

PRODUCTIVITY OF A JOHN DEERE HARVESTER UNIT IN DECIDUOUS STANDS

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Abstract

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The aim of the presented paper was to determine the productivity of a John Deere 1070D harvester in deciduous coppices of *Quercus petraea* and *Fagus sylvatica*, in thinnings over 50 years of age. The research area was located in Tribeč mountain ridge, western Slovakia. The terrain incline did not exceed 20%. The productivity of the harvester in oak stands was 9.97 m³.h⁻¹ without downtimes (breaks, failures, etc.). Performance with breaks was 4.98 m³.PMH⁻¹ (productive machine hour). The productivity of the harvester was influenced by a large portion of passes of the harvester, which constituted 23.47% of the time of the operating cycle. The large number of passes was caused by the fact that the operator did not respect the technologic process and a high portion of tree extraction (8.45%). Furthermore the productivity was decreased by frequent failures of the machine and downtimes, which could be prevented by proper and regular maintenance. The productivity in beech stands was 6.36 m³.h⁻¹ without downtimes and 5.35 m³.PMH⁻¹ with downtimes included. Lower productivity was caused by the numerous and thick branches and frequent presence of trees with multiple tree tops, ergo unsuitable structure of the stand. Absence of a worker with a chainsaw was considered to be a disadvantage, because this worker is often a necessity when harvesters operate in deciduous stands.

Keywords: forest harvester, forwarder, performance, deciduous stand, Broadleaved thinnings

INTRODUCTION

At present ecologization and scientific development is necessary in every field, including forestry. In logging the former is ensured by application of integrated technologies, mostly by employing multioperational machinery. Although harvester units (harvester + forwarder) are more expensive in comparison with the classical technology, we need to take the added value of lower damage to the remaining stand, which will show in better assortment quality in the main harvest, into account. We should also take the health of forests into account. This is nowadays, when the share of incidental felling is more than 60% (Zelená správa, 2010), interesting. Application of this technology in the deciduous stands carries additional demands on the quality of the exploitation's management and technological preparation of the logging process with emphasis on the selection of appropriate stands. To enable a correct decision on which stand

is appropriate and which is not for this technology. It is necessary to create a framework based on empirical data from actual harvests. The aim of this paper is to determine the productive parameters of harvesters in deciduous stands of *Quercus petraea* and *Fagus sylvatica* in thinnings over 50 years. Based on results of our measurements it is possible to identify the advantages and disadvantages of the applied technology in context of selected logging practice. We can then use these measurements in future planning of harvest-silviculture measures with use of harvester technology.

MATERIAL AND METHODS

We carried out the research in the Topolčianky branch of Lesy SR SOE, forest district Nitrianska Streda, in stands n. 1361, 1450 and 1463. The description of the stand (Tab. I) is taken from forest management plan effective until 1.1.2020 for forest management area Partizánske. Stand n. 1361 is

I: Description of the stand

Part n.	Area	Age	Crop dens.	Tree species	Avg. stem (h/d _{1.3} /V)	Reserve per ha	Exp.	Incline
1361	16.21 ha	75 r.	0.80	DZ 100	22/27/0.50	3744/231	Z	15%
1450	14.30	75	0.80	BK 100	22/23/0.40	3575/250	Z	15
1463	10.87	70	0.85	BK 100	20/22/0.38	2772/255	Z	17

mainly coppice, the forest management plan states 1st generation of coppices.

A John Deere (JD) 1070D harvester with performance of 129/2000 kW.rev.min⁻¹, hydraulic crane reach of 9700 mm and harvester head JD H754 was used selected to carry out the silvicultural actions. The machine is owned by Lesy SR SOE, Forest machinery branch.

For the purposes of this paper a harvester-forwarder method of experimental measurements of logging technology was used (Koreň, Tajboš, 2004).

Determination of productivity and effectiveness of harvester technology

We determined the productivity of harvester and forwarder with chronometric measurements (basic time consumption of individual operations) on the area of the stand using the data from the harvester's computer on the volume of produced assortments. We recorded the time sample with a digital video camera and the data was processed in MS Excel and STATISTICA 8.0. In time sample creation mainly the times of work cycles were important. The work cycle of every operation consisted of individual work operations.

We carried out the calculations of harvester technology using the:

- budget items from the data of supplier,
- the deal between the supplier and consumer of the exploitation.

Time and technical units of the harvester's work cycles

We use the classification according to Dvořák *et al.* (2011):

- t'_{A121} : Time of drive to new position,
- t'_{A122} : Time of adjusting the harvester head,
- t'_{A123} : Time of grabbing and cutting the tree,
- t'_{A124} : Time of processing the tree,
- t'_{A125} : Time of pre-skidding,
- T' : Time of inoperation, dose and shift.

RESULTS AND DISCUSSION

A) Productivity of the harvester in oak stand n. 1361

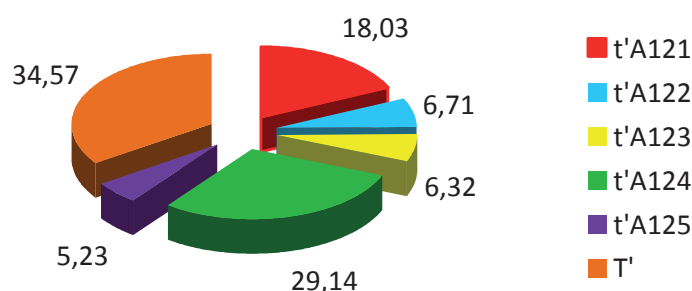
Based on the chronometrics and the output of the harvester's computer we calculated the productivity per one PMH (productive machine hour) including a 15 minute break and shift productivity (including all downtimes). Tab. II shows average values of selected performance indicators during the actual shift and the structure of work operations, which are presented for an average operational cycle. Fig. 1 documents the structure of the average cycle during the shift with relative share of individual phases of the work operations including breaks (T' phase).

When comparing the productivity of the harvester per hour with the data from Lukáč (2005), who states productivity of circa 9 m³.h⁻¹ for 0.22 m³ stem volume, our data shows 9.97 m³.h⁻¹ (0.97 m³.h⁻¹ higher). Slugeň (2007) states, that in spruce stands with average stem volume of 0.20 m³ productivity is 8.28 m³.h⁻¹, which is 1.69 m³.h⁻¹ lower than the productivity we observed. Tréger (2005) states productivity of 10.52 m³.h⁻¹ at stem volume of 0.22 m³

II: The average values of selected performance indicators of harvester

Indicator	Unit	
Avg. volume of felled trees	m ³ .pcs ⁻¹	0.22
Volume of harvested timber	m ³	35
Number of harvested stems	Pcs	159
Time of work of the machine	h	7.03
Productivity	m ³ .h ⁻¹	9.97
	m ³ .PMH ^{-1*}	7.48
	m ³ .h ⁻¹	4.98
Time consumption per cycle	min	2.02
From which: - work operations ($t'_{A122} - t'_{A124}$)	min	0.85
drives ($t'_{A121} + t'_{A125}$)	min	0.47
other (T')	min	0.70

* productive machine hour including 15 minute break per one hour of machine work



1: The structure of the average operational cycle, downtimes included

in coniferous stands, which is $0.55 \text{ m}^3 \cdot \text{h}^{-1}$ higher than in our case. Slugeň (2009) states that in beech coppice stands with average stem volume of 0.13 m^3 the JD 1270 harvester's productivity was $6.28 \text{ m}^3 \cdot \text{h}^{-1}$. Dolejský (2000) states the productivity of mid class harvesters in deciduous stands is $7.33 \text{ m}^3 \cdot \text{h}^{-1}$. Based on this comparison we can say that the type of tree is irrelevant and the productivity achieved corresponds with the results of other authors.

Hourly productivity was $4.98 \text{ m}^3 \cdot \text{PMH}^{-1}$, which was caused by a large share (34.57%) of downtimes (breaks, failures, etc.). Potentially feasible shift productivity could reach to 104.69 m^3 but the real productivity was 52.29 m^3 per shift (10.5 h), half of the potential shift productivity. The potential productivity does not account for necessary downtimes of the machine (in general this is 15 minutes per hour of work). Real productivity is achieved by multiplying the potential productivity with a 0.75 coefficient. The value of real productivity is $7.48 \text{ m}^3 \cdot \text{PMH}^{-1}$. Shift productivity is lower and reaches 66.60% of the potential productivity. Based on the data from Forest machinery branch, Banská Bystrica, an average productivity of $4.40 \text{ m}^3 \cdot \text{PMH}^{-1}$ (3.96 to $4.90 \text{ m}^3 \cdot \text{PMH}^{-1}$) was achieved in 8 shifts. The data we acquired corresponds with this average. The structure of an average work operation without breaks (t'_{A121} to t'_{A125}) is documented on Fig. 2.

For detailed analysis of the average operational cycle of the harvester we used data from a database of 159 measurements.

a) t'_{A121} : Time of drive to new position

The average value of drives is 0.36 minutes (21 s) which presents 18.03%. Standard deviation $s_x = 0.93$, coefficient of variation $s_x\% = 255.27\%$. The standard drive lasted maximally for

3.73 min., minimally 0.00 min. The total time of drive was 58.03 min.. The average length of drive was 11.08 m, at $s_x\% = 267.65\%$. Maximal length of drive was 350 m (in drive to a different forwarding line), minimal length was 0.00 m. The total length of drives was 1761 m.

b) t'_{A122} : Time of adjusting the harvester head

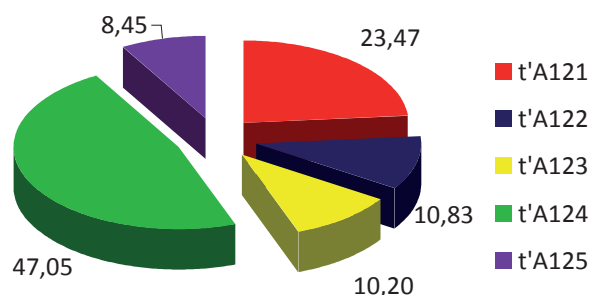
The average value was 0.14 min. (8.4 s), i.e. 6.71%, $s_x\% = 49.26\%$. Maximal value was 0.63 min., when the harvester operator had to grab the tree twice, minimal value was 0.05 min..

c) t'_{A123} : Time of grabbing and cutting the tree

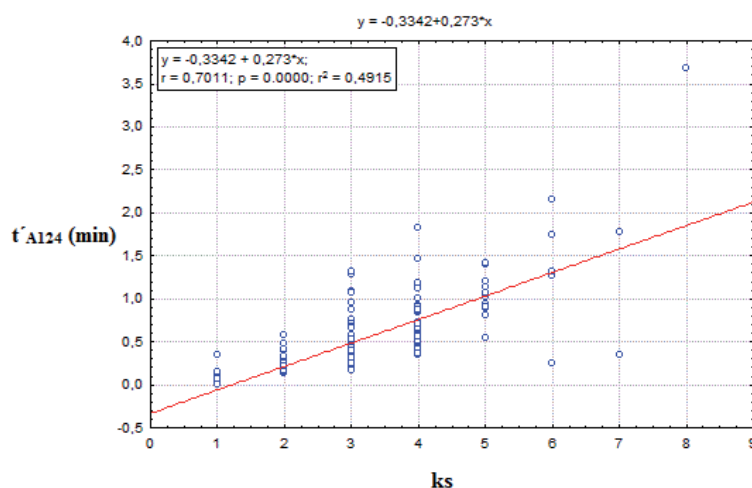
The average value was 0.13 min. (8 s), i.e. 6.32%, $s_x\% = 90.84\%$. Maximal value was 0.77 min., minimal value was 0.00 min., when the harvester processed a windthrow.

d) t'_{A124} : Time of processing the tree

The average value was 0.59 min. (35 s), i.e. 29.14%, $s_x\% = 76.19\%$. Maximal value was 3.68 min. (3 min 41 s), when the operator had to repeatedly grab the stem due to thick branches. In this cycle there was also a maximal value of *bunching* sub phase. Minimal value was 0.00 min. when the operator only cut the tree and placed it on the biomass for wood chips assortment pile (further in the text referred as biomass assortments), since it was a small tree ($d_{1,3} = \text{circa } 6\text{--}7 \text{ cm}$). Another factor affecting the total duration of this work operation was the occurrence of snags, because cutting them was often problematic due to their hardness. On one occasion this caused an increase in time consumption to 1.17 min., and reached 224.36% of the average value. The number of assortments produced from each tree and the distance of individual piles of assortments to which these



2: The structure of the average operational cycle, downtimes excluded



3: Dependence of tree manipulation time consumption on the number of produced assortments

assortments were piled had the biggest effect on the time consumption. The dependence of time required to complete this phase on the number of produced assortments was tested through a regression analysis in the STATISTICA 8.0 program. The correlation coefficient was $R = 0.70$, the dependency exists, although the variance of the values is large. This is where we can identify the effect of tree species. A more difficult delimbing, gradual cutting of the thick branches and forks contributed to extension of tree processing. Another factor we identified from direct observation was classification of produced assortments onto piles, which were unjustifiably too distant from each other. By eliminating these factors we presume a tighter correlation. The results of the analysis are shown on Fig. 3.

e) t'_{A125} : Time of pre-skidding

The average value of this operation was 0.11 min. (6 s), i.e. 5.23%, $s_x\% = 164.95\%$. Maximal recorded value was 1.22 min., minimal 0.00 min. The total duration of this phase was 16.83 min. This phase consisted of extracting the timber to the forwarding line or extracting the timber to the assortment piles. Extraction to the assortment piles was the biggest error of the applied technological practice and here lay the ways of securing greater productivity of the harvester.

f) T' : Time of inoperation, dose and shift

The average value was 0.70 min. (42 s), i.e. 34.43%, $s_x\% = 506.33\%$. Maximal recorded value was 27.03 min., when the operator of the harvester assisted in forwarder failure servicing. Maximal value of this phase which had to do with the harvester's work was 25.27 min., when a failure of the harvester's hydraulics occurred and was serviced. The total time of downtimes was 111.24 min. (1 h 51 min 14 s). The biggest share of this phase belonged to machine failure (chain ruptures and hydraulics failures). This phase always occurs in different durations in harvester operation. Due to this fact many authors state

the overall productivity of machines in PMHs by adding a 15 minute break per hour of operation. This is an average time needed for breaks (small service, breaks, discussions with the management, etc.).

Comparison of an average work cycle without downtimes is shown in Tab. III. The results of aforementioned authors were recalculated, because they were shown with breaks and downtimes. We can see that in observed shift without drives and pre-skidding (t'_{A121} and t'_{A125}) individual phases correspond with the results obtained by these authors. In drives we can see that their share is bigger. In pre-skidding phase we can see this too, which is caused by operator's effort to concentrate the assortments into bigger piles to decrease the number of load points of the forwarder, as well as inconsistency of the width of the operational plots and in unfavorable structure of the stand, which demands the harvester to drive into the stand outside the forwarding line. Other phases show lower shares, which is probably due to sufficient operational space for manipulation with harvested timber or better visibility in the stand.

B) Productivity of the harvester in beech stands n. 1450 and 1463

Tab. IV shows the average values of the selected indicators of harvester productivity and the structure of the operations in an average operational cycle, documented on Fig. 4, where the relative share of the individual phases of the operations with downtimes (phase T') is shown. The harvester operator used a different technique in these stands. The operator felled trees in groups, after which he bunched them and when the whole group was felled he proceeded to manipulate them.

When comparing the hourly productivity of the harvester with the data from Lukáč (2005), who states that the productivity at 0.18 m^3 average stem volume is about $7 \text{ m}^3 \cdot \text{h}^{-1}$, we can see that the productivity we measured ($6.36 \text{ m}^3 \cdot \text{h}^{-1}$) is lower ($\Delta = -0.64 \text{ m}^3 \cdot \text{h}^{-1}$).

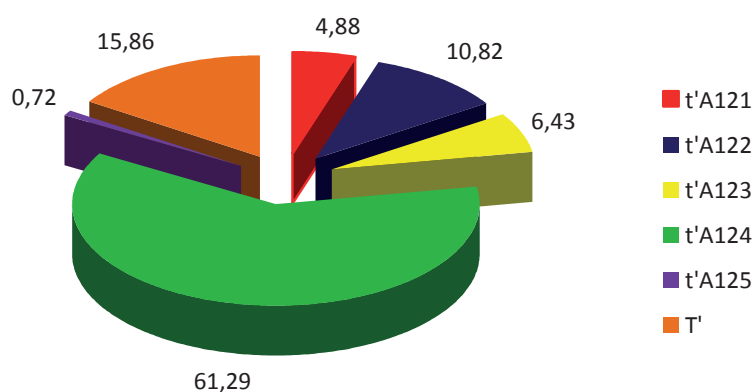
III: Comparison of the structure of the operations with the results of other authors

Source	Tree species	Phase				
		t'_{A121}	t'_{A122}	t'_{A123}	t'_{A124}	t'_{A125}
Dvořák (2011)	Spruce	21	12	15	51	1
	Pine	17	20	14	49	0
Lukáč (2004)	Spruce/Fir/Larch/Birch	20	14	14	53	-
Niemistö (2012)	Spruce	11	23	13	52	-
	Spruce	8	23	11	58	-
	Spruce	7	22	11	59	-
Ovaskainen (2004)	Pine	11	25	18	47	-
Slugeň (2007)	Spruce /Fir	18	15	14	54	-
	Spruce /Fir/Larch/Birch	24	17	11	48	-
	Spruce	21	19	10	50	-
Tréger (2005)	Spruce /Fir	18	19	10	54	-
Own	Oak	28	10	10	45	8
	Beech	6	13	8	73	1

IV: The average values of selected performance indicators in beech stands

Indicator	Unit	
Avg. volume of felled trees	$\text{m}^3.\text{pcs}^{-1}$	0.18
Volume of harvested timber	m^3	37.45
Number of harvested stems	Pcs	308
Time of work of the machine	h	7.00
Productivity	$\text{m}^3.\text{PMH}^{-1*}$	6.36
	$\text{m}^3.\text{PMH}^{-1}$	4.77
	$\text{m}^3.\text{h}^{-1}$	5.35
Time consumption per cycle	min	2.02
From which: - work operations ($t'_{A122} - t'_{A124}$)	min	1.59
drives ($t'_{A121} + t'_{A125}$)	min	0.11
other (T')	min	0.32

* productive machine hour including 15 minute break per one hour of machine work

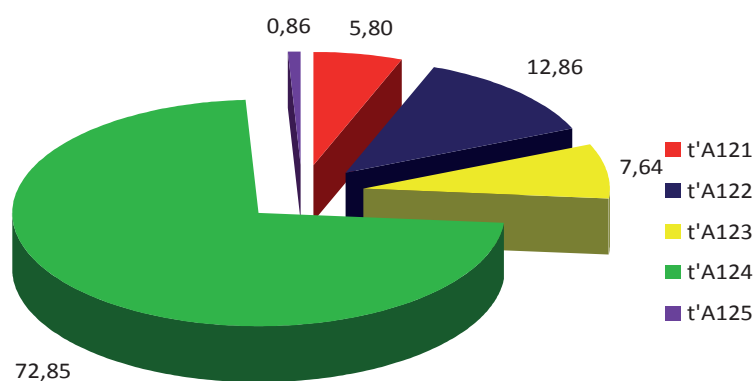


4: The structure of the average operation cycle including downtimes

Slugeň (2009) states that the productivity of a John Deere 1270D in deciduous stands with prevalence of beech is $6.28 \text{ m}^3.\text{h}^{-1}$. The average stem volume was 0.13 m^3 . Dolejský (2000) states that the productivity of mid class harvesters in deciduous stands is $7.33 \text{ m}^3.\text{h}^{-1}$. Kwf (1996 in Slugeň, 2007) state the

productivity of harvesters in beech thinnings is $7.8 \text{ m}^3.\text{h}^{-1}$. Based on this comparison we can see that the productivity was lower in the observed stands.

Hourly productivity was $5.35 \text{ m}^3.\text{h}^{-1}$. This was caused mainly by a large share of time needed for manipulation, due to a high number of branches



5: Structure of the average operational cycle, excluding downtimes

(61.29%) and their thickness. Potential productivity could reach to 69.29 m^3 , real productivity was 58.85 m^3 per shift (11 hours). Potential productivity does not count for necessary machine downtimes (15 minutes per hour of operation in general). The structure of the average operational cycle without downtimes is shown on Fig. 5.

The average operational cycle of the harvester was calculated from a set of 308 operational cycles recorded during the measurements.

a) t'_{A121} : Time of drive to new position

The average value was 0.10 minutes (6 s) which presented 4.88%. Standard deviation $s_x = 0.23$, coefficient of variation $s_x\% = 237.12\%$. The average length of drive was 2.29 m, at $s_x = 5.48$ $s_x\% = 239.27\%$. Maximal length of drive was 25 m (1.2 min), minimal length was 0.00 m. The total length of drives was 149 m.

b) t'_{A122} : Time of adjusting the harvester head

The average value was 0.22 minutes (13 s), i.e. 10.82%. Standard deviation $s_x = 0.17$, coefficient of variation $s_x\% = 77.18\%$. Maximal value was 0.97 min., when the harvester had to grab the stem multiple times to achieve a desirable position of the harvester head. Minimal value was 0.05 min.

c) t'_{A123} : Time of grabbing and cutting the tree

The average value was 0.13 min. (8 s), i.e. 6.43%, $s_x = 0.20$, $s_x\% = 150.74\%$. Maximal value was 1.1 min, minimal value was 0.0 min. when the operator processed a blow-down.

d) t'_{A124} : Time of processing the tree

The average value was 1.24 min. (74 s), i.e. 61.29%, $s_x = 0.92$, $s_x\% = 74.35\%$. Maximal value was 3.9 min. (234 s), when the operator had to gradually cut and process thick branches one at a time. Minimal value was 0.18 min.

e) t'_{A125} : Time of pre-skidding

The average value of this operation was 0.01 min. (this operation lasted for 57 s on total for the whole shift), i.e. 0.72%, $s_x = 0.07$, $s_x\% = 463.76\%$. Maximal recorded value was 0.4 min., minimal value was 0.00 min. This phase was almost nonexistent during the work of the harvester in this stand, or it lasted less than the minimal recorded (3 s). We

present it solely for the purpose of integrity and comparability with other stands.

f) T' : Time of inoperation, dose and shift

The average value was 0.32 min. (19 s), i.e. 15.86%, $s_x = 1.13$, $s_x\% = 354.24\%$. Maximal recorded value was 6.5 min. This phase always occurs in machinery operation, though with different durations.

The comparison of the average operational cycle, excluding the downtimes is shown in previously mentioned Tab. III. In case of the beech stand we can see that the structure of the shares of the operational phases resembles mostly the structure achieved by Niemistö (2012) and partially by Ovaskainen (2004), although the authors acquired data in spruce and pine stands. The share of the "Time of processing the tree" (t'_{A124}) is caused by the thickness of branches and a larger share of trees with two tree tops, which can be expected in beech stands of this age. We can say that the stand was improperly selected for harvester harvesting, when taking the below the average productivity into account. Although it is technically possible to use the technology, the effectiveness and related profitability of such usage is unfavorable at best.

CONCLUSION

From the results of the presented research of harvester use in deciduous thinning oak and beech stands we can draw multiple conclusions. During the research we found out that this technology is suitable for effective work in oak stands without significant decrease of productivity. Limiting factors of operation in comparison with work in coniferous stands are the structure and origin of the stand. We have to keep that in mind when selecting stands for multioperational machines. The most significant factors affecting the productivity of the harvester were: not complying to the technological practice and frequent failures of the machine. By analyzing the harvester we observed an increased share of drive operation. This was caused by not complying to the technologic process in case of the oak stand. The harvester, when finished with one operational plot, did not continue to the next uphill area but

instead moved to the top of the next forwarding line and worked downhill, although the incline and terrain configuration enabled antigravitational harvest. The increased share of drives was caused by also by wide operational plots – the harvester had to drive into the stand to cut trees. Based on the empirical knowledge of workers of the Forest district Nitrianska Streda we can state that the effectiveness is higher than classical technology with more or less equal costs (classical technologies are 2–3 €·m³ cheaper). Besides the aforementioned faults we have to state that the supplier of the work did not manage the harvester unit properly – organizational and logistics wise.

In case of the beech stands the lower productivity was mostly caused by the branches, which were numerous and thick, and frequent presence of trees with multiple tree tops, ergo unsuitable structure of the stand. Employing harvesters in deciduous stands is problematic and completely different from work in coniferous stands. We can formulate some basic recommendations for employing harvesters in deciduous stands:

- selection of suitable stands, which should be of generative origin, with quality silviculture, where

there is a large share of trees with shorter tree tops and thin branches,

- precisely thought out and selected technological practice, minimizing unproductive drives,
- employing a worker with a chain saw who would fell trees with unfavorable shape and origin. The worker would fell trees to the reach of the hydraulic crane of the harvester and cut thick or unfavorably shaped branches if necessary,
- employing modern harvester head types of suitable construction. These are mainly shorter heads with top saw and fortified construction (Warath HTH 624 C, JD H290, Logset 5L, etc.),
- ensuring an adequate and quick service in case of failures.
- Tasks of further research should be mainly these:
- elaboration and empirical verification of technological practices with chain saw worker employment into the technological unit,
- elaborating a comparative database of harvester units from stands of different structure, age and tree types (deciduous) in Carpathian forests of Central Europe.

SUMMARY

The paper analyzes work operations (phases) and work performance of a John Deere harvester in deciduous coppices of *Quercus petraea* and *Fagus sylvatica*. Whole workshift was recorded with use of video camera. Exact time of individual work operations and work phases were determined from the record. Obtained data was then statistically processed. The recording served for determining the exact start and end times of each operation and shares of individual operations. The results showed, that potential productivity of the harvester was 7.48 m³ per machine hour (one hour of machine operation including 15 min break) in the oak stand, excluding downtimes (breaks, failures, etc.) the productivity was 9.97 m³·h⁻¹. In the beech stands potential productivity was 4.77 m³·PMH⁻¹ and excluding the downtimes it was 6.36 m³·h⁻¹. Real work efficiency of the harvester was only 4.98 m³·PMH⁻¹. The main reason of that fact was improper technologic process and frequent machine failures, which can be prevented by regular maintenance. The results showed, that harvester technology may work efficiently even in the oak stands without decrease of work efficiency, when the technological preparation of the work place is strictly kept. The most important limiting factors of harvester technology in the oak stands are the structure and origin of the stand.

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