]		Subsection 53-d, [22/10/2014]	
	1-st shift	2-nd shift	1-st shift	2-nd shift
Productivity, [dka / shift]*	5.78	5.97	3.47	3.23
Hourly output, [dka/h]	1.28	1.34	0.73	0.70
Operating speed, [km/h]	0.51	0.53	0.36	0.35

*Note: * The time for one shift is six hours*

The obtained results show higher performance in the second operational section regardless of the lower coefficient of use of work time. This is due to the presence of relatively large stumps in the third operational section and the need for more energy and thus more time for crushing them.

Specialized milling unit Prime Mover PT-400 breaks entirely the competitive vegetation as intensively mixed and aerated crushed biomass with soil layers. Thus it creates prerequisites for improving the soil fertility and reducing the risk of spread of diseases and pests. Primary processing of forest areas which have heavy clay soils allows stabilization and aeration of fertile soil and leveling the land, without the need of subsequent further processing, such as disking and harrowing.

CONCLUSIONS

Introduction of innovative specialized milling units for removal of stumps, clearing debris and standing timber and parallel deep primary tillage, would significantly shorten the time for preparation of forest lands for afforestation, also would shorten the time of planned agriculture. As a result of this study over specialized milling unit Prime Mover PT – 400 the following conclusions could be made:

1. There have been composed route pictures of working day for the specialized milling unit for clearing and mulching of tree and shrub vegetation and clearing debris, shredding of stumps and roots, for deep loosening and leveling the ground;

2. There have been established the technical performance of forest milling unit - working speed coefficient of use of working time, operational performance and the productivity by hour and by shift: *2.1. Coefficient of work time using*: A/Mulching and Subsoiling – τ_{sh} = 0.745; B/ Mulching, Sumps Crushing and Subsoiling – τ_{sh} = 0.78; *2.2 Operating productivity*: A/ Mulching and Subsoiling – Wh = 1.28÷1.34 dka.h^{-1}; B/ Mulching, Sumps Crushing and Subsoiling – Wh = 0.70÷0.73 dka.h^{-1};
3. Data have been obtained and an evaluation has been made of the quality of the structural composition of processed wood biomass and grain-mechanical composition of the treated soil.

The obtained results can be used for normalization and planning the costs for labor and materials for mechanized land preparation work with specialized milling unit Prime Mover PT-400 for afforestation of barren and non-renewable forest areas with severe and profound, low stony soils over plain and slightly sloping terrains.

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