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THE COST OF TIMBER HARVESTING WITH A HARVESTER IN STANDS UNDER REBUILDING WITH THE USE OF PARTIAL CUTTING

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Abstract: *The present research concerns the efficiency and economic effectiveness of timber harvesting by means of Silvatec Sleipner harvester. Measurements were taken in pine stands in the stage of rebuilding with the use of partial cutting related to improved gradual shelterwood cutting. In the course of harvesting, a constant time study was performed with the working day picture method. After the completion of felling, the volume of the harvested timber was measured.*
Timber harvesting efficiency was calculated in the operating time. Comparative calculations were also made of the cost of harvesting tasks with the use of a chain saw, which is a standard method in such stands. The level of utilization of the operating time of a shift, including wood processing, the time of preparing loads for skidding and of changes at work sites, was low and amounted to 0.62. The main categories of the operating time were debranching (45%) and travelling times (31%). Researchers approximated the equation of regression allowing for predicting the work efficiency of a harvester on the basis of the time of tree cutting. In the analyzed stands, slightly lower unit costs of work with the use of a harvester were noted, namely 3.97 €/m^3 for a 12-hour shift and 3.47 €/m^3 for a 16-hour shift, as compared to the work of a chain-saw operator: 4.02 €/m^3 for an 8-hour shift. Due to a low share of fixed costs in the costs of using a harvester in the analyzed stands, prolonging a shift affects the improvement of the economic effectiveness of the examined technology only to a small degree.

1. Introduction

Under the economic conditions of Polish forestry, the introduction of the machine system of timber harvesting encounters large obstacles. Such a status quo is due to numerous factors, among which is, above all, the relatively low cost of labour and insufficient financing of the enterprises which carry out commissions for the State Forests. According to Nurek (2005), about 95% of the tasks connected with tree cutting, debranching and bucking are performed with the use of chain saws. In the free market economy, one of the basic assessment criteria concerning the technological processes of timber harvesting is their economic effectiveness, expressed as the service price which, according to the Bill on State Commissions, is an essential criterion for settling the tenders for job performance in the public sector. Due to large competition on the Polish market of forest services, the use of work methods characterised by low unit costs is the largest advantage of timber harvesting enterprises. It is advisable to introduce more commonly the technology of timber harvesting on the machine- or half-automatic level of technology with the use of forwarders and multi-function equipment for tree cutting and processing. The use of this equipment is connected with a relatively small burden for the environment and with comfort at the work-stand (Giefing, 1994), which also justifies their more common implementation. Although the forest work sector in Poland is dominated by small enterprises with limited financial capabilities (Kocel,

2003) and with no highly efficient but very expensive timber harvesting equipment, still the number of harvesters has increased several times since 2000 and there are now about 170 of them (Sowa, 2009).

The aim of the present research was to determine the effectiveness and costs of timber harvesting by means of Silvatec 8266 TH Sleipner harvester. Measurements were performed in pine stands with fir undergrowth, rebuilt with the use of partial felling corresponding to improved gradual shelterwood felling.

2. Methods

2.1. Research area

The research was conducted in pine stands set up in the 1950s on former farmland. At present, stands of this type occur in southern Poland within the Regional Directorate of the State Forests in Cracow and Krosno and occupy the total area of about 19,000 ha; their stock amounts to almost 3.8 mln m^3. The measurements were taken in Gorlice Forest District, belonging to the Regional Directorate of the State Forests in Cracow. The analysed stands were maintained with the method of partial large-area felling IIa. It consists in the even thinning of a pine stand by means of single item cutting, performed in the regeneration period of about 20 years. Once the regeneration layer appeares, the next cuts which improve the access of the undergrowth to sunlight lead to the independence of the saplings following total stand clearing (Jaworski, 1990, 1994). In the stands described here one cutting was performed in the preparation period, which was followed by the introduction of fir on the whole experimental plot, leading to the formation of even-age and single-storey saplings. Snowbreaks which occurred in the research areas in 2003 caused pine stand thinning at some points. Broken trees were cut down and the timber harvested was skidded to timber storage yards at the felling sites via an irregular network of skidding trails following the existing gaps in the stand and the damage concentration spots. Increased access to light led to the spontaneous formation of fir regeneration, as a result of which in 2009 cutting was performed in the pine stand in the form of improved gradual shelterwood felling, using its advantages, such as: cutting flexibility consisting in the differentiation of the kind and method of cutting, depending on the degree of formation of fir regeneration, stand preparation connected with regeneration work done in the past and with the removal of snowbreaks as well as extending the work to the whole research area. Felling consisted in removing trees from the middle of the regeneration centres so as to obtain their off-centre extension along the E-W axis. The basic characteristics of the examined stands are presented in Table 1.

Table 1. Characteristics of research stands

Forest inspectorate	Forest district	Compartment	Forest area [ha]	Forest site type	Silvicultural stand type	Stand composition	Age [years]	Stocking of stand	Crown density	D.B.H. [cm]	Height [m]	Stand quality	Large timber [m^3/ha]	Mean tree volume [m^3]
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
Gorlice	Krzywa	26a	22,06	Mountain forest	Beech - Fir	Stand		0,7	Broken crown closure					
						9 pine	58			26	18	II	165	0,41
						1 beech	58			21	18	II	15	
						Under-growth								
						6 fir	18				1			
						1 beech	18				2			
						1 spruce	18				2			
						1 beech	33				7			
						1 fir	33				5			
Low quality pine trees (large-sized timber quality class: WC, WD) were characterised by wide crowns (diameter 6m); because they grew on a fertile site, in good light and low density, their system of branches was strong (mean width of knot 85 mm). Fir saplings of very good quality, with varied height (but not age) as part of regeneration centres														

2.2. The equipment used and the felling work system

The basic technical parameters of Silvatec Sleipner harvester, used in the present research, are presented in Table 2.

Table 2. General technical data of Silvatec 8266 TH Sleipner harvester

Weight	1700 kg
Dimensions: length / width / height	7,7 / 2,6 / 3,3 m
Turning radius	7,5 m
Crane …/reach	Loglift 220 V - 83 / 8.3 m
Engine	Mercedes OM 906 LA
Power of engine	205 kW / 278 HP at 2100 rpm.

The harvester travelled along skidding trails, which were partly determined during previous felling. These trails went in curved lines around the appearing fire regeneration centres. Their width was enlarged to about 3.5 m. Additionally, new trails were made along straight lines, dividing dense fir clusters. In this way, the harvester worked in the spatial system of trails like in the mixed stand availability model in the manual-machine and the half-automatic technologies (Rzadkowski, 2000).

The pine stand availability system, presented in Fig. 1, took advantage of small gaps in the stand, emphasized the outline of the formed regeneration centres, while the distance of maximum 20 m between the trails (which conditioned the width of regeneration clusters) allowed for the direct access of the cutting head to the butt-ends of the pine trees being felled. The trees were cut and debranched, and then segmented into logs 5 and 7 m long. In the process, the timber was partly sorted according to the lengths obtained.

2.3. Measurements and calculations

During the harvesting work, a time study was made for three full shifts of the harvester by means of PSION data recorders using TIMING software. The measurement precision amounted to 1s. The duration of particular activities, registered during the research, was ascribed to appropriate categories in accordance with BN-76/9195-01 in the National Forest Equipment System (Botwin, 1993; Laurow, 1994; Glazar and Wojtkowiak, 2009). The classification of the worktime and the adopted symbols are presented in Table 3.

Table 3. Worktime classification

Shift time in working area									
		Time of technical mainte-nance T_3	Operational time T_{02}						
			Auxiliary time T_2				Effective worktime T_1		
T_5	T_{42}	T_{31}	T_{21}	T_{22}	T_{221}	T_{23}	T_{11}	T_{12}	T_{121}
1	2	3	4	5	6	7	8	9	10
Time of rest	Time of removal of technical dfects	Time of daily servicing	Time of technical breaks	Travelling time	Time of walking in workplace	Time of forming the load for skidding	Time of cutting and felling	Time of debranching and bucking	Time of debranching and bucking by the chain saw operator

On completion of the above tasks, some of the logs were measured (the central diameter and the length). On the basis of the mean volume of a log 5 and 7 m long, calculated according to these data, the total volume of the timber harvested during a shift was obtained. In further calculations it was assumed that the economic effectiveness of the analysed work-stands would be best characterised by their unit costs (1), expressed in €/m^3.

$$K_j = \frac{K_e}{W} \qquad (1)$$

where K_j, K_e, W are unit costs, [€/m^3], costs of exploitation, [€/h], calculated productivity in operational time T_{02}, [m^3].

In the case of the harvester, work productivity was calculated for the empirical data from three shifts. The lack of significance of differences in the operational time structure noted on particular days was tested by means of analysis of variance. For the chain saw operator, productivity was adopted in accordance with the Catalogue of Forest Work Time Standards – the production of large-sized timber, over 24 cm thick, in the third degree of harvesting difficulty in upland and mountain areas (partial and shelterwood felling with the protection of saplings and seedlings at the altitude of 800 m.).

The harvester exploitation costs *Ke* (2) were calculated taking into account the costs of amortization, capital interest, fuel and grease, repairs and wages (formulas 3-7). In the case of the chain saw operator's work-stand, the costs considered were: amortization, repairs, wages (formulas 2, 6, 7) as well as fuel and grease (calculated on the basis of consumption standards (Suwała, 1998; Zychowicz, 1998; Suwała and Rzadkowski, 2001; Glazar and Wojtkowiak, 2009).

$$K_e = K_a + K_k + K_p + K_n + K_{p\text{ł}} \qquad (2)$$

where K_e, K_a, K_k, K_p, K_n, $K_{p\text{ł}}$ are cost of exploitation [€/h], cost of amortization [€/h], cost of capital interest [€/h], cost of fuel and grease, [€/h], cost of repairs [€/h], cost of wages [€/h].

The above components were calculated in the following way (3-7):

$$K_a = \frac{C_z}{T \times H} \qquad (3)$$

where C_z, T, H are purchase price of the machine [€], period of machine exploitation [years], time of exploitation in a year [h].

$$K_k = \frac{C_z \times k}{H} \qquad (4)$$

where k is capital interest rate [%], the remaining symbols as in (2).

$$K_p = (1+n) \times Z_p \times C_p \qquad (5)$$

where n, Z_p, C_p index of costs of oil and grease used, in relation to the costs of fuel used [%], fuel consumption [dm^3/h], fuel price [€/dm^3].

$$K_n = \frac{C_z \times i}{T \times H} \qquad (6)$$

where i is index of repair costs [%], the remaining symbols as in (2).

$$K_{p^3} = c \times (1+\beta) \qquad (7)$$

where c, β are net wage [€/h], index of overheads on wages [%].

The examined harvester was in the postamortization age. However, the assumption made in the calculations was that the machine used was new (Tab. 4).

Table 4. The numerical data assumed in the cost calculation

Items	Chain saw HQV 372XP	Silvatec Sleipner Harvester
Purchase price (*Cz*) [€]	855	195000
Exploitation period (*T*) [years]	2	8
Time of exploitation per year (*H*) [h]	2024	3036 (12h/shift) / 4048 (16h/shift)
Capital interest rate (*k*) [%]	-	13
Fuel cost (C_p) [€/dm^3]	1.03	0.91
Oil cost (C_o) [€/dm^3]	2.93	-
Fuel use (Z_p) [dm^3/h]	2,31	-
Oil use (Z_o) [dm^3/h]	1.2	-
Index of used oil and grease cost (*n*) [%]	-	12
Index of repair costs (*i*) [%]	20	100
Net wage (*c*) [€/h]	3.05	4.89
Index of overheads on wages (*β*) [€]	48	48

3. Results and discussion

On the basis of the assumptions made, the costs of exploitation of the equipment used in the analysed processes were: the chain saw – Ke = 5.36 €/h, the harvester – Ke = 40.72 €/h. The detailed structure of costs is presented in Tab. 5.

Table 5. Structure of hourly costs of the examined equipment

Cost item [€/h]	Chain saw	Silvatec	Silvatec

	HQV 372XP (shift 8h)	Sleipner Harvester (shift 12h)	Sleipner Harvester (shift 18h)
Amortization	0.21	8.02	5.35
Capital interest	-	4.17	2.78
Total of permanent costs	**0.21**	**12.19**	**8.13**
Fuel and grease	0.59	13.25	13.25
Repairs	0.04	8.03	5.35
Wages	4.51	7.24	7.24
Total of variable costs	**5.14**	**28.52**	**25.84**

The cost structure of the chain saw operator's work is dominated by variable costs, which constitute about 96% of the total costs. What follows, prolonging the shift is not going to result in considerable cost decrease for this job. For instance, work for 1.5 of a shift (12 hours a day) will lower the exploitation costs by about 2%, i.e. down to 5.27 €/h. The cost consumption in the case of timber harvesting by means of a harvester is different. The share of variable costs in the total exploitation costs increases from about 70% during a 12-hour shift to about 76% during shifts whose entire length is 18 hours. Working in a multiple-shift system brings a decrease of unit costs by about 17%, i.e. down to 33.97 €/h.
Figure 2 presents the structure of the total time of the harvester operator's shift in the analysed stands.

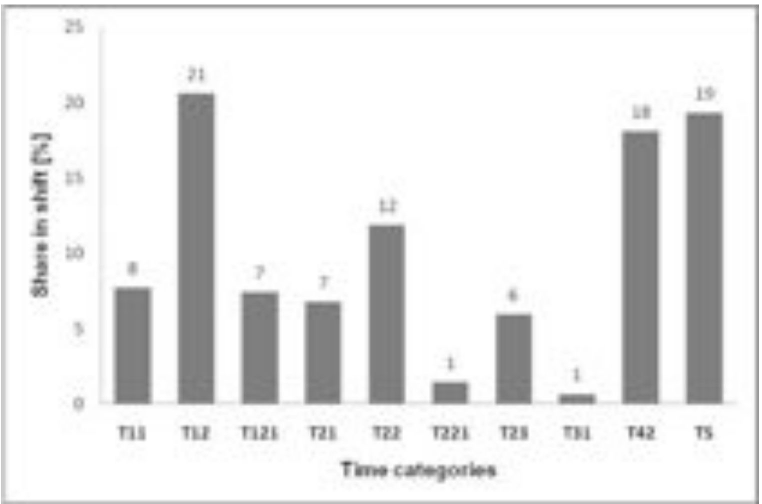

Figure 2. Structure of worktime

A surprising item among the categories of the times directly related to performing tasks is the debranching time T_{12}, whose share in a shift amounted to 21%. Such a high value corresponds to the long unit time of debranching, amounting to about 60 seconds/tree. This is over 30% more in comparison with the values noted by other researchers in stands similar in the volume of the harvested trees. In the present study, the average time of cutting and felling T_{11} was about 25 seconds/tree, which is a value more than 40% higher than the data given by other researchers for pine stands of similar age and volume. The share of travelling time T_{22} amounted to 12%, which does not fully reflect the long time of shift change in this job, which was 36 seconds. In comparison with the length of several seconds, observed for thinnings, this time is longer even by several hundreds per cent (Moskalik, 2004). The described regularities as well as a large share of the time of removing technical faults point to difficulties in the performance of the equipment in stands which are spatially and age differentiated.

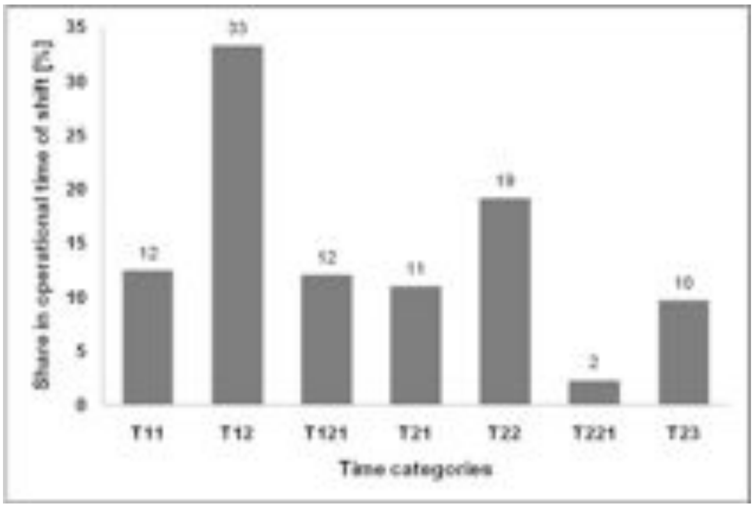

Figure 3. Structure of worktime in operational time

The structure of the operational time (Fig. 3) preserves the trends described above; however, due to excluding the obviously unstable times of service and breaks, it emphasizes the above regularities. The largest share in the operational time in the analysed stands was noted for the debranching time (T_{12}=33%) and, next, for the travelling time (T_{22}=19%).

The length of the time of debranching T_{12} of particular trees in three analysed shifts was characterised by a high level of variability (V%=0.92). Such high variability was related to problems with moving the head of the harvester along the side surfaces of richly branched trees during their debranching. Sometimes it was also necessary to gradually draw long timber from regeneration centres, which considerably prolonged the time of debranching. However, analysis of variance revealed a lack of statistically significant differences between the length of debranching times in the analysed shifts ($F=2.34$; $p=0.05$). That is why the researchers decided to consider jointly the measurement data from particular days.

The time of cutting and felling was definitely more stable: T_{11} (V%= 0.7), which allowed for approximating the equation describing the dependence of the harvested timber volume on the cutting and felling time (Fig. 4).

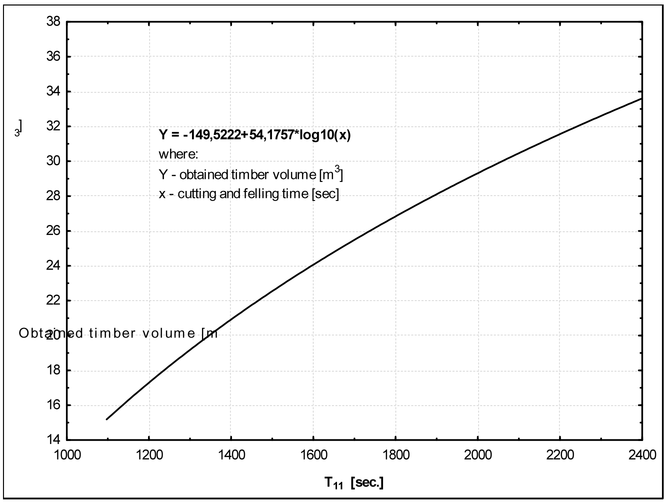

Figure 4. Dependence of obtained timber volume on cutting and felling time T_{11}

The effectiveness of the chain saw operator's work was determined, on the basis of the tabular data, on the level of 1.1 m^3/h of the operational time of work. The effectiveness of the harvester was calculated on the basis of a time study in field and amounted to 10.25 m^3/h of the operational time.

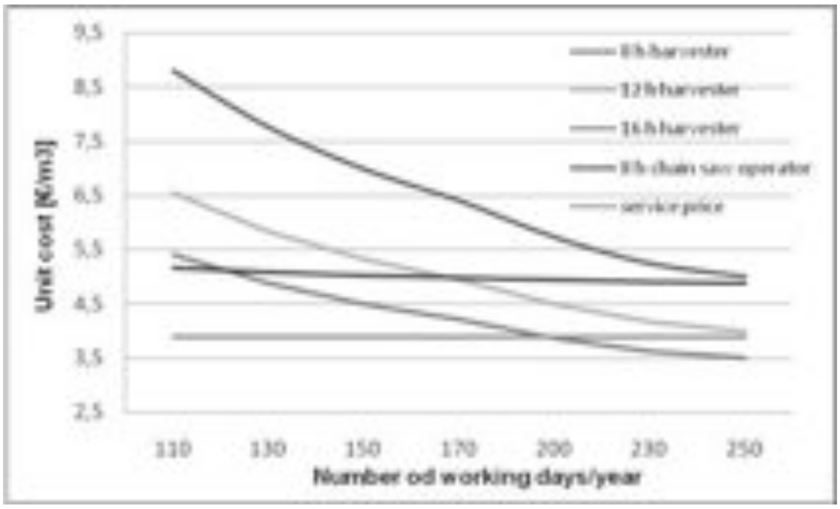

Figure 5. Unit cost of harvester's work

Figure 5 presents a simulation of unit costs of timber harvesting with the use of the harvester and by the chain saw operator in the analysed stands in relation to the number of hours of work during a working day as well as the number of working days/year. These costs are very diviersified; in the case of machine harvesting they range from 8.8 €/m^3 to 3.49 €/m^3, and in the case of the chain saw operator's work they amount to about 5 €/m^3. Prolonging the shift and increasing the number of working days/year significantly lowers the unit costs of machine timber harvesting. For example, in the analysed conditions, work in a two-shift system (16h) for 250 days/year causes a decrease in unit costs by about 150% in comparison with single-shift work (8h) for 110 days/year. Thus the effectiveness of applying these technical measures depends on such work arrangement which ensures the maximum use of the equipment. It must be noted that prolonging the working day, thanks to the possibility to better use the time of the shift, should allow for its better use and, what follows, one may expect a decrease in the costs of task performance even by several per cent (Nurek, 2008). As opposed to the situation described, there remains the manual-machine timber harvesting system (performed by the chain saw operator), where the unit costs are practically unchanged, irrespective of the prolongation of the shift. The current wage offered for timber harvesting (without skidding) by the State Forests is 3.88 €/m^3, and it does not depend on the harvesting technology used. As results from the data in Fig. …, the profitability threshold is defined by timber harvesting with the harvester, in two shifts, for at least about 200 days a year. Timber harvesting by the chain saw operator in in all cases uneconomical. As it is hard to assume a considerable increase in work effectiveness in the difficult conditions of harvesting in the mountains and in the stands which are differentiated as concerns their space and age, one ought to consider raising the prices for timer harvesting so as to obtain proper profitability.

Rational timber resource management in stands assumes the preservation of the main stand until it reaches the top current increment of volume. Afterwards, its role is limited to functions connected with the management of soil and of saplings which occur in the bottom stand layer. Free growth without a shield above accelerates volume increment whereas the presence of a shield above or of strong side pressure limit it. Site fertility is an important factor which causes an earlier culmination of current volume increment (Weck, 1955). In the analysed case, both the growth of pine trees as a forecrop in the open space and a fertile site should allow pine trees to achieve the peak of increment around the age of 50 years. Figure 6 presents the curve of changes in pine volume depending on tree age (Jaworski, 2004).

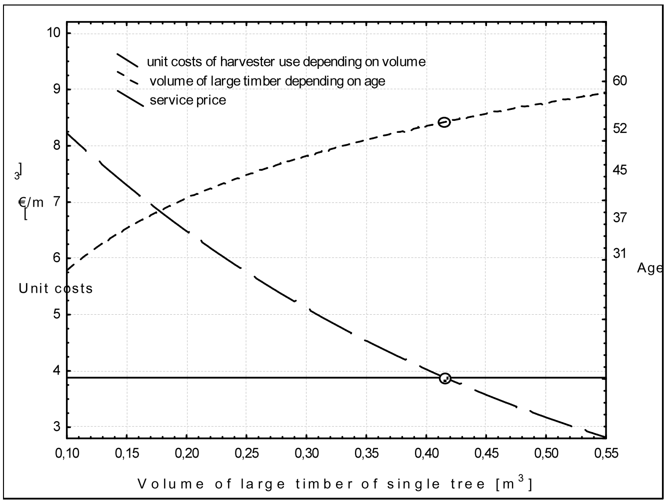

Figure 6: harvester profitability threshold

As the research shows, from the age of 50 years the volume increment is not as intensive as before. From this age, one can plan gradual removal of the top shield above fir saplings in a way described in the Methods, i.e. with the purpose of forming regeneration centres of fir. According to Moskalik (2004), the unit costs of timber harvesting with the use of a harvester in conditions similar to the ones in the present research decrease expotentially along with an increase in the volume of large timber of the harvested trees (Fig. …). Considering the current harvesting rate of 3.88 €/m^3, it is evident that profitability may be achieved above the large timber volume of 0.42 m^3 of a single tree. Such volume is reached by pine trees around the age of 53 years. From that age, machine harvesting of timber may be profitable. In the present study, cutting was 10 years late, due to which fir saplings had already reached the maximum height of 5 m. Consequently, it made the harvesting more difficult and affected a decrease in productivity. The above considerations may serve for the determination of auxiliary values of felling ages, indispensable for the rational performance of forest management tasks in stands.

4. Conclusions

1. Hourly costs of the use of the harvester in the analysed stands amounted to about 40 €. The variable costs were dominant. The share of the variable costs in relation to the permanent ones increased together with increasing the number of working hours in a year.
2. Due to a low share of the permanent costs in the costs of harvester exploitation, prolonging a shift affected an improvement in the economic effectiveness of the analysed technology only to a small degree.
3. The unit costs of the harvester and the chain saw operator are considerably differentiated; ranging from 8.8 €/m^3 to 3.49 €/m^3 in the case of machine timber harvesting, and amounting to about 5 €/m^3 in the case of work in the manual-machine system.
4. Prolonging a shift and increasing the number of working days/year results in significant lowering of unit costs of machine timber harvesting. Under the analysed conditions, work in two shifts (16h) for 250 days/year is going to lower the unit costs by about 150% in comparison with work in a single shift (8h) for 110 days/year.
5. Considering the current harvesting rate of 3.88 €/m^3, the profitability threshold for timber harvesting with the use of the harvester in the analysed stands was determined as two-shift work for about 200 days/year, for large timber volume above 0.42 m^3 of a single tree, i.e. the age of a pine stand of about 53 years.
6. When planning forest management tasks, one should take into consideration the profitability of practicable technological solutions, particularly the profitability threshold of timber harvesting, determined by stand age.

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