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Comparison of harvester and motor-manual logging in intermediate cuttings of deciduous stands

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Abstract: Recently, new models of operational harvester heads that are suitable for work in deciduous forests and are able to process hooked trees or trees originated from stump shots have been designed. A mechanized harvesting method (harvester with head) is compared with conventional motor-manual harvesting methods in which a chain saw is used for felling, trimming, and crosscutting. Species composition of the sample stand was as follows: 58% aspen (*Populus tremula*), 19% lime (*Tilia platyphyllos*), 22% birch (*Betula verrucosa*), and 1% oak (*Quercus robur*). The study was completed under the aegis of the project of the 6th General Program of the EC. The labor efficiency was estimated using a time study method. Compared with common motor-manual harvesting, a UTC harvester with a CTL 40 HW head reduces the production time by about 70%. Depending on the number of timber assortments made per tree, operation of the harvester was from 1.7 to 3 times more efficient than chain saw operation.

Key words: Hardwood, harvester, harvester head, wood harvesting technology

Introduction

Conditions are favorable for the growth of trees in the Baltic States and so the diversity of tree species is high. The soils tend to be deep and rich, and the humidity allows the trees to develop high volumes of timber. For forest operations, however, the conditions are difficult and requirements for precision and quality of assortments are high. Low impact on forest soil is one of the main environmental requirements, but, at the same time, powerful and heavy machines are needed to process large stems. Soil compaction caused by heavy tires reduces water infiltration, root development, and yield, while increasing bulk density, penetration resistance, and soil strength (Aksakal and Öztaş 2010; Aksakal et al. 2011). Forest machines can move over forest soils without any risk only when the soil is extremely stony. Unlike in Scandinavian locations, this is not the case in Lithuania. For most soils, the danger that the soil will lose its trafficability increases when the moisture in the soil at the moment of traffic is high (Horn et al. 2007). The risk that a specific soil will lose its trafficability in wet weather conditions is also high (Duszyński and Walczyk 2009). The moisture in the forest soils depends on the difference between rainfall and water loss through transpiration, drainage, etc. (Attarod et al. 2011). During the winter and periods of longer rainfalls, the risk increases that forest soils will lose their trafficability, especially in heavy soils with slow drainage and low transpiration.

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The ratio of mechanized to manual work depends highly on the economic characteristics of different countries, including labor costs, the availability of a labor force, and, generally, on income level. National legislation on soil protection differs widely across Europe. The regulations of forest certification systems (FSC, PEFC) are applied differently as well (Erler 2007).

Various technologies and machinery, such as chain saws, harvesters, harwarders, forwarders, and trailers with cranes, are used for wood production in Baltic State forests (Muiste et al. 2006). There is a lack of economic analysis on the costs of various wood production technologies (Mizaras et al. 2000). Nurminen et al. (2006) suggested that the time consumption and productivity of harvesting are dependent on stand conditions, the operators' skills, working techniques, and the characteristics of the forestry machinery. According to Demir (2010), it is important to consider long-term harvesting plans that require mechanization so that total harvesting cost can be reduced in the long term.

It should be noted that level of non-clear cutting in state owned forests in Lithuania is constantly increasing. Forecasts (Mizaras et al. 2009) show that the amount of non-clear cutting will increase in the future and will reach 20% of the final cuts in forests of group II and at least 50% in forests of group III (Figure 1). In private forests, this ratio is hard to define due to the lack of reliable statistical data.

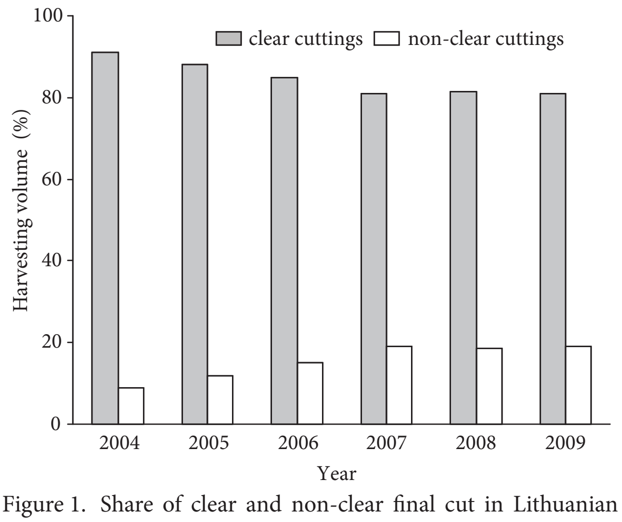

Figure 1. Share of clear and non-clear final cut in Lithuanian state forests.

The cost of mechanized harvesting in stands with low average volume is lower by 20%-30% than the traditional technique in which chain saws are used (Bacher-Winterhalter 2004). According to Ohrner (1999), the productivity of the harvesting machinery when harvesting trees with a stem volume of 0.2 m^3 is approximately 8-10 m^3 h^{-1}, or 8-10 times greater than when the trees are harvested with chain saws. It has also been noted that the efficiency of the harvester is more closely related to the volume of the felled trees compared to the efficiency of the motor-manual method.

On the other hand, the bigger the average stem volume, the higher the underbrush, and the fewer trees that are felled per unit of area, the more acceptable is the motor-manual harvesting technique (Dummel and Forbrig 1992). When the motor-manual method is used, the timber can be crosscut better, thereby separating more valuable assortments, but in this case the labor costs usually increase.

The frequency of damage to the remaining trees mostly depends on the characteristics of the harvesting machinery, the distance between the strip roads, the rapidity of tree felling, the timber extraction method, the number of felled trees per unit of area, and the topographical situation (Butora and Schwager 1986; Bacher 1999; Acar and Dinç 2001).

Development of machine-based harvesting in Lithuania shows that mostly versatile harvesters of average size, which can be used in different conditions, are being introduced. However, the characteristics of these machines are considerably different. They can be divided into versatile larger, versatile medium, and versatile smaller types. Along with traditional harvesters, 11 excavator-based harvesters, which can be considered medium type harvesters, are being used for forest harvesting in Lithuania. Combi and Dual types of harvester-forwarders can be also considered medium type if they are used only for harvesting (Table 1).

The latest development of harvester heads enables the use of the multi-operational harvesters in deciduous stands with small and medium stem volume. Investigation shows that it is possible to process the curved trees and large branches within the quality requirements (Guglhör 1994; Gabriel 1996).

Table 1. Development of forest harvester use in the Lithuanian forest sector.

Producer	Year						Total	Type [1]		
	2004	2005	2006	2007	2008	2009		L/V	M/V	S
John Deere (Timberjack)	1	1	1	2	4	-	9	7	1	1
Valmet	1	1	4	3	2	2	13	12	1[2]	-
Ponsse	-	2	-	3	2	-	7	2	1+4[3]	-
New Holland Kobelco	-	1	4	4	2	-	11	-	11[4]	-
Logset	-	-	-	2	1	-	3	3	-	-
HSM	-	-	2	-	-	-	2	2	-	-
Sampo Rosenlew	-	-	-	1	2+1[5]	-	3+1[5]	-	1	3
Pinox	-	-	-	1	-	-	1	1	-	-
Total number delivered	2	5	11	16	13+1	2	50 (49+1)	27	19 (15+4)	4
Total number of machines used	2	7	18	34	47+1	49+1				

[1] types of harvesters: L/V - larger versatile harvester for final cut, suitable for late commercial thinning
M/V - medium versatile harvester for small-scale final cut and thinning
S - small harvester for thinning

[2] “Combi” type

[3] “Dual” type

[4] excavator-based harvester

[5] detachable harvester

Pausch (2002) suggests that the optimum processing capacity of the harvester can be reached when cutting conifers with a solid volume around l m^3. When the tree volume is less than 0.2 m^3 solid, the productivity of the harvester is significantly reduced. For example, when trees with an average diameter of 14 cm diameter at breast height (DBH) are cut, the productivity of the harvester is only 5 m^3 h^{-1}, but when the average diameter of trees in the stand is 34 cm DBH, the productivity increases by 5 times up to 25 m^3 h^{-1}.

Forbrig (2000) maintains that the productivity of the harvesters mostly depends on the tree type and volume, the terrain, and the machine operator. It has been determined that the operator’s skills have a great impact on the productivity of the harvester and it can vary from 20% to 50% (Glöde 1999). Heinimann (1998) states that the productivity of the multi-operational harvester also depends on the machine type, the number of felled trees per unit of area, and the list of assortments prepared.

Brunberg (1997) thinks that the time needed to drive from one tree to another depends on the maximum reach of boom, the density of the stand, the harvester speed, and the terrain. Stampfer (2001) states that the forward movement of the harvester mostly depends on the slope fall and stand density. Beyer and Schieck (2001) have not stated the greater influence of the operator on the forward movement of the harvester (unpublished data). Some investigators think that the duration of the processing cycle depends on the tree species, the position of the harvester on the strip road, and the number of the trees cut per unit of area. In the special case of a combined harvesting method, in which both harvesters and chain saws are used, the duration of the harvesting process is also influenced by the number of trees felled by chain saw (Brunberg 1997; Stampfer 2001). Pausch and Ponitz

(2002) have stated that the working efficiency of the multi-operational harvester depends on the average distance covered by a machine in order to reach each tree, the number of assortments made per tree, and the height and foliage of the undergrowth.

This study, done under the aegis of the project of the 6th General Program of the EC, showed that motor-manual logging methods prevailed in Lithuania and other neighboring countries. Forest soil protection restrictions for logging are included in the laws of Austria, Lithuania, Poland, Hungary, and Germany. Logging includes a strip road system in the cutting areas only in Lithuania and Germany. The main problems are logging in wet deciduous forest stands and extracting big diameter logs (Steponavičius and Zinkevičius 2010). The goal of this study was to compare the efficiency of mechanized and motor-manual harvesting technologies in intermediate cuttings of deciduous stands.

Materials and methods

The investigation object is timber harvesting technologies in intermediate cuttings of deciduous stands in Lithuania. A mechanized logging method using a UTC harvester and CTL 40 HW head is compared with a traditional motor-manual method in cut-to-length logging (CTL). The UTC harvester was driven by a 24-year-old operator with 3 years of harvesting experience. The specific features of the CTL 40 HW harvester head (designed for hardwood) are presented in Figure 2.

The harvester head is able to cope with bending trees because there is only one pair of knives and a flexible top knife. It has a hydraulic system that is optimized for cutting thick and steeply rising branches. The saw does not tend to jump out of the bar while cutting multiple trees as much as standard heads are known to do.

The field research was carried out in a deciduous stand in the Dotnuva forest district of the Kėdainiai state forest enterprise. The composition of tree species in the sample stand was as follows: 58% aspen, 19% lime, 22% birch, and 1% oak. The full characteristics of the sample stand are provided in Table 2. For cutting and processing of trees, a 2-month-old Husqvarna 365 chain saw was used. The length of the chain bar was 45 cm (18”), and the type of the chain was H-42 (7/32”, 5.5). The chain saw was operated by a 23-year-old logger with 1.5 years of experience.

A time study method was used to determine productivity. A chronometer with a precision of 0.01666 s was used. Time consumption for the

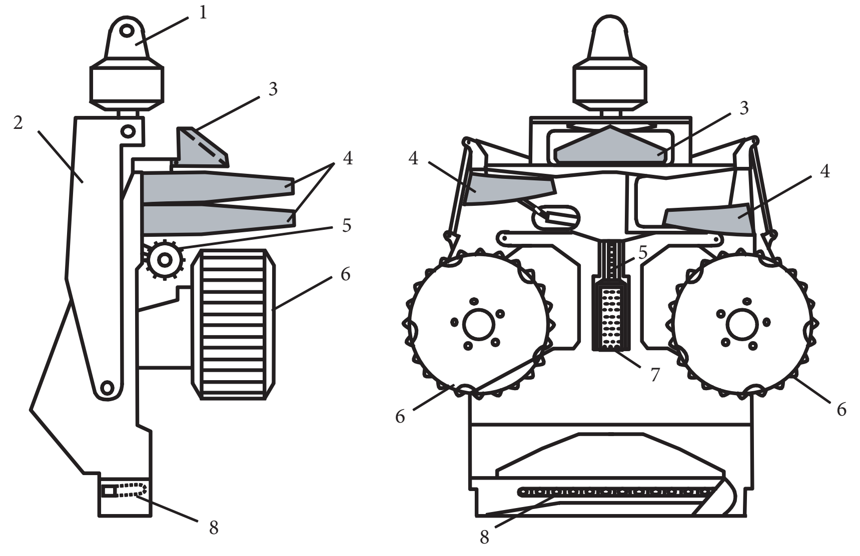

Figure 2. The CTL 40 HW harvester head: 1, hanger; 2, frame; 3, flexible top knife; 4, pair of flexible side knives; 5, wheel to measure the tree’s length; 6, pair of tree-pulling rolls; 7, tree-pulling wheel; 8, chain saw.

Table 2. The characteristics of the research area and conditions.

Location	Lithuania, State Forest Enterprise Near Kėdainiai city 55°22′54″N; 23°48′04″E
Size of operation	6.7 ha
Weather	Dry and sunny, temperatures close to 0 °C in the morning, later up to 20 °C
Soil	Type of soil: *Pseudogley* Volume of stones: <20% Depth of soil: 80 cm
Forest stand	Tree species: 58% aspen, 22% birch, 19% lime, 1% oak Basal area of remaining trees: 21.3 m^2 ha^{-1} Mean diameter of remaining trees: 11.9 cm Mean height of remaining trees $h_{g:}$ 12.6 m Basal area of cut trees: 4.8 m^2 ha^{-1} Mean diameter of cut trees: 10.3 cm Mean height of cut trees $h_{g:}$ 12.3 m
Harvesting method	Cut-to-length, thinning (distance between skid roads 24 m)

preparation of technological operations and for the main operations (felling, trimming, cross-cutting), and also for other miscellaneous operations (repairing the chain saw, refueling, resting) was registered. In addition, the amount of time it took for a helping worker to take away piles of the shortwood and clear the area by moving tree branches to the strip road was registered.

For evaluation of productivity, the number of shortwood pieces cut per tree was used instead of tree volume, because the variation in the volume of the trees in the cutting area was small. In this case, the number of shortwood pieces cut per tree can be regarded as an important factor influencing the productivity of harvesting.

Statistical analysis

Experimental data were processed according to statistical methods. The average values of the data and their confidence intervals ($P = 0.05$) are presented. In order to establish correlation between 2 factors, the correlation coefficient R^2 was calculated. The correlation of 2 factors was established according to Fisher criteria. In order to establish the direction and size of the factor correlation, regression equations were made.

Results

The number of timber assortments made from one stem was from 1 to 7. From all the trees harvested during the test period, 319 pieces of shortwood were cut using the multi-operational harvester and 224 pieces were cut using a chain saw. The average duration of a whole cycle of the multi-operational harvester was 55.5 ± 14.5 s (Figure 3) and for the chain saw it was 154.8 ± 63.7 s. When the trees were cut into 2 shortwood pieces of 3 m length using the multi-operational harvester, the full cycle lasted for 42.2 ± 4.5 s, and when the trees were cut into 6 shortwood pieces of the same length it took 73.9 ± 13.6 s (Figure 3). The obtained results correspond with those described by Väätäinen et al. (2006), who state that the efficiency of harvesting depends on the number of shortwood pieces cut per tree. When the chain saw was used for tree cutting, the full cycle lasted for 83.0 ± 8.2 s for 2 shortwood pieces and 237.6 ± 23.5 s for 6 shortwood pieces. It has been determined that tree processing when a multi-operational harvester was used was 2.7 ± 0.7 times faster than when done motor-manually. Furthermore, when more shortwood pieces were cut from one tree (i.e. when a taller tree was cut) the advantage of the multi-operational harvester increased when compared with using a chain saw.

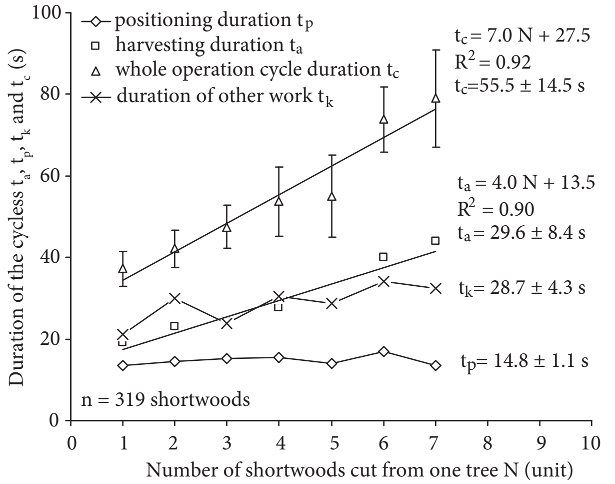

Figure 3. Relationship between the operation cycle duration (s) when using a multi-operational harvester to the number of shortwood pieces cut per tree (N): t_c: duration of the whole operation cycle; t_a: harvesting duration (tree felling, branch limbing, and cutting into shortwood pieces); t_p: positioning duration; t_k: duration of other operations.

The ratio Δt_c of the duration of the full operation cycle can be used for efficiency comparison of both tree harvesting methods. This ratio is the duration of the operation cycle of the chain saw divided by the duration of the operation cycle using the multi-operational harvester, and demonstrates how many times more quickly work is done with the multi-operational harvester comparing to motor-manual work. The ratio Δt_c was 1.7 when trees were cut into 2 shortwood pieces of 3 m length, and it was 3.0 when the trees were cut into 6 shortwood pieces of the same length. This means that, depending on the number of shortwood assortments made per tree, work with the harvester was 1.7 to 3 times more efficient than when trees were cut and limbed with a chain saw.

More time is needed (from 19.1 ± 2.8 s when one shortwood piece is cut to 40.0 ± 9.0 s when 6 shortwood pieces are cut) when a multi-operational harvester is used to cut more shortwood pieces per tree (i.e. to fell the tree, limb the branches, and cut shortwood from the stem) (Figure 3), but the fraction of the time (t_a, %) used for the main operation increases only insignificantly. Accordingly, when one shortwood piece is cut, the duration of the main operation t_a is only 51.4%, and when 6 shortwood pieces are cut, it is 54.1% (Figure 4).

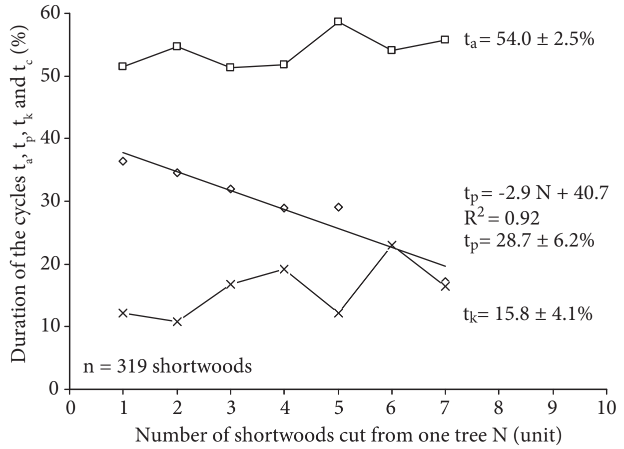

Figure 4. Relationship between the operation cycle duration (%) when using a multi-operational harvester to the number of shortwood pieces (N) cut per tree.

When trees were cut with a chain saw, the time used for the main operation t_a in relation to the number of shortwood pieces made per tree increased linearly ($R^2 = 0.95$) (Figure 5). The time consumption for fulfillment of the main operation of cutting 1-6 shortwood pieces varied by 3.5 times (Figure 5), and was equal to 73.7% and 85.1%, respectively, in relation to the whole operation cycle time (Figure 6).

Positioning duration t_p when trees were cut with a multi-operational harvester did not depend on the number of shortwood assortments and was almost constant at 14.8 ± 1.1 s (Figure 3). However, when

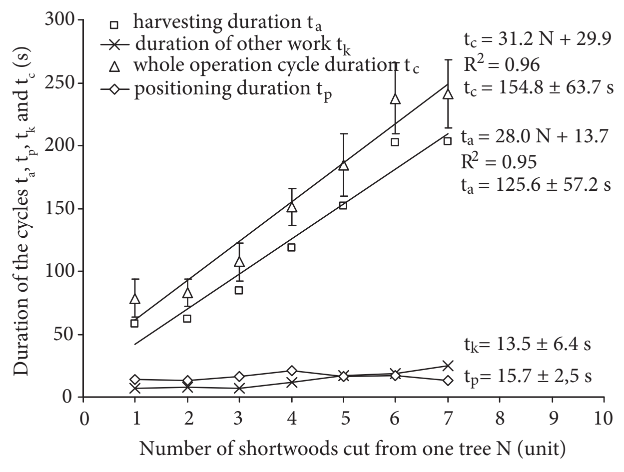

Figure 5. Relationship between the operation cycle duration (s) when using a chain saw to the number of shortwood pieces (N) cut per tree.

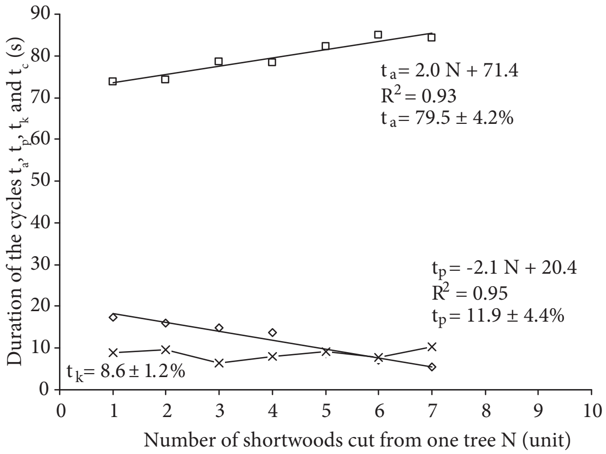

Figure 6. Relationship between the operation cycle duration (%) when using a chain saw to the number of shortwood pieces (N) cut per tree.

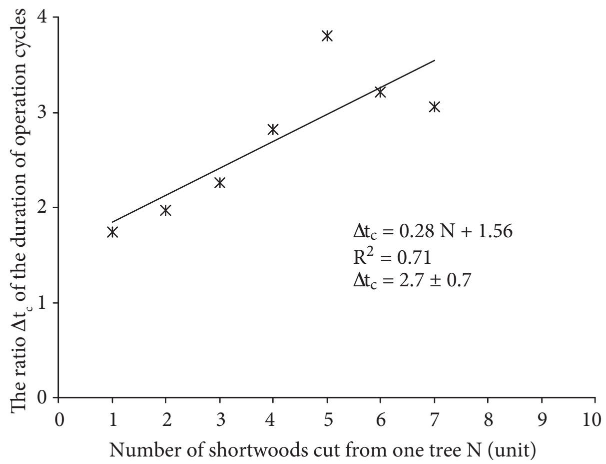

Figure 7. The ratio Δt_c (duration of the whole chain saw operation cycle divided by the duration of the whole multi-operational harvester operation cycle) in relation to the number of shortwood pieces (N) cut per tree.

the number of shortwood pieces was increased (taller trees were cut) the time needed for positioning could be significantly reduced when estimating the time needed for 1 piece of shortwood. When only 1 piece of shortwood was cut from a tree, this time duration was 36.4% of the whole operation cycle duration t_c, and when 7 shortwood pieces were cut it decreased to 17.2% (Figure 4). A similar change of the positioning duration t_p was noted when trees were cut with a chain saw (Figures 5-7).

The whole operation cycle duration t_c comprised not only the duration of the main operation t_a and positioning duration t_p, but also the time needed for equipment adjustment, maintenance, repair, etc. This time is called the duration of other time t_k. The tests showed that the duration of other time t_k was barely affected by the number of shortwood assortments made per tree in either of the tested timber harvesting methods. Its numerical value when working with a multi-operational harvester varied from 21.2 s (when 1 piece of shortwood was cut) up to 32.5 s (when 7 pieces of shortwood were cut), i.e. on average the other work lasted for 28.7 ± 4.3 s (Figure 3). This comprised 12.1% and 16.5%, respectively (Figure 4).

After the analysis of the operation cycle duration of both timber harvesting cases was completed, it was determined that the greatest fraction of the time was spent on the main operation, at 54.0 ± 2.5% for working with a multi-operational head and 79.5 ± 4.2% when working with chain saw (Figure 8). When working with a multi-operational harvester, the duration of time spent for positioning t_p was equal

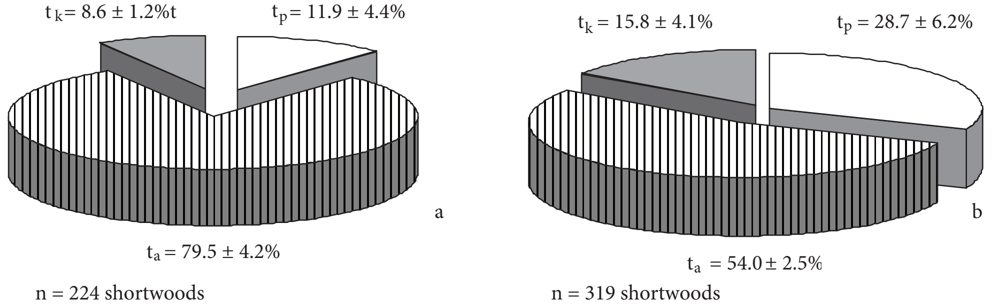

Figure 8. Structure of the operation cycle duration (%) when working with a chain saw (a) and a multi-operational harvester (b). t_a: harvesting duration (tree cutting, branch limbing, and cutting into shortwood pieces); t_p: positioning duration; t_k: duration of other operations.

to half of the main operation t_a duration, or 28.7 ± 6.2%. Working with the chain saw, the positioning duration comprised only 1/6 of the duration of the main operation t_a, or 11.9 ± 4.4% of the whole operation cycle. The remaining fraction of the operation cycle duration (8.6 ± 1.2%) was used for the accomplishment of other work (t_k).

Compared with motor-manual harvesting, which is common under these difficult conditions, the UTC harvester with the CTL 40 HW head reduces the production time by about 70%. The processing capacity of the harvester head is 7.79 m^3 h^{-1} while the motor-manual harvesting capacity is 2.74 m^3 h^{-1}. It shows that in intermediate cuttings of deciduous stands, the harvesting productivity of a UTC machine with a CTL 40 HW head is almost 3 times higher compared to motor-manual operations.

Felled trees were cut into shortwood pieces 3 m in length. Before cutting each shortwood, the chain saw operator measured its length using a measuring tape. The actual shortwood lengths were estimated by measuring each of 224 assortments using a measuring tape. The length of about 1/3 of the cut shortwood specimens was either greater than or less than the predetermined measure (3.00 m) by more than 2 cm. The dispersion of the shortwood length was similar to the curve of the normal distribution law (Figure 9). The results obtained with the multi-operational harvester (Figure 10) correspond with those described by Mederski et al. (2008).

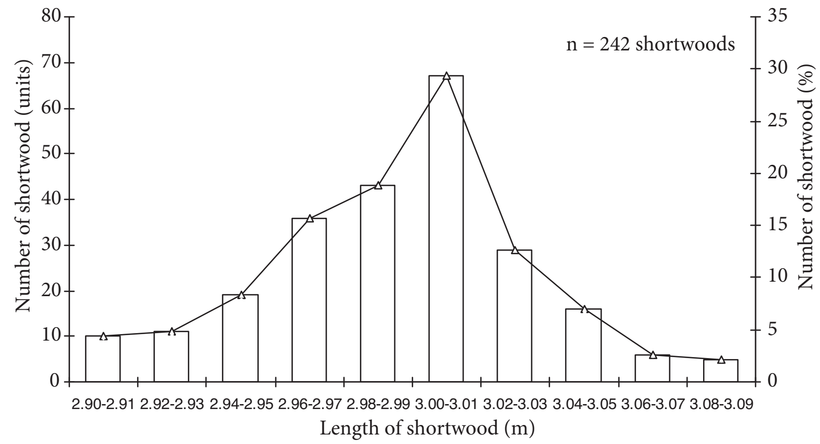

Figure 9. The distribution of shortwood length when cut by a chain saw operator and prepared by a helper. The average length of the shortwood was 2.99 ± 0.05 m.

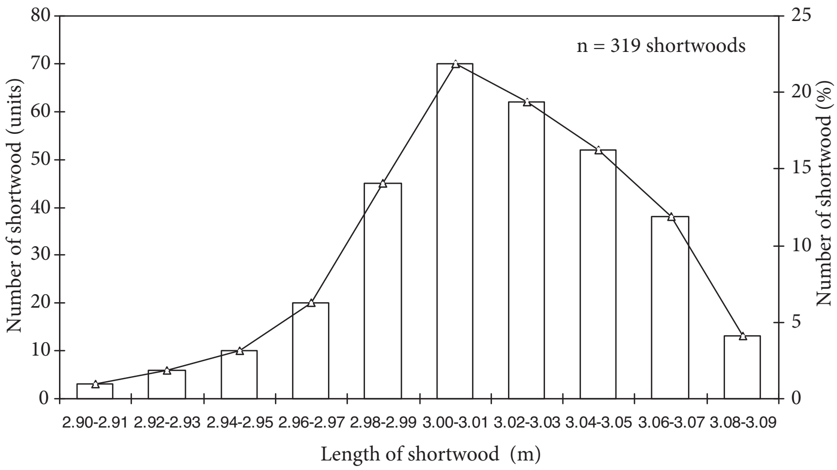

Figure 10. The distribution of shortwood length when cut by multi-operational harvester. The average length of the shortwood was 3.02 ± 0.04 m.

Their results showed that 16% of the logs harvested with a CTL 40 HW harvester head were accurately cut at 3 m, while 29% were shorter and 55% were longer.

Discussion

The duration of operation cycle obtained in this study (Figure 8) can be compared to the results of other authors. Mizaras et al. (2009) found that with a big harvester in mature pine stands, the main operation t_a comprises 73.7% of the total time, the positioning duration t_p is 6.7% and the duration of other operations t_k is 19.6% (Figure 11). However, the conditions of the stands and characteristics of the harvesters in the 2 studies were not identical. Ideally, both the stands and the technological conditions of the time studies should be as similar as possible to make the results comparable.

The productivity of the harvester measured in this study reached 7.79 $m^3 h^{-1}$. This number falls into a range of productivity for the same CTL 40 HW harvester head provided by other authors. Erler (2007) gave the range of productivity as 4.9 to 16.4 $m^3 h^{-1}$ for the CTL 40 HW head, depending on the mean stem volume. The average tree size is the main factor limiting the productivity of harvesters. Pausch (2002) states that for trees with a diameter of 14 cm, the productivity reaches only 5 $m^3 h^{-1}$. Other characteristics of stands, such as species composition, are also significant (Mizaras et al. 2009).

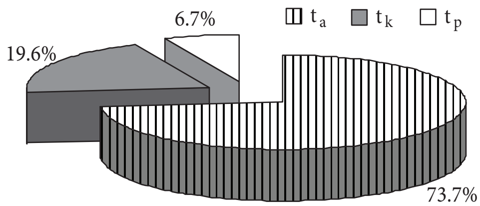

Figure 11. Structure of the operation cycle duration (%), working with multi-operational harvester: t_a – harvesting duration (the tree cutting, branch limbing, and cutting into shortwoods); t_p – positioning duration; t_k – duration of other operations (Mizaras et al. 2009).

The difference in the productivity of a harvester compared to a chain saw was 70%. Other research (Wöll and Jónsson 2009) shows that the difference is usually from 1.5 to 3 times when thinning depending on the average tree size.

Pruning in this study was easy and there were no special problems or complications observed during this process. This can be explained by the relatively small size of the trees, as the research was done when thinning. Consequently, the thicknesses of the branches were not measured. However, according to other studies (Mizaras et al. 2009), a lot of pruning time is wasted if the trees have large branches. Brunberg and Westerlund (1994) found that the Timberjack 1270/762B and Valmet 911/960 harvesters have pruning problems if the diameter of the pine branches is larger than 7.0 cm and 7.2 cm, respectively. In birch and aspen stands, the performance of the harvesters depends on the number and size of the branches. The pruning quality is acceptable only in the case of branches with a small diameter. If trees with multiple tops or large branches prevail in the stand, it is recommended to use chain saws or to combine machine-based harvesting with production of wood chips (Mizaras et al. 2009).

Conclusions

Our study shows that the UTC harvester with the CTL 40 HW head reduces the production time by about 70% compared to motor-manual harvesting, which is common under the conditions of the sample stand. The accuracy of the shortwood cutting by a motor-manual operator was more precise compared to using the CTL 40 HW harvester head. The deviation of assortment length was greater than 2 cm in 1/3 of the cases for motor-manual harvesting, and in 1/2 of the cases for mechanized harvesting.

Acknowledgements

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