TECHNOLOGICAL SPEEDS FOR SOIL PREPARATION OF FOREST AREA WITH SPECIAL FORESTRY TILLER

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ABSTRACT

In this paper are presented the results of an experimental study of the performance of multifunctional forestry tiller FAE 300/S, powered by a self-propelled unit PT-400, for soil preparation for poplar plantations establishment. The machine is tested in different speed regimes while mulching the shrubs, coppice and wood debris from the felling areas. The other observed operation is soil tillage up to 50 cm. The study was conducted in poplar clearings along the Danube River. The purpose is to establish the fuel consumption and the performance of the machine at different milling speed. Based on the results are constructed graphical dependencies, in order to express the relative fuel consumption and operational performance, depending on the operating speed of the machine. At the end is performed an optimization of the process of deep tillage of the soil, using the criteria for minimizing the power consumption. And based on this is defined optimal operating speeds of the examined forestry tiller.

Key words: milling, optimization, energy consumption, performance.

1. INTRODUCTION

The poplar plantations are an alternative source for the production of valuable timber for construction, industry and energy, and can relieve the pressure on the forest resources (Christersson 2008). The soil preparation is among the most power-consuming and labor-intensive activities in the establishment of new forest plantations. This is most applicable for the plantage poplar establishment, where it is required more intensive treatment of the soil (Dimitrov and Panov 1982, Hansen at al 1984, Böhlenius and Övergaard R. 2015). One significant part of the financial expenses for establishing and growing poplar cultures are invested in the first year, as most of them are for soil preparation (Keča and Pajić 2015). The application of intensive silvicultural practices is crucial for increasing the productivity of poplar plantations. The introduction of innovative machinery and technologies for soil preparation is the key for reducing the labor costs (Vasilev and Dimitrov 1978). In modern forestry more often are introduced specialized forestry milling machines for land preparation. The introduction of such new technologies on the basis of these specialized milling machines is an important factor for improving the quality of work and productivity. The site preparation technologies to create poplar plantations are based on the use of a definite system of machines (Marinov 2013). Recently for the plantage poplar forestry many countries increasingly begin to use specialized forestry tillers. According to its purpose and technological capabilities, these machines can be used for mulching shrubs and wood debris, for grinding stumps and roots, and for primary deep tillage (Hallbrook at al. 2006). Technologies for site preparation, built on the usage of such specialized forest tillers, are distinguishing with high quality work and high quality production. Several years before, Northwest State enterprise, Vratsa bought a new modern multifunctional forestry tiller FAE-300/S for site preparation of forest areas in order to create poplar plantation. This machine can perform several technological operations carried out so far by several completely different machines till now. The first initial research on this machine showed high environmental and quality performance and shorter time for soil preparation (Marinov 2014, Marinov and Yordanova 2015 and 2016). As well known disadvantage of these milling machines is considered their high energy consumption per unit area processed. To minimize the energy consumption is necessary to optimize the process of milling. This can realize with the establishment of the optimal operating speed of the tiller.

The purpose of the study is to establish the optimal speed for soil preparation of poplar clearings with multifunctional tiller FAE-300/S.

The main objectives of the study are: 1/ To determine the performance and fuel efficiency of operation mulching standing trees, coppice vegetation and shrubs, and operation deep soil loosening, up to 50 cm; 3/ To optimize the technological process by minimizing the power consumption and determining the optimal operating speed of the tiller.

2. METHODS AND MATERIALS

2.1. OBJECT, LOCATION AND CONDITIONS OF THE STUDY

The object of the study is multifunctional forest tiller FAE300/S-225, powered by self-propelled tracked Prime Mover PT-400.

To conduct the research are used experimental forest sites along the Danube River within the Forestry State „Vidin“ and „Oryahovo“. The soil in the experimental sites is alluvial, partially floodplain, very deep and non-rocky. The terrain is flat with altitude of 250 m. All habitats are type M-I-2, $D_{2,3}$. The sites have rectangular shape, which favors the movement of the milling aggregate. To differentiate the operating conditions for the operation of mulching standing trees, coppice vegetation and wood debris we use previously introduced categorization of poplar clearings: *1^{st} category clearings* – they are cleaned of standing trees and coppice vegetation, also of wood chips, may consist low shrubs with height up to 2 m; *2^{nd} category clearings* – cleaned from standing trees and wood chips, but with high vegetation, consisting of coppice, Amorphous and other bushes with height above 2,5 m; *3^{rd} category clearings* – not cleaned from standing trees and wood waste, with low shrubs with height up to 2 m; *4^{th} category clearings* – not cleaned from standing trees and wood waste, with high vegetation, consisting of coppice, Amorphous and other bushes with height above 2.5 m.

Figure 1: Multifunctional forestry tiller FAE 300/S-225 with Prime Mover PT-400

The measuring equipment consists of measuring tape, stopwatch, penetrometer „Dickey-John“ to determine the hardness of the soil; laboratory scales „Sartorius

ME235S“ to measure the weight of soil samples with an accuracy of 0,01 g. The soil moisture is determined via weighting method, by drying the samples in a desiccator at a temperature T=103 ±2°C.

2.2. PARAMETERS OF THE STUDY

To establish the operational speed of the forest tiller for deep soil milling are carried out experimental observations with pre-defined input and output parameters.

Input parameters. The input parameters known as input factors can affect directly the process and can be manageable and unmanageable.

Input manageable factors. To monitor the process are selected two controllable factors: transmission gear (speed gear) of the movement of the unit and the frequency of rotation of the milling drum (revolutions). The speed gear of the driving machine PT-400 and the frequency of rotation of the tiller FAE 300/S can be managed, as they can be maintained at the same level during the experiments. They are independent, manageable and compatible, so they are the correct choice for input manageable factors. These parameters are the basis of the choice of technological modes of the milling machines as they directly affect on the cutting speed and and the feed rate of the working body. Due to these factors is possible the optimization of the technological process by selecting the appropriate operating speed.

1. *Transmission gear*. The first three speed gears of the transmission of the drive module PT-400 – are examined – 1st, 2nd and 3rd speed gear, which are suitable for mulching and main tillage. Together with the mulcher revolution, this factor affects on the step of cutting and degree of deformation of the soil and wood;

2. *Frequency of rotation of the milling drum.* It directly effects on the cutting speed. The management of the mulching revolutions is carried out from 0 to 500 min^{-1}. To explore more fully the research process, based on prior information, it is found that the range of variation of this factor should be between 275 min^{-1} and 500 min^{-1}. The lower revolutions hampers the machine operation and reduces the quality. To limit the number of the experimental attempts and to track the amendment of the output parameters in this range are chosen three basic levels of variation in the speed of the rotor: lower level – 250 min^{-1}; average level – 375 min^{-1} and upper level – 500 min^{-1}.

Unmanageable input factors. These factors are associated with the production conditions and during operation can not be managed, but during experiments they can be maintained at a certain level. These are:

a) Slope – 2÷3°;
b) Mechanical structure and category of the soil: sandy loam, moderate;
c) Soil moisture – 48÷52%;
d) Soil hardness – 1,8÷2,0MPa.

These conditions are typical for floodplain areas and land along the Danube River. They are very suitable for intensive cultivation of poplar plantations in Bulgaria.

Output parameters. The output factors of the study, which can be measured and used to determine the power consumption, are: 1) Fuel consumptions, litters; 2) Duration of the operations, sek; 3) Distance, meters; 4) Operating speed, km/h.

3. RESULTS AND ANALISYS

3.1. MULCHING OF WOOD DEBRIS AND STANDING VEGETATION

The experimental observations were performed in the period from 2014 to 2016 on the territory of Forestry State „Oryahovo“

and „Vidin". According to the type and the quantity of existing vegetation and wood pulp in the clearings, the operational conditions are differentiated in 4 different categories. For the experimental observations are used totally 12 experimental sites, by 3 for each category. The experimental sites are with size between 52 and 65 dka. In accordance with the methodology described above, the study is carried out with the machine in motion at three levels of the transmission speed gears – 1st, 2nd and 3th, and at three levels of revolutions of the mulching drum – 250 min^{-1}, 375 min^{-1} and 500 min^{-1}. Within each experiment were performed three separate experimental observations. From the obtained results are constructed graphical relationships expressing the variation of the operating speed of the unit depending on the levels of the speed gear and milling drum revolutions. To express the characteristics of the various operating conditions for different categories of the clearings are built separate graphs presented in Figures 2, 3, 4 and 5.

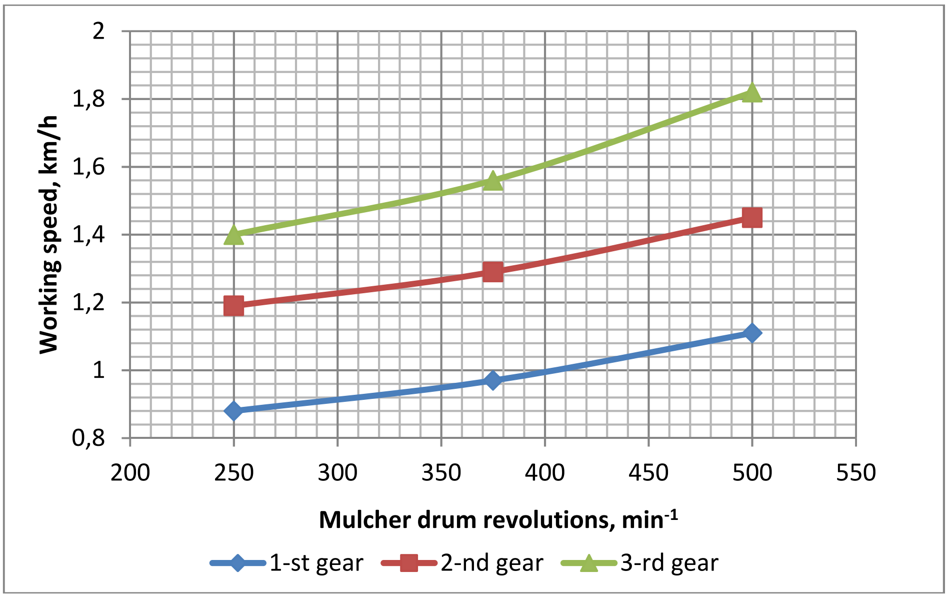

Figure 2: Working speeds of the milling unit PT-400 with forestry tiller FAE 300/S for mulching 1-st category poplar clearing, depending on the levels of the speed gear and milling drum revolutions

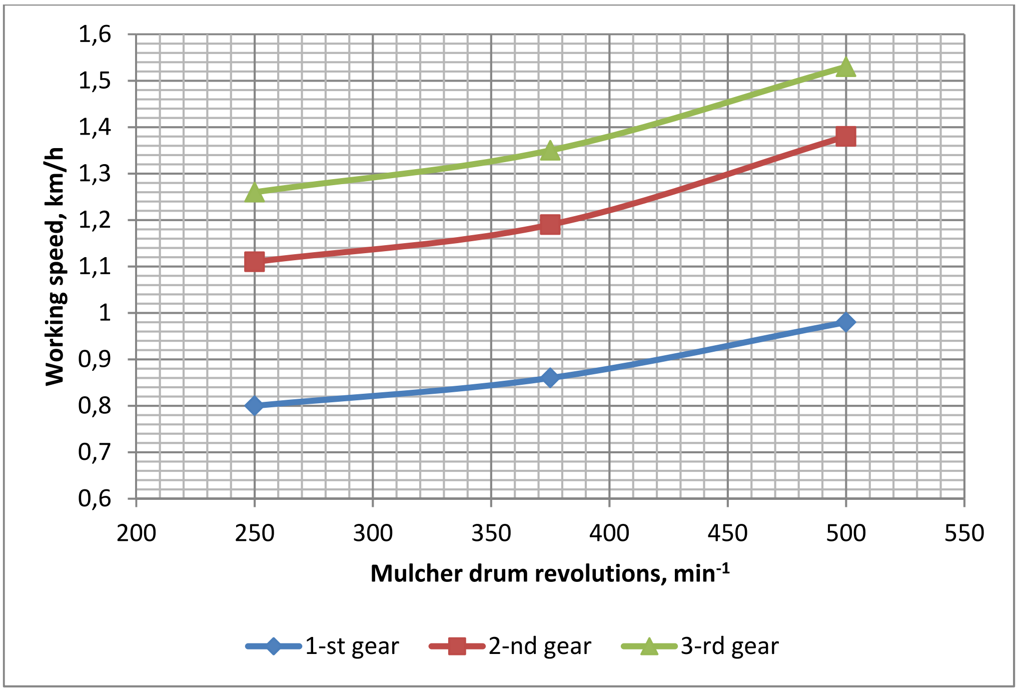

Figure 3: Working speeds of milling unit PT-400 with forestry tiller FAE 300/S for mulching 2-nd category poplar clearing, depending on the levels of the speed gear and milling drum revolutions

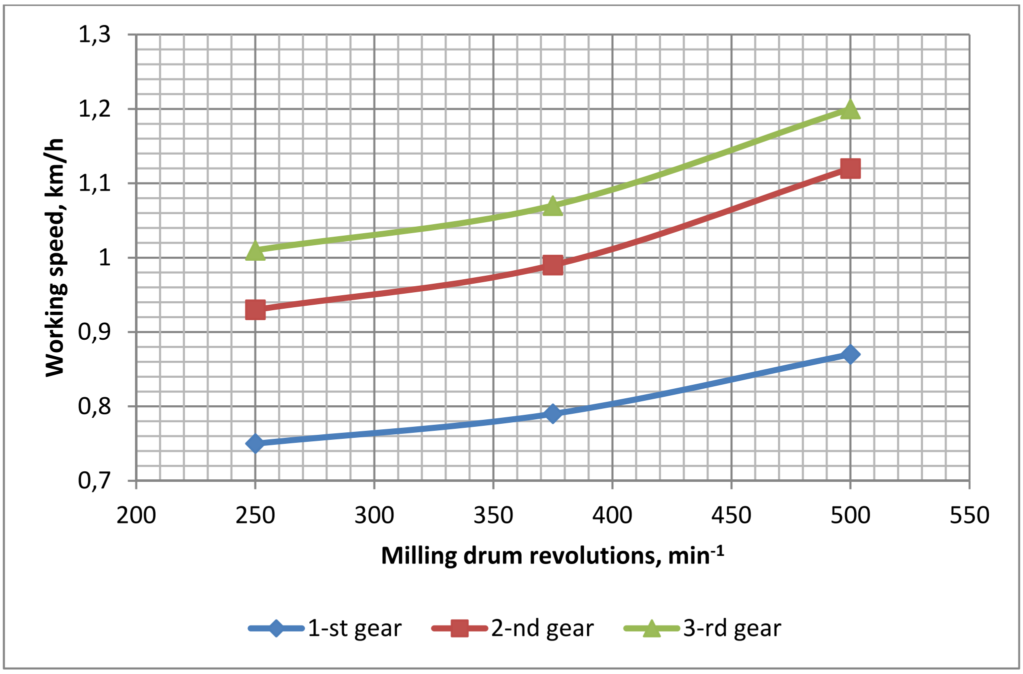

Figure 4: Working speeds of milling unit PT-400 with forestry tiller FAE 300/S for mulching 3-rd category poplar clearing, depending on the levels of the speed gear and milling drum revolutions

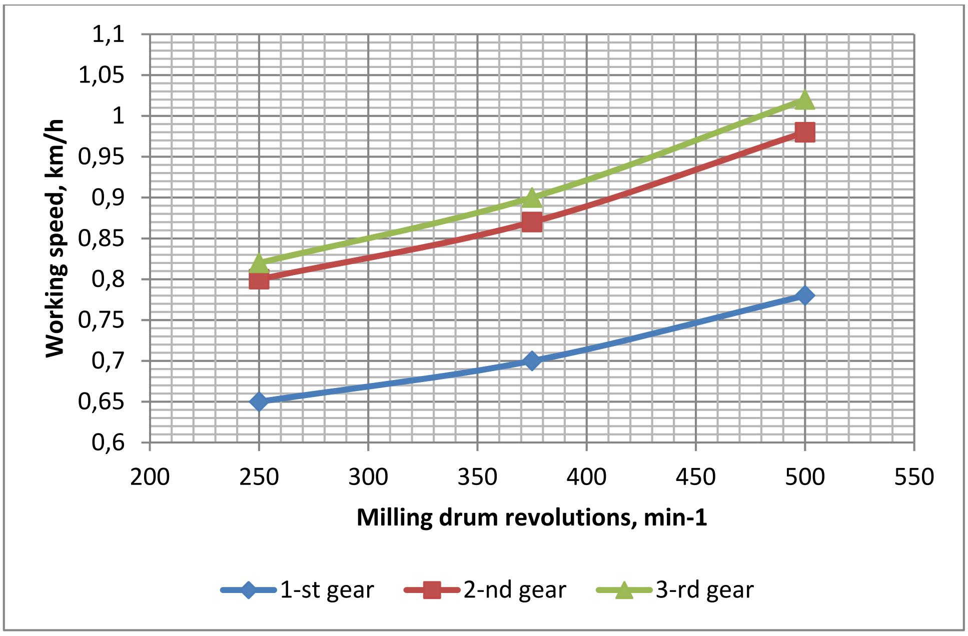

Figure 5: Working speeds of milling unit PT-400 with forestry tiller FAE 300/S for mulching 4^{-th} category poplar clearing, depending on the levels of the speed gear and milling drum revolutions

From the thus constructed graphs from Figure 2 it can be seen that when operating in lightest conditions in the clearings, these from first category, operational speed is highest in third speed gear and has the greatest excess from 1,39 km/h to 1,91 km/h respectively for milling drum revolutions from 250 min^{-1} to 500 min^{-1}. When operating in 2^{-nd} category clearings where the standing trees and bushes has larger volume, this trend continues, but the operating speed decrease by 9% to 19 %, and from lower to higher milling drum revolution it varies from 1,27 km/h to 1,54 km/h. In 3^{-rd} category clearings where there is large amount of woody debris the average operating speed lower by 15 to 30 %, as here the difference between 2nd and 3rd speed gear is less. At maximum milling drum revolutions, the operating speed at 3rd speed gear is 1,19 km/h, while at 2nd speed gear it is 1,12 km/h. In the most severe operating conditions, in 4 category clearings, the operating speed at 3 speed gear closer to that at second speed gear and reaches 1,02 km/h. Operating speed when driving at first speed gear is the lowest for all category clearings. It should be noted, however, that at this speed transmission the quality of the soil treatment is the highest. This is best expressed in operation mulching wood residues and standing vegetation in clearings of 3 and 4 category. Bu in all cases where is using the same speed transmission of the driving unit, the operating speed and the quality of processing are higher at higher milling drum revolutions.

The summary results for the operating speed of the unit, operating in different categories clearings at the highest milling drum revolutions, and the movement of the aggregation in idle mode on stiff ground and on cultivated soil, are presented in the Table. 2.

Table 2. Operating speed of the milling machine in motion in idle mode on stiff ground and on cultivated soil and operating speed for mulching in poplar clearings at milling drum revolutions of 500 min^{-1}, [km.h^{-1}].

Transmis-sion gears	Stiff ground	Cultivated soil	Clearing 1^{-st} category	Clearing 2^{-nd} category	Clearing 3^{-rd} category	Clearing 4^{-th} category
1-gear	1.5	1.2	1.11	0.96	0.87	0.78
2-gear	2	1.6	1.45	1.28	1.12	0.98
3- gear	3	2.4	1.82	1.53	1.2	1.02

From the obtained results are built graphical dependencies, expressing the operating speed variation depending on the operating conditions and speed gear (Figure 6).

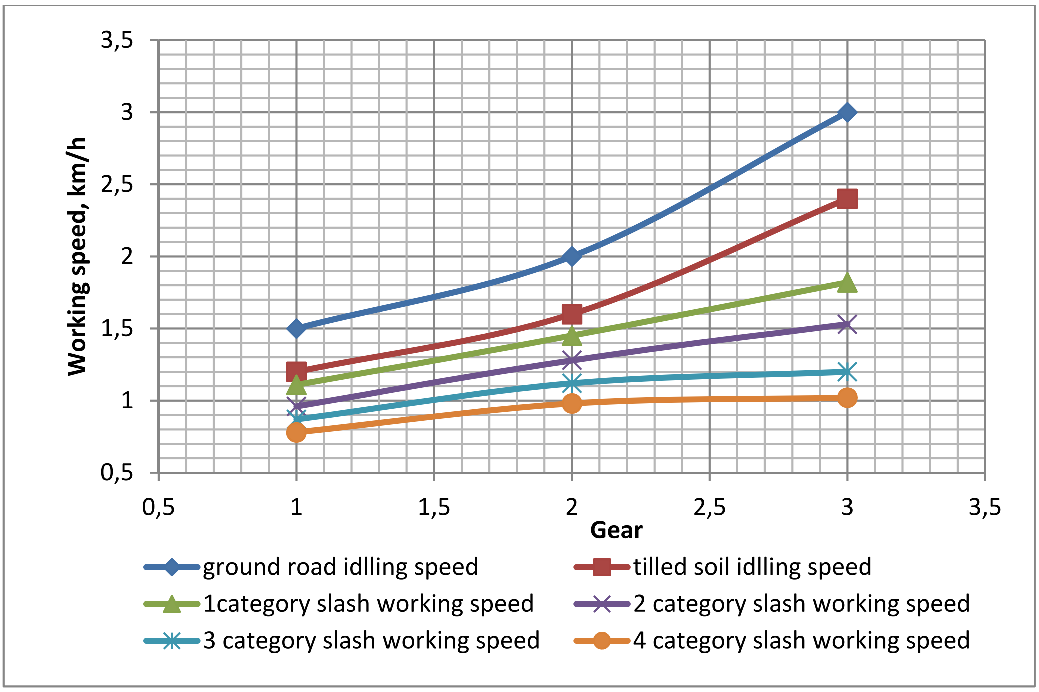

Figure 6: Speed of the milling unit PT-400 with forestry tiller FAE 300/S when moving idling on stiff ground and tilled soil, and when mulching poplar clearings (slash) from different category at maximum mulching drum revolutions, depending on the transmission gear

In conclusion it can be noted that with the increase of the frequency of the milling drum rotation, the operating speed increases also. This trend is more pronounced at frequencies above 375 min^{-1}. This means that when mulching standing vegetation and wood residues in clearings. The operating speed of the tiller should be maintained at a maximum level. From the constructed graphs can be noticed that for this operation can be used higher milling drum revolutions, but specifically for this machine they are limited to 500 min^{-1}. Due to the fact that the milling unit is used also for primary tillage, at higher milling drum revolutions there is a real risk that the soil may be sprayed, resulting in a deterioration of its structure and fertility, as well as provoking wind erosion. This fact is especially risky when operating on dry and sandy soils.

3.2. PRIMARI TILLAGE OF THE SOIL

To establish the optimal operating speed of the tiller for primary tillage to a depth of

50 cm, are conducted experimental studies on the territory of the Forestry State „Oryahovo“. For the purpose is performed soil preparation in three working sites with an area of 20 dka. In each of these are set out by 27 experimental sections, each with a length 100 m. It is performed soil preparation in advance of these sites with the same machine, including the following operations - fully eradication of the stumps and mulching of the coppice vegetation, shrubs and wood residues. The mechanical structure of the soil is sandy–clay and the soil category is moderate. The hardness of the soil, measured immediately before the milling is 1,95 MPa. The measured humidity is relatively high – 53%, which is typical for flooded areas. In accordance with the adopted methodology of the study is conducted an active two-factor experiment. The obtained results for the operating speed for the operation primary tillage with forest tiller FAE 300/S are presented in Table. 3.

Table 3: Milling unit working speed at the various drum revolutions and transmission speed gears, [km/h]

Milling drum revolutions [min^{-1}]	1^{-st} gear	2^{-nd} gear	3^{-rd} gear
250	0.571	0.813	0.889
375	0.746	0.984	1.1
500	1.008	1.259	1.412

Based on the obtained results are built graphical dependencies, which are expressing the amendment of the operating speed of the unit depending on the milling drum revolutions (Figure 7). From these dependencies can be established that with the increase of the the milling drum revolution, the operating speed increases proportionately. In contrast with the operation mulching, the curve of change of the operating speed for the operation deep primary tillage is closer to a linear approximation, as there is a slight tendency to increase above 350 min^{-1}. Another feature of the research process is that because of the greater resistance during deep soil tillage, the operating speed of the unit at the 3^{rd} speed gear increases relatively less. The difference with the highest milling drum revolution is only 0.15 km/h.

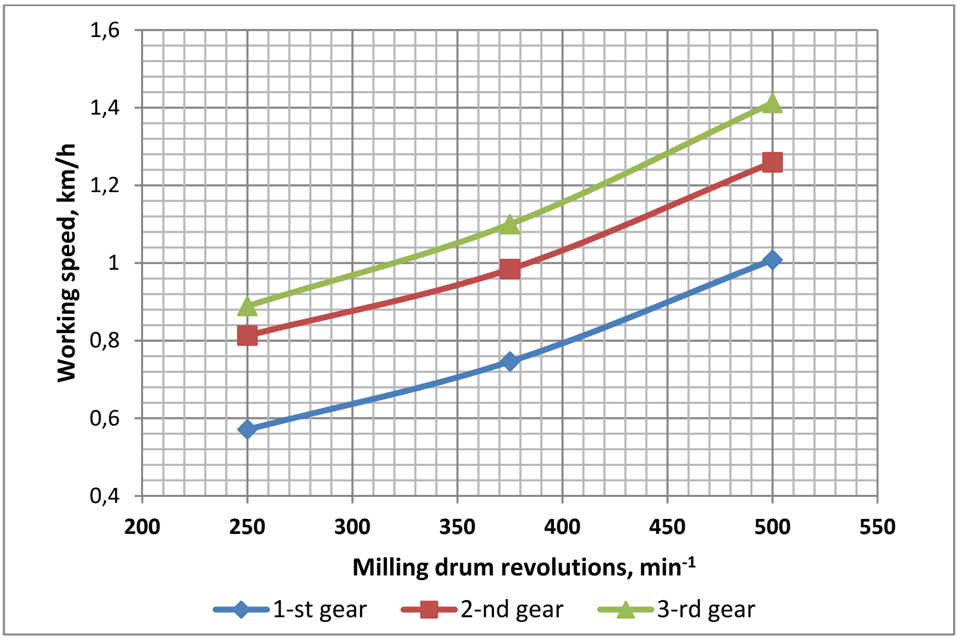

Figure 7: Variation of the working speed milling unit with forestry tiller FAE 300/S for soil deep milling up to 50 cm, depending on the speed gears of PT-40 and milling drum revolutions

However due to greater load on the engine at third gear, the power consumption increased significantly. In our previous study of the same machine was established relatively high energy consumption during operating at 3rd speed gear. To determine the appropriate speed gear for the operation of deep soil milling, is performed an optimization of the speed modes by searching the minimum of power consumption. From the obtained results are built graphical relationships which are depicted in Figure 8.

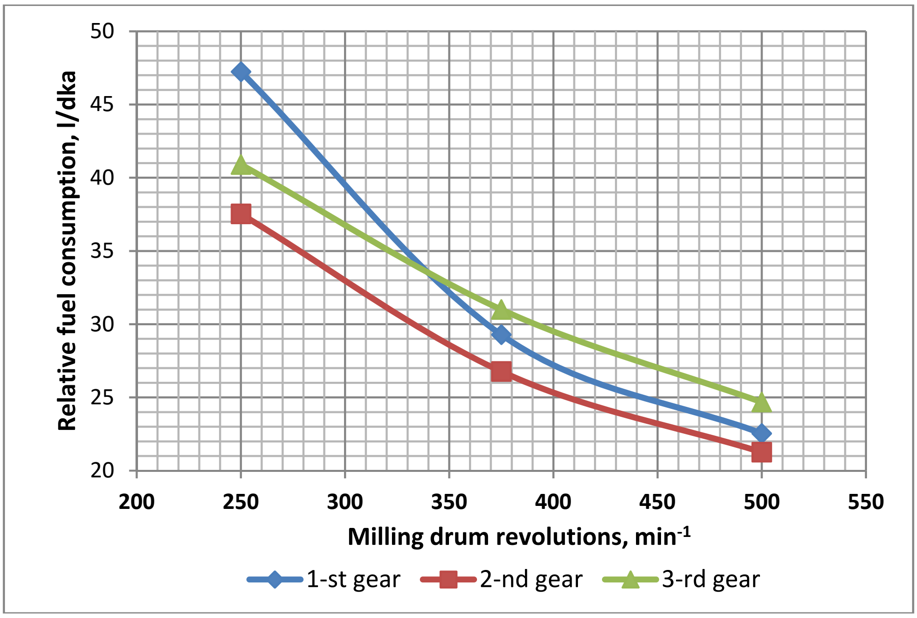

Figure 8: Variation of the fuel consumption milling unit with forestry tiller FAE 300/S for soil deep milling up to 50 cm, depending on PT-400 speed gear levels and milling drum revolutions

From the received values can be concluded that for primary tillage with multi-functional forestry tiller FAE 300/S in previously prepared areas, with moderate soil, hardness of 1,95 MPa and humidity around 52%, the minimal power consumption per unit area is obtained when operating at second gear and maximum milling drum revolution. The power consumption must be considered for optimal for the operation deep soil tilling up to 50 cm, only on soils with similar physic-mechanical properties. When tilling heavier soils with higher moisture should expect lower power consumption during operation at first gear. When working on lighter, sandy and drier soils are recommended to operate at third or second speed gear, but at lower milling drum revolutions, because of the possibility for the soil to deterioration its structure, to become more powdering and lose fertility.

CONCLUSION

A significant portion of the capital expenditure for establishing and growing poplar plantations is concentrated during the first year. The biggest part of these expenses – about 60% to 70%, is invested for soil preparation. In the last several years, increasingly are implemented technologies based on specialized forest tillers for soil preparation for establishment of poplar plantations. The introducing of such innovative technologies, based on these milling aggregates is an important factor for the increase of the quality of work and the productivity, meantime to decrease the expenses for soil preparation and to shorten the silvicultural terms. The implantation of such machine in the region of the Northwestern Forestry Enterprise „Vratsa“ led to a significant improvement of the performance for the soil preparation. By an inventory, made at the end of the first growing season of young poplar plantations, established on sites treated with this forestry unit, was determined comparatively high rate of intercepted saplings (98%). Labor costs, which were established for full soil preparation per 1 acre of poplar clearing, treated with the new machine were within 2.76÷2.93 h/dka, which is from 2.5 to 4 times less compared to the labor costs with the previous technologies. The price per 1 acre full soil preparation using this forestry milling aggregate is within 148÷157 €/dka. This price is comparable to the price of technology based on the rotor eradicators, but is almost 60 % lower than those of the technological schemes based on bulldozer units and frontal tooth eradicators.

In this paper is studied the work of the specialized unit PT-400 with multifunctional forest tiller FAE 300/S for soil preparation of poplar clearings. Experiments are conducted with different operating speed and operating modes of the unit. To differentiate the operating conditions and for more adequate comparison of the expenses for soil preparation is introduced categorization for the poplar clearings. Two basic technological operations are examined – mulching of standing trees, coppice vegetation, shrubs and wood residues, and primary tillage, with deep milling up to 50 cm. From the conducted research can be made the following basic conclusions and recommendations:

1. It has been performed an experimental study to determine the operating speed of specialized milling unit with multifunctional forestry tiller FAE 300/S for full soil preparation of poplar clearings.
2. An optimization has been made by technological and operating criterion for the process soil milling, in order to minimize the energy consumption per unit area. This helped to establish the optimal operating speed of the tiller.
3. There have been determined the optimal speed gear for the movement of the driving module PT-400 and the optimal milling drum revolutions of the forestry tiller FAE 300/S-225, where will be realized minimal costs for soil preparation.

The results have a scientific and applied-science contribution to mechanized soil preparation for establishing poplar plantations. They can be used to determine the appropriate speed modes in the design of forest mills and in normalization of milling aggregates and development of technologies for soil preparation of poplar clearings.

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