Productivity of Harvesting Machines and Costs of Mechanized Wood Harvesting: Lithuanian Case Study

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Mizaras S., Sadauskienė L. and Mizaraitė D. 2008. Productivity of Harvesting Machines and Costs of Mechanized Wood Harvesting: Lithuanian Case Study. *Baltic Forestry*, 14(2): 155–162.

Abstract

During the last years the demand for mechanized wood harvesting is increasing in Lithuania. Harvesting machines produced only 3.8 % of wood in state forests in 2005 and this amount increased up to 12.2 % in 2006. But productivity of harvesting machines under Lithuanian conditions also costs of mechanized wood harvesting were not studied up to now.

This study examines the productivity of harvesting machines used in Lithuania and costs of mechanized wood harvesting. The research was performed on six cutting sites. The productivity of two harvesters and two harwarders (integrated harvester-forwarder) was investigated. The harvesting machines were filmed in normal working situations and data were analyzed by time study method.

The productivity of machines ranged from 10.7 to 46.5 m^3/h (solid m^3 per effective hour) for study areas. The harvesting machines' productivity in relation with stem size models were formed.

The wood harvesting costs of Timberjack 1270D harvester ranged from 8.0 to 1.7 EUR/m^3 (stem size 0.1-2.0 m^3) in clear cuttings and that of harwarders varied from 29.9 to 3.1 EUR/m^3 for (stem size 0.1-1.0 m^3). The wood harvesting costs of Sampo 1046X harvester amounted to 6.8–2.2 EUR/m^3 in clear sanitary cutting and to 12.4 -3.5EUR/m^3 (stem size 0.1-0.5 m^3) in selective sanitary cutting.

Key words: wood production, harvesting machine, productivity, costs, time study

Introduction

Recently wood production by chainsaws is replaced with wood production by harvesting machines in Lithuania. During 2007 Lithuanian enterprises purchased 14 harvesting machines and the total amount of them increased up to 34 (Zinkevičius 2008). Harvesting machines produced only 3.8 % of the wood in state forests in 2005 and this amount increased up to 12.2 % in 2006 (GMU 2007). The rapid increase in the demand for mechanized wood harvesting was determined by decreasing labour force supply and the equalisation of mechanized and manual wood harvesting costs. Wood production mechanization level in European countries is very different: from few percent up to almost 100 percent in Scandinavian countries (Axelsson 1998).

Productivity of harvesting machines was not studied up to now in Lithuania. It is widely studied in Scandinavian countries (Lageson 1997, Glöde 1999, Brandenberg 2000, Hanell *et al.* 2000, Kärhä *et al.* 2004, Ovaskainen *et al.* 2004, Nurminen *et al.* 2006), also in North America (Tufts and Brinker 1993, Kellogg and Bettinger 1994, MCNeel and Rutherford 1994, Landford and Stokes 1995, Tufts 1997). Time studies usually are carried out having the task to investigate the main factors affecting work productivity and to establish a base for cost calculation (Nurminen *et al.* 2006). There are two main types of time studies: comparative and correlation. Comparative studies are done to compare machines, work methods or treatments, while correlation studies describe the relationship between the productivity and influencing factors.

Time studies can be carried out using continuous time study methods or indirect work sampling. During the last 20 years, timing techniques in forestry operations have developed from decimal watches to automated data recorders of forest machines. The automated data collectors attached o forest machines' computers enable the collection of more accurate and detailed data (Nuutinen *et al.* 2008). However new methods cannot automatically register unforeseen situations and the change in conditions.

All time study methods have the advantages and disadvantages. Direct following or videotaping of operation can affect operators performance even if they were asked to work as normally as possible. Many large studies have revealed that the productivity of the operators may rise to a higher level during the time study than in normal working period (Nurminen *et al.*

2006). A follow-up study gives a more reliable picture of the productivity in every day work (Kärhä *et al.* 2004). In other case, following up studies involve operators in the data recording process. Operators should record the work time, the cause and time of breaks and interruptions, time for machine service, stand information. So the reliability of data depends on the honesty and dutifulness of operators.

The productivity of harvesting machines depends on forest stand, site and operational factors such as ground conditions, operators' motivation and skill, operational layout, tree size, tree form, branch size, log assortments processed, undergrowth density and machine design (Jiroušek *et al.* 2007).

Harvesting machines productivity is closely related to the tree size (Kärhä *et al.* 2004, Nurminen *et al.* 2006, Jiroušek *et al.* 2007). However, the relationship is not linear. After a certain stem size optimal to the machine, the productivity starts to decrease. The second important factor related to cutting productivity is operator (Kärhä *et al.* 2004, Nurminen *et al.* 2006). Other factors that affect productivity are harvesting intensity, terrain conditions (slope, surface structure, bearing capacity) and machinery.

Wood production costs depend on work productivity, harvesters' price and operational costs. Jiroušek *et al.* (2007) maintain that harvesting machine costs vary between 2 and 9 EUR/m^3 (tree volume 0.10-1.0 m^3). The costs difference between machines' classes is very small in the tree volume area larger than 0.5 m^3. However, the tree volume smaller 0.5 m^3 causes higher differentiation of costs. From the economic point of view it is better to use the small harvester in such cases.

The cutting costs for the thinning harvesters amounts to 12.1-4.9 EUR/m^3 (stem size 0,05-0,10 m^3) in first thinnings and to 7.3-4.0 EUR/m^3 (stem size 0.10-0.15 m^3) in second thinnings (Kärhä *et al.* 2004). Siren and Aaltio (2003) maintain that thinning harvester (class I machines) is the cheapest alternative comparing with medium-size harvesters or with harwarders in first thinnings.

In comparison to harvester-forwarder system, the main advantage of harwarders are mostly related to time savings since some work elements are combined into the same working phase or working cycle (Asikainen 2004). Harwarders are suitable on sites both with small removals (less than 100 m^3) and with long translocation distances, when translocation costs play a big role in total costs (Väätäinen *et al.* 2006). The harwarder is able to compete with harvester based system in the stands with a short extraction distance and a few assortments (Bergkvist *et al.* 2003). Additionally, direct processing onto load space can save a lot of time compared to separate log loading.

In Lithuania all economical calculations were done by using data of foreign countries, irrespective of different economical and natural conditions.

The study aim was to estimate the productivity of harvesting machines used in Lithuania and costs of mechanized wood harvesting. This study is a part of the larger project and the more detail results will be presented later.

Material and methods

Experimental stands and studied machines

The time study was conducted on the six study areas. The main characteristics of the study areas are provided in Table 1. The stands investigated grew on mineral soils of normal moisture (N). The terrain in the study stands was relatively easy.

Studied harvesting machines, cutting type and distribution of harvested trees by species are presented in Table 2.

Timberjack 1270D is a harvester designed for selective thinning and regeneration harvesting. According to Athanassiadis *et al.* (1999) classification, this harvester belongs to large sized harvesters as its motor output is 169 kW. The Sampo SR 1046 X harvester is small-sized harvester with motor output up to 80 kW and it is ideal to thin young forests. Valmet Combi is a full combi machine that uses a harvester as a base machine. It has a turning cabin and it is equipped with a load space and a combi head that can undertake both cutting and loading of timber. Ponsse Dual uses a forwarder as a base machine. It has two interchangeable heads for the crane: normal harvester head for cutting the timber and a grapple for loading the timber.

Climatic and terrain conditions were quite similar in all study areas. Sample plots cover 0the area in both sides of strip road and strip road also. The area of sample plot in clear cuttings and second thinning was 0.1-0.2 ha, in clear sanitary cutting 0.05 ha and in selective sanitary cutting 0.4 ha. The total harvested area in the time study was 1.05 ha.

Experience of the operators

Operators of Timberjack 1270D harvester had 3 and 2 year experience in working with studied machine. Operators of Ponsse Buffalo Dual and Valmet Combi harvarderds had 1 year experience in working with the studied harvarders. Also they had about ten years experience in working with forwarders. Sampo 1045X harvester operators had one year experience in working with harvester and few years with forwarder. No one operator had professional qualification of harvester operator.

Table 1. Main characteristics of study areas

No of study area	Forest Enterprise/ Forest district/	Block	Plot	Area, ha	Species composition	Age, year	DBH, cm	H, m	Stocking level	Productivity class	Forest site/Forest type series	Volume, m^3/ha
1	Druskininkai/ Druskininkai	399	7	5.6	10Pine	105	30	23	0.7	III	Nal *Vacciniosa*	280
2	Varėna/ Zervynai	342	13 16	5.1	10Pine	105	30	24	0.6	III	Nbl *Vaccinio-Myrtillosa*	260
3	Šalčininkai/ Dieveniškės	5	12	0.8	7Spruce 1Pine 1Birch 1Aspen	75 85 65 65	28 32 28 28	25 23 26 24	0.5	II	Ncl *Oxalidosa*	260
4	Trakai/ Rūdiškės	13	15a	1.2	7Spruce 3Pine Birch Aspen	70 105	24 34	19 27	0.8	II	Nbl *Vaccinio-Myrtillosa*	370
5	Šiauliai / Kurtuvėnai	6	3	21.4	7Pine 2Spruce 1Birch	65 65 65	32 28 28	 27 27 25	0.8	II	Nbl *Vaccinio-Myrtillosa*	370
6	Šiauliai / Kurtuvėnai	6	3	21.4	7Pine 2Spruce 1Birch	65 65 65	32 28 28	27 27 25	0.8	II	Nbl *Vaccinio-Myrtillosa*	370

Table 2. Studied machines, cutting type, distribution of harvested trees by species

No of study areas	Cutting type	Harvesting machine	Index	Species of harvested trees: Pine	Spruce	Birch	Aspen	Total
1	Clear cutting	Timberjack 1270D	N*	79				79
			V	0.545				0.545
			STD	0.279				0.279
2	Clear cutting	Timberjack 1270D	N*	43				43
			V	1.067				1.067
			STD	0.539				0.539
3	Clear cutting	Ponsse Buffalo Dual (harvarder)	N*		38	14	1	53
			V		0.304	0.506	0.991	0.386
			STD		0.269	0.379	-	0.329
4	Clear cutting	Valmet Combi (harvarder)	N*		44	4	3	58
			V		0.387	0.263	0.467	0.469
			STD		0.313	0.404	0.181	0.395
5	Clear sanitary cutting	Sampo 1046 X	N*		30	1		31
			V		0.266	0.197		0.263
			STD		0.217			0.214
6	Selective sanitary cutting	Sampo 1046 X	N*	3	31			34
			V	0.344	0.285			0.289
			STD	0.067	0.273			0.261

*N - Number of harvested trees; V- average stem volume, m^3; STD - standard deviation of average stem volume, m^3

Time study

The study of harvesting machines productivity was conducted in the summer of 2007 and work was performed during daylight hours. Field study material was collected using a digital video camera. The DBH of all trees in sample areas were measured before the harvesting. The number was written on the trees. During filming the harvesting of tree, the number was filmed. The time study data consisted of 7.8 hours of effective work on video tape. The harvested wood volume was determined using wood volume tables (Kuliešis *et al.* 1999) according to species, DBH and stand height class. The video material was analysed according to the stop-watch study principle using the time counter of video camera. Harvesting time was assigned to the tree according to its number.

Cycle times for each machine were split into the time phases (cutting, processing, movement and idle time) considered to be typical of the functional process analysed and all time elements and related time motion data were recorded.

Two different techniques were utilized in forming a model for the productivity (Nurminen *et al.* 2006). Regression analysis was used for these work phases in which time consumption could be explained with some independent variable such a stem size. Other work phase models were designed using average time consumption values. The model of total time consumption was formed by combining the work phase models. Finally, the total time consumption was converted into productivity. Machine effective productivity was measured in cubic meters per productive hour (m^3/ PMH_0) without any delays. Total productivity was calculated dividing the effective productivity by ratio 1.4 (Brandenberg 2000).

Cost calculation

The wood production costs were calculated according to Equation 1:

$$S = t \times (d + Z) \tag{1}$$

where:

S – wood production costs, EUR/m^3;

t – work time expenditure, hour/m^3;

d – labour costs per time unit (hour), including social insurance payments (31%) and additional costs (for holidays and other benefits (12%), EUR;

Z – operational costs of harvesting machine , EUR/hour.

The operational costs of equipments were calculated according to Equation 2:

$$Z = (V_p - V_l)/E + R/E + \sum(D_d \times k_d) \tag{2}$$

where:

Z -operational costs per working hour of harvesting machine, EUR/hour;

V_p -market price of harvesting machine, EUR;

V_1 - price for the harvesting machine after its life cycle, up to 10% of market price, EUR;

E - duration of equipment exploitation, according to the regulations of the Lithuanian Government, hour;

R - costs for current repair and technical maintenance in percent of market cost, EUR;

D_{ed} - consumption of fuel and lubricants per one working hour of harvesting machine, litre/hour;

k_d - cost of fuel and lubricants for one unit, EUR/litre.

The salary of 1303 EUR/month for harvesting machines' operators was ascertained from interviews with the heads of logging companies. Operational costs of harvesting machine calculated according to Equation 2 were: Timberjack 1270D harvester, 67.5 EUR/hour, Ponsse Buffalo Dual harwarder, 56.0 EUR/hour, Valmet Combi harwarder, 76.2 EUR/hour, Sampo 1046X harvester, 29.5 EUR/hour.

Results and discussion

Productivity of harvesting machines varied from 10.7 m^3/ PMH_0 up to 46.5 m^3/ PMH_0 in the research areas (Table 3). The highest productivity was reached by Timberjack 1270D harvester in pine stand with an average stem volume of 1.067 m^3. The productivity of Sampo 1046X harvester was the lowest in the selective sanitary cuttings with an average stem volume of 0.289 m^3.

Table 3. Productivity of harvesting machines in study areas

No of study areas	Cutting type	Harvesting machines	Average stem volume, m^3	Productivity per effective work hour, m^3	Productivity per work hour, m^3
1	Clear cutting	Timberjack 1270D	0.545	32.9	23.5
2	Clear cutting	Timberjack 1270D	1.067	46.5	33.2
3	Clear cutting	Ponsse Buffalo Dual	0.386	14.8	10.6
4	Clear cutting	Valmet Combi	0.469	14.1	10.1
5	Clear sanitary cutting	Sampo 1046 X	0.263	16.6	11.9
6	Selective sanitary cutting	Sampo 1046 X	0.289	10.7	7.6

Using the experimental data, the models of relationship between harvesting machines' productivity and work time expenditure with stem volume were made (Table 4). The determination coefficients (R^2) of all models were – 0.8-0.9 ($p<0.05$).

Table 4. Models for calculation of harvesting machines productivity and work time expenditures, calculated productivity in relation with stem size (V)

No of study areas	Cutting type	Harvesting machine	Models for calculation of harvesting machines' productivity per effective work hour (N) and work time expenditures (S)	Stem size. m^3				
				0.1	0.3	0.5	1.0	2.0
				Models based productivity per effective work hour, m^3/h				
1 2	Clear cutting Clear cutting	Timberjack 1270D-0610 Timberjack 1270D-0611	$S=0.0225 \times V^{(-0.5205)}$ $N=44.352 \times V^{0.5205}$ [V limits from 0.1 up to 2.0 m^3]	13.4	23.7	30.9	44.4	63.6
3	Clear cutting	Ponsse Buffalo Dual	$S=0.0324 \times V^{(-0.8048)}$ $N=30.856 \times V^{0.8048}$ [V limits from 0.05 up to 1.0 m^3]	4.8	11.7	17.7	30.9	
4	Clear cutting	Valmet Combi	$S=0.0411 \times V^{(-0.7857)}$ $N=24.32 \times V^{0.7857}$ [V limits from 0.02 up to 1.2 m^3]	4.0	9.4	14.1	24.3	
5	Clear sanitary cutting	Sampo 1046 X	$S=0.0251 \times V^{(-0.6946)}$ $N=39.81 \times V^{0.6946}$ [V limits from 0.02 up to 0.5 m^3]	8.0	17.3	24.6		
6	Selective sanitary cutting	Sampo 1046 X	$S=0.0375 \times V^{(-0.7804)}$ $N=26.68 \times V^{0.7804}$ [V limits from 0.02 up to 1.0 m^3]	4.4	10.4	15.5		

In the cases of equal stem size, the highest productivity reached Timberjack 1270D harvester (Table 4.). When the stem size increased from 0.1 to 2.0 m^3, the productivity of this harvester increased from 13.4 to 63.6 m^3/PMH$_0$ (Figure 1). Järvinen (2006) considers that when stem size is 0.193 m^3 these figures are about 13 percents higher in Finland. Timberjack 1270D harvester worked in clear cuttings where real stem size varied from 0.046 up to 2.93 m^3. The main factors decreasing harvester productivity were large branches and two tops of the tree.

The wood harvesting costs of Timberjack 1270D harvester ranged from 8.0 to 1.7 EUR/m^3 (stem size 0.1-2.0 m^3) in clear cutting (Figure 1). The biggest costs were calculated for cutting trees with low stem size. When stem size increased from 0.1 m^3 to 0.5 m^3 harvesting costs decreased more than twice.

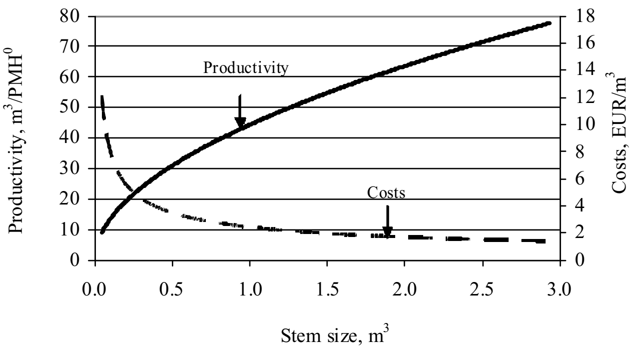

Figure 1. Influence of stem size on productivity and costs of Timberjack 1270 harvester

Productivity of Ponsse Buffalo Dual and Valmet Combi harwarders in clear cutting depended on stem size and varied from 4.0 to 30.9 m^3 per effective work hour when the stem size increased from 0.1 to 1.0 m^3 (Figure 2). The productivity of Ponsse Buffalo Dual and Valmet Combi harwarders was by 1.7-2.1 times lower then that of Timberjack 1270D harvester (when stem size 0.5 m^3). Productivity between Ponsse Buffalo Dual and Valmet Combi harwarders differed insignificantly. This difference can be explained by the unlike natural conditions and few operators (Figure 2). According to Siren and Aaltio (2003), productivity of harvester-forwarders is 8.2 m^3/hour including wood forwarding by distance of 250 meters (when stem size 0.264 m^3). Our study revealed the lower productivity cutting the trees of the same stem size: Ponsse Buffalo Dual – 10.6 m^3/hour, Valmet Combi - 8.5 m^3/hour but without wood forwarding.

The wood harvesting costs of Ponsse Buffalo Dual harwarded amounted to 20.2 -3.1 EUR/m^3 in clear cutting and that of Valmet Combi harwarder were equal to 29.9-4.9 EUR/m^3 (stem size 0.1-1.0 m^3) (Figure 2). The operational costs of Valmet Combi harwarder were higher but the productivity was lower than that of Ponsse Buffalo Dual harwarder. Therefore wood harvesting costs of Valmet Combi harwarder were by 50-60 percents higher than that of Ponsse Buffalo Dual harwarder.

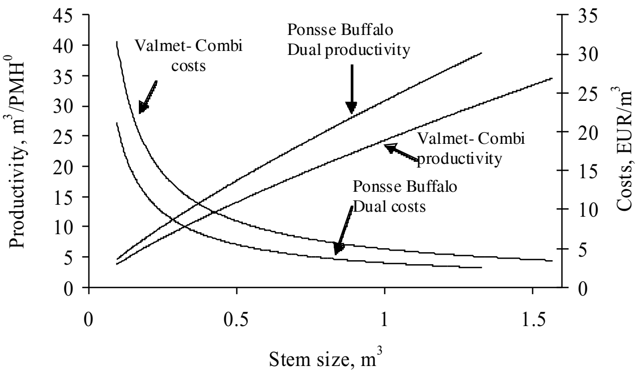

Figure 2. Influence of stem size on productivity and costs of harwarders

Sampo 1046X harvester reached the higher productivity than harwarders. However this machine worked in sanitary cuttings where no strip roads were performed, only few assortments were produced, also logging residues were left in piles.

Sampo 1046X harvester belongs to class I machines, so it cut only small stem size trees – up to 0.5 m^3. The productivity of Sampo 1046 X harvester varied from 8.0 to 24.6 m^3 per effective work hour in clear sanitary cutting and from 4.4-15.5 m^3 per effective work hour in selective sanitary cutting (stem size 0.1-0.5 m^3) (Figure 3). Productivity of Sampo 1046X harvester was 1.6-1.8 higher in clear sanitary cutting than in selective sanitary cutting because moving time was 2.5 times higher in the second one.

The wood harvesting costs of Sampo 1046X harvester amounted to 6.8-2.2 EUR/m^3 in clear sanitary

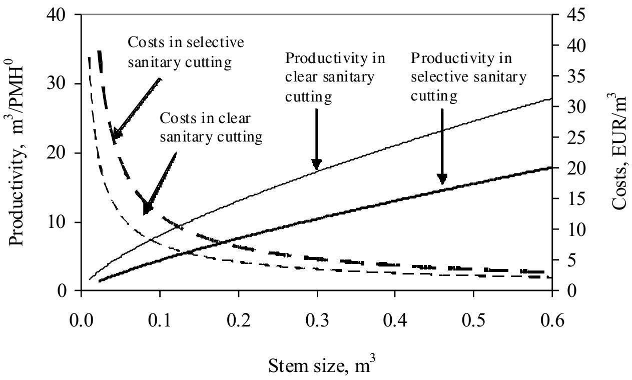

Figure 3. Influence of stem size and cutting type on productivity and costs of Sampo 1046X harvester

cutting and to 12.4-3.5 EUR/m^3 in selective sanitary cutting (stem size 0.1-0.5 m^3) (Figure 3). Sampo 1046X harvester had lowest costs when stem size was small, so in the stands where average tree stem size is up to 0.5 m^3, harvesters of class I can be recommended.

Timberjack 1270D harvester worked in a *Vaccinio-myrtillo Pinetum* forest type stands where only one tree species (pine) was cut. This factor can influence the bigger productivity of Timberjack 1270D harvester as compared with the other studied harvesting machines which worked in *Oxalido-Piceetum* forest type stand with two or three tree species. According to Nurminen *et al.* (2006), each new wood assortment bucked from a stem decreases the productivity by 1.5 to 4 % when stem size ranges from 0.3 to 0.8 m^3. This factor can explain the lower productivity revealed in our study in Lithuania as compared with the other studies. In our study the average number of wood assortments was 4 for all studied tree species in final fellings and 2 in sanitary cuttings. Nurminen *et al.* (2006), mentioned that the number of wood assortments for pine, spruce and birch is 2 in final felling and 1 in thinnings in Finland.

The productivity of cutting of pine and spruce is quite equal in final fellings when stem size varied from 0.3 to 0.8 m^3 (Nurminen *et al.* 2006). With larger stems the productivity of cutting pine stems become lower than spruce stems. The productivity of cutting birch stems is lower than cutting softwood.

Kärhä *et al.* (2004) states that the productivity of Sampo 1046X harvester in thinnings is 5.6-10.3 m^3/hour (stem size 0.05-0.10 m^3), 9.1-12.7 m^3/hour (stem size 0.10-0.15m^3), 18.7 m^3/hour (stem size 0.29 m^3). Our study revealed lower productivity. The reasons can be different cutting type, lower cutting intensity and an insufficient experience of operator.

The study revealed that Timberjack 1270D harvester reached the highest productivity between studied machines, however wood production costs in stands with small stem size (up to 0.5 m^3) can be lower when class I harvesters are used (*eg.* Sampo 1046 X). The productivity of harwarders was lower than that of harvesters; it was obvious that long machine reduces its mobility. Also the individual feature of operators can influence the results. Valmet Combi harwarder did not use the opportunity to bunch logs directly to the bunk.

Researches consider that the main advantages of harwarders are mostly related to time savings since some work elements are combined into the same working phase or working cycle (Asikainen 2004). Additional time and cost savings are achieved through reduced machine translocations between logging sites (Talbot *et al.* 2003, Asikainen 2004). Harwarders are more feasible to allocate to the cutting sites where either the removal per stand or per hectare is small.

Wood production costs were calculated doing presumption that all machines will work equal time per year. However, the annual amounts of wood production should be planned. If the annual harvested volume of the harvester-forwarder chain is less than 20000 m^3, harwarder concepts can compete better in economy (Väätäinen *et al.* 2006).

The harvesting machines can be seen as innovation in Lithuania. Only one or two operators work with the machine, the experience of operators is different. According to Siren and Altio (2003) the strong influence of the operator on the productivity and costs should be kept in mind when comparing the machine costs. Therefore study results are preliminary, but they indicate general possibilities to produce wood by harvesting machines.

Conclusions

1. The productivity of Timberjack 1270D harvester depended on stem size and ranged from 13.4 to 63.6 m^3 per effective work hour in clear cutting when the stem size increased from 0.1 to 2.0 m^3.
2. The productivity of Ponsse Buffalo Dual and Valmet Combi harwarders depended on stem size and varied from 4.0 to 30.9 m^3 per effective work hour in clear cutting when the stem size increased from 0.1 to 1.0 m^3. The productivity of harvester-forwarders was 1.7-2.1 times lower then that of Timberjack 1270D harvester (when stem size 0.5 m^3).
3. The productivity of Sampo 1046 X harvester varied from 8.0 to 24.6 m^3 per effective work hour in clear sanitary cutting and from 4.4-15.5 m^3 per effective work hour in selective sanitary cutting when the stem size increased from 0.1 to 0.5 m^3.
4. The wood harvesting costs of Timberjack 1270D harvester ranged from 8.0 to 1.7 EUR/m^3 (stem size 0.1-2.0 m^3) in clear cuttings and that of harwarders varied from 29.9 to 3.1 EUR/m^3 for (stem size 0.1-1.0 m^3). The wood harvesting costs of Sampo 1046X harvester amounted to 6.8–2.2 EUR/m^3 in clear sanitary cutting and to 12.4 -3.5EUR/m^3 (stem size 0.1-0.5 m^3) in selective sanitary cutting.
5. The biggest costs were calculated for harvesting trees with small stem size. When stem size increased from 0.1m^3 to 0.5 m^3 harvesting costs decreased more than twice.

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Received 03 June 2008
Accepted 06 November 2008

ПРОИЗВОДИТЕЛЬНОСТЬ ЛЕСОЗАГОТОВИТЕЛЬНЫХ МАШИН И ДЕНЕЖНЫЕ ЗАТРАТЫ НА МЕХАНИЗИРОВАНУЮ ЗАГОТОВКУ ДРЕВЕСИНЫ: ИССЛЕДОВАНИЕ СЛУЧАЯ В ЛИТВЕ

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Резюме

Объемы рубок леса лесозаготовительными машинами в Литве увеличиваются. В 2005 году в государственных лесах ими было заготовлено только 3,8 процентов древесины, а в 2006 году уже 12,2 процентов. Однако научные исследования производительности лесозаготовительных машин в условиях Литвы, а также денежных затрат на механизированую заготовку древесины до сих пор не выполнялись.

В статье анализируются производительность используемых в Литве лесозаготовительных машин и денежные затраты на механизированую заготовку древесины. Исследования затрат труда были проведены на шести обьектах. Наблюдались два харвестера и два харвестера-форвардера. Работа харвестеров снималась видеокамерой и изучалась методами хронометрирования.

В изучаемых объектах производительность лесозаготовительных машин изменялась от 10,7 до 46,5 м^3 за час оперативного времени. Разработаны модели зависимости производительности лесозаготовительных машин от среднего объема хлыста.

Денежные затраты на заготовку древесины харвестером Тимберджак 1270D в сплошных лесорубках составили от 8,0 до 1,7 EUR/м^3 (средний объем хлыста 0,1-2,0 м^3), а харвестером-форвардером от 29,9 до 3,1 EUR/м^3 (средний объем хлыста 0,1-1,0 м^3). В сплошных санитарных лесорубках денежные затраты на заготовку древесины харвестером Сампо 1046X составили от 6,8 до 2,2 EUR/м^3, а в выборочных санитарных от 12,4 до 3,5 EUR/м^3 (средний объем хлыста 0,1-1,0 м^3).

Ключевые слова: лесозаготовка, лесозаготовительные машины, производительность, денежные затраты, исследования затрат труда