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EFFECTS OF INNOVATIVE THINNING OPERATION IN A BIRCH STAND

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Abstract. Cut-to-length technology for broadleaved species is a novelty in forest operations, also causing various difficulties. The purpose of the study was to find effects of an application of the CTL 40HW head[1] for broadleaves mounted on the UTC 150-6LS harvester used in a thinning operation in a birch stand in northern Poland. For this, productivity, the level of damage in the remaining stand and soil disturbances were analysed. The results present a satisfactory outcome: the average productivity was 13.4 $m^3 \cdot h^{-1}$ (h of operational time). Analysis of the remaining stand showed 4-7% trees with damage. Analysis of the soil on the harvester strip roads showed a bulk density increase of 0.16--0.21 $g \cdot cm^{-3}$. It was also observed that there was lower mean soil moisture after harvesting, though this change was not statistically confirmed. The biggest soil penetration resistance increase was observed after two machine drives: 50% on 30 cm of depth and after a single drive 45% on 10 cm of depth.

Key words: harvester, broadleaves, thinning, productivity, stand damage, soil damage

INTRODUCTION

The development of mechanised forest operations in terms of harvesters has a history going back to the 1950s [Drushka and Konttinen 1997]. The first forwarders of the MacCall prototype, Mark II, III and IV Bonnard Prehauler were constructed between 1951-1955 in Canada [Silversides 1988]; the first harvester was built in 1959 by Tom Bush from Louisiana, USA [Samset 1992]. However, the first equipment acting as a harvester and mounted on a trawler tractor was first designed by John Pope of Hay River

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[1] The CTL 40HW harvester head was developed in ForstInno project: Development of an ecologically compatible, highly productive method of timber harvesting for Central European forestry – COOP-CT-2005-512681; supported by EC in 6 Research Framework Programme.

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in 1955 in Canada [Murphy et al. 2002]. This idea was turned into a prototype with a high performance in delimbing, but never went beyond this point [Murphy et al. 2002].

Nowadays harvesters play an important role in North America, and some European countries, especially in Scandinavia. In Central Europe though, broadleaves are well represented and the need for mechanised harvesting of these species is also bigger. Trial of beech harvesting was done in Poland in 1995 [Hołota 1995], however because of large tree sizes (final felling) it was not very successful. According to Bornschein (personal communication) tests with harvesters for conifers have been carried out in Germany since 1997 with the cutting of beech in premature stands. Again in Poland birch was cut successfully with use of Rottne harvester in 2001 [Bembenek and Mederski 2005]. Also various broadleaves were harvested in Croatia in 2002 [Beuk et al. 2007]. There were also minor changes made to adapt heads for broadleaves, so beech, oak and chestnut trees have also been harvested in experimental research [Sionneau and Cuchet 2001].

Ponsse focused its work on designing a harvester head for broadleaves in the late nineties and eventually a new HW60 was produced in Ponssé Centre at Peyrat-Le-Château (France) based on Markku Huttunen project [Demo... 2002]. A new HW60 was used officially in an oak dominated (90%) stand in Burgundy and the same head was later used successfully in a chestnut stand in France, as well as in special birch stands in Finland [Demo... 2002, Bussiere... 2003]. In 2006 Ponsse proposed a new head for eucalyptus harvesting and debarking, initially used in Brazil and the Republic of South Africa [Pousse... 2006 a, b, 2007]. At the same time, the Finish company AFM offered a specialised AFM 60 Euca harvester head for eucalyptus, a special head with one pair of movable knives and a shorter base for hardwood species – AFM 50 L, for softwood and hardwood AFM 45 L, and for bigger, hardwood and softwood trees AFM 60 [AFM 2008].

Since harvesters for conifers have become popular in Europe, the problem of using harvesters on broadleaves was recognised in European countries with a larger percentage of these species. Therefore, in 2005, a new ForstInno project was launched to contribute to the further development of timber harvesting for Central-European forestry. One of the aims of ForstInno was to build and test a new harvester head for broadleaved species: CTL 40 HW. The hypothesis of the study was that the use of a harvester for thinning operations in a birch stand (broadleaved species) will meet with difficulties because of birch trunk morphological features (which are more irregular in comparison with coniferous species, e.g. spruce or pine) and the more sensitive soil conditions.

The aim of this paper is to present a trial of development and testing of the CTL 40 HW harvester head in a birch stand in northern Poland. This research contributes to the development of forest operations needed in Central Europe [Paschalis 1996] and as an overall action is described as “continuous improvement of the facilities and networks of technical and transaction processes required to harvest and to transport biomass” [Heinimann 2007].

MATERIAL AND METHODS

Study area

Sample plots were established in a birch (*Betula pendula* Roth.) dominated stand, with the participation of species: 50% birch, 10% alder, 10% aspen, 10% willow

(52-year-old) and 20% birch (67-year-old). The study area was located in a flat terrain of northern Poland, the Regional Directorate of the State Forests (RDSF) Olsztyn. Three sample plots of an area of 0.25 ha were established in the Forest District Zaporowo, sector 81a, marked as SP 01, SP 02 and SP 03. In the middle of each sample plot, a 3.5 m wide strip road was marked for a harvester. The stands selected for research were of regular density without gaps or a dense shrub layer.

Preliminary work and thinning operation

In the stand, strip roads no wider than 3.5 m were marked, bearing in mind the width of the machinery used in the thinning operation. The distance between the axis of strip roads was a maximum 20 m. On each sample plot stand data before treatment was recorded. Diameters were measured with the Haglöf Digitech Professional. Diameter distribution in the stand after thinning was calculated by subtracting the trees extracted from pre-logging stand data (Table 1).

In the stand 24% of the stand volume was extracted and 25% of the number of trees. The thinning operation was carried out in March 2007 in sunny weather conditions by an operator with 3600 hours of experience in working on harvesters in Canada. In a prepared stand trees were cut using a UTC 150-6LS harwester with a CTL 40HW head for broadleaved species mounted on a 10 m long Pika 8900 crane. The harvester was produced in 2000, empowered with 110 kW Perkins engine on 6 wheels with tyres Nokian 700-22.5. The CTL 40HW harvester head, 610 kg of weight, was designed to cut trees with a max. diameter 450 mm with feeding force 22 kN, feeding speed 4 $m \cdot s^{-1}$ and chain speed 45 $m \cdot s^{-1}$. For operation 160-180 $l \cdot min^{-1}$ of oil flow was required and a max. pressure 200-230 bar. The head was equipped with a 540 mm long saw bar and 0.404” chain. The relatively short head (1270 mm) had a width 880-1180 mm and length 800 mm.

Time analysis and productivity

During thinning, timing was carried out at all stages of the operations using a stopwatch to distinguish the stages of thinning operations, which were differentiated according to the schedule of work time classification [Mederski 2006]. Harvested logs had two different lengths: 6.0 m processed from the bottom of tree trunks and 2.5 m from the tops of trees. Finally, the data obtained concerning operational time (T_{02}) of thinning and volume of harvested timber was used in the analysis of operational time productivity (P_{02}), understood as:

$$P_{02} = \frac{Q}{T_{02}} \tag{1}$$

where Q is the volume of harvested wood, m^3.

Soil disturbance and remaining stand damage

Bulk density was analysed on SP 01 after a single pass and on SP 03 after a double harvester pass. On SP 01 the harvester passed once during the operation (with stops) and on SP 03 additionally with driving back after finishing timber harvesting. Soil samples

Table 1. Summary of the stand characteristics in sample plots selected for study
Tabela 1. Opis drzewostanu na powierzchniach próbnych

	Number of trees Liczba drzew (n)		Diameter at breast height (DBH) Pierśnica cm		Average volume Średnia miąższość $m^3 \cdot ha^{-1}$	
	birch brzoza	all species wszystkie gatunki	birch brzoza	all species wszystkie gatunki	birch brzoza	all species wszystkie gatunki
Before treatment – Przed zabiegiem						
Sample plot – Powierzchnia próbna						
01	108	172	24.0	23.0	199.80	289.08
02	135	178	22.8	21.5	219.08	266.92
03	94	156	22.6	20.5	151.88	215.60
Mean – Średnia	112	169	23.2	21.5	190.24	257.20
After treatment – Po zabiegu						
Sample plot – Powierzchnia próbna						
01	72	112	25.7	25.0	155.12	219.32
02	87	123	24.9	23.0	154.88	198.96
03	68	118	24.2	30.0	118.32	166.64
Mean – Średnia	76	118	24.9	26.0	142.80	194.96
Extraction – Pozyskanie						
Sample plot – Powierzchnia próbna						
01	36	60	19.8	19.7	44.68	69.76
02	48	55	17.0	16.6	64.20	67.96
03	26	38	16.7	18.3	33.56	48.96
Mean – Średnia	36	43	17.8	18.2	47.48	62.24
Thinning ratio[a] Współczynnik intensywności trzebieży[a]			0.71	0.70		

[a] Thinning ratio is mean diameter (DBH) of extracted trees divided by mean diameter of the residual trees (after treatment).

[a] Współczynnik intensywności trzebieży: stosunek średniej pierśnic ($d_{1,3}$) drzew usuwanych do średniej pierśnic drzew pozostających (po zabiegu trzebieży).

for dry bulk density were taken by means of Kopecky soil cores: 5 cm diameter, 100 cm^3. Samples were collected every 10 m from ruts and beyond ruts where no evidence of compaction was observed. In the analysis, soil beyond the ruts was considered to have the same properties as soil from the rut area before harvester driving. Soil samples were collected from the surface mineral layer, oven dried for 24 h at 105°C and weighted on an accurate (0.01 g) laboratory scale. Additionally, a cone penetrometer test (CPT) was carried out at depths 5-40 cm (at depth intervals of 5 cm) every 5 m along the strip roads: within the left (LR) and right (RR) rut, beyond left (LLR) and beyond right (RRR) rut using a hand penetrometer (Eijkelkamp Agrisearch Equipment, the Nederlands). A sixty-degree cone was used with a cone basal area surface 1 cm^2.

After the thinning operation, damage to the remaining trees was measured. Trees with damage were analysed taking into consideration: (1) number of trees with damage and their biosocial position according to the Kraft classification system [Kraft 1884]; (2) their distance from a strip road: on the skirt of a strip road, 1-7 m and over 7 m from a strip road; (3) quality of damage: bark, wood tissue; (4) size: small <10 cm^2, medium 10-100 cm^2 and big >100 cm^2 and (5) damage place on a tree as height measured in m with use of Haglöf Vertex III.

RESULTS

Productivity of thinning operation

Average operational productivity from all sample plots was 13.40 m^3·h^{-1} (Table 2). This was obtained from 153 trees (110 birch trees) which gave 46.67 m^3 of merchantable timber (min. diameter over bark 7 cm). The mean volume of wood obtained from one tree was 0.31 m^3.

Table 2. Volume of harvested timber and operational productivity in analysed thinning
Tabela 2. Miąższość pozyskanego drewna oraz wydajność procesu trzebieży

	Sample plot – Powierzchnia próbna			Mean Średnia
	01	02	03	
Volume of harvested timber, V, m³ Miąższość pozyskanego drewna, V, m³	17.44	16.99	12.24	15.56
Productivity, P_{02}, m³·h⁻¹ Wydajność, P_{02}, m³·h⁻¹	10.90	14.20	15.10	13.40

Soil disturbance and remaining stand damage

After both, single and double harvester passes soil compaction was observed and it was statistically different to the soil beyond the ruts (Table 3). There were two different bulk densities observed beyond the ruts: 1.27 and 1.16 g cm^{-3}, but similar densities were recorded after a single drive: 1.43 g·cm^{-3} (on SP 01) and after a double drive: 1.45 g·m^{-3} (on SP 03) of the harvester. Average soil moisture beyond the ruts on SP 01 and 03 was 24% and 21% respectively. In both cases, after harvester driving lower moisture was recorded in the ruts (mean 21% and 18% on both plots respectively), however these changes were not statistically different. The CPT showed that the mean penetration resistance after a single and double harvester pass was bigger at all depths in both ruts (Fig. 1).

After a single drive, only on the right rut, a lower resistance was recorded at 30 and 40 cm depth (Table 4).

Table 3. Bulk density as influenced by treatment: test t, $p < 0.5000$
Tabela 3. Zagęszczenie gleby po procesie pozyskiwania drewna: test t, $p < 0,5000$

		Mean Średnia	Standard deviation Odchylenie standardowe	N	Difference Różnica	Standard deviation difference Odchylenie standardowe różnica	t	p
SP 01 1HP PP 01 1PH	BR/PK	1.269256	0.284539					
	WR/WK	1.428711	0.165345	9	–0.15946	0.206213	–2.31977	0.048937
SP 03 2HP PP 03 2PH	BR/PK	1.149931	0.198714					
	WR/WK	1.448985	0.142734	13	–0.29905	0.150464	–7.16617	0.000011

SP – sample plot, HP – harvester passes, BR – beyond ruts, WR – within ruts.
PP – powierzchnia próbna, PH – przejazdów harwestera, PK – poza koleiną, WK – w koleinie.

A statistically different high penetration resistance was only observed on SP 01 at depth 5, 10 and 15 cm. On SP 03 with a double harvester pass, higher penetration resistance was observed on both ruts at all depths, though significant statistical differences were only at depths of 20, 25 and 30 cm; on the left rut at 15 cm and on the right one at 5 and 10 cm depths. On all sample plots trees with damage amounted to 5.3%, from which most of them were from 1 and 2 Kraft classes (Table 5). Most common damage was observed on bark with wounds of a size up to 100 cm^2.

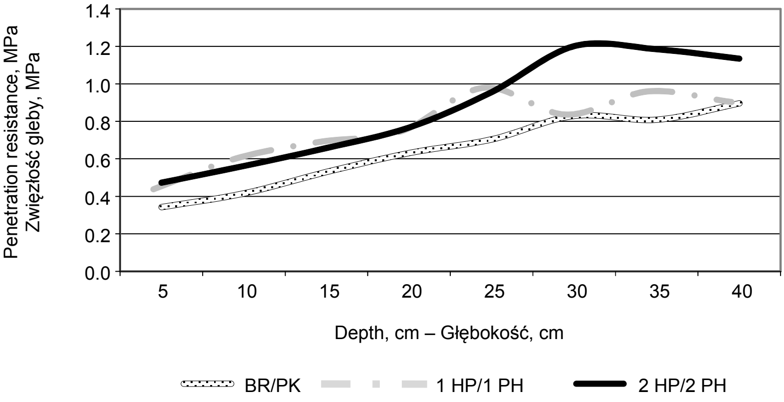

Fig. 1. Cone penetrometer test results, mean values of resistance in function of depth: BR – beyond rut, 1 HP – single harvester pass, 2 HP – double harvester pass
Rys. 1. Średnie wartości zwięzłości gleby badanej penetrometrem w zależności od głębokości: PK – poza koleiną, 1 PH – jeden przejazd harwesterem, 2 PH – dwa przejazdy harwesterem

Table 4. Cone penetrometer test, resistance
Tabela 4. Zwięzłości gleby badanej penetrometrem

Depth Głębkość cm		5	10	15	20	25	30	35	40
		MPa							
SP 01 1HP PP 01 1PH	LLR	0.29	0.37	0.54	0.67	0.76	0.82	0.84	0.85
	LR	0.45	0.59	0.70	0.74	0.85	0.91	1.00	0.94
	RR	0.42	0.61	0.67	0.75	1.10	0.76	0.92	0.86
	RRR	0.33	0.44	0.56	0.66	0.70	0.87	0.75	0.90
SP 03 2HP PP 03 2PH	LLR	0.39	0.46	0.50	0.62	0.68	0.84	0.86	0.83
	LR	0.48	0.58	0.68	0.80	0.88	1.20	1.16	1.08
	RR	0.46	0.54	0.63	0.73	1.02	1.19	1.20	1.18
	RRR	0.36	0.40	0.51	0.58	0.66	0.79	0.79	0.99

LLR – beyond (to the left) left rut, LR – on the left rut, RR – on the right rut, RRR – beyond (to the right) right rut (other abr. like in Table 3 and Figure 1).

PLK – poza lewą koleiną (na lewo od koleiny), LK – w lewej koleinie, PK – w prawej koleinie, PPK – poza prawą koleiną (na prawo od koleiny) (pozostałe skróty jak w tabeli 3 i na rysunku 1).

Table 5. Distribution of damage in remaining stand
Tabela 5. Rozkład uszkodzeń w drzewostanie po zabiegu trzebieży

Distance from a strip road Odległość od szlaku			On skirt Na brzegu		1-7 m		> 7 m		Damage Uszkodzenia %
Biosocial position (Kraft classification) Pozycja biosocjalna (klasyfikacja Krafta)			1, 2	3, 4, 5	1, 2	3, 4, 5	1, 2	3, 4, 5	
SP 01 PP 01	10-100 cm^2	bark kora	0	0	0	0	1	0	3.6
	> 100 cm^2		0	0	1	0	0	0	
	10-100 cm^2	wood tissue włókna drzewne	0	0	0	0	0	0	
	> 100 cm^2		1	0	1	0	0	0	
SP 02 PP 02	10-100 cm^2	bark kora	0	1	3	0	0	0	7.3
	> 100 cm^2		0	1	0	0	1	0	
	10-100 cm^2	wood tissue włókna drzewne	0	0	2	0	0	0	
	> 100 cm^2		1	0	0	0	0	0	
SP 03 PP 03	10-100 cm^2	bark kora	1	1	0	2	0	0	5.1
	> 100 cm^2		2	0	0	0	0	0	
	10-100 cm^2	wood tissue włókna drzewne	0	0	0	0	0	0	
	> 100 cm^2		0	0	0	0	0	0	

SP – sample plot.
PP – powierzchnia próbna.

DISCUSSION

Productivity of thinning operation

The productivity achieved in the analysed thinning operation with the use of a harvester and the new CTL 40HW harvester head was satisfactory if compared with results obtained in coniferous stands or other experiences in broadleaved stands. Suwała and Jodłowski [2002] analysing Timberjack 1270B, obtained 9.90 $m^3 \cdot h^{-1}$ of working shift when an average harvested tree was 0.4 m^3. In a 72-year-old pine stand Mederski [2006] obtained 8.70 $m^3 \cdot h^{-1}$ in operational time with an average volume of harvested tree 0.68 m^3. In an oak dominated stand, Ponsse had 14.00 $m^3 \cdot h^{-1}$, with a mean volume 0.27 m^3. In the analysed birch thinning operation harvested logs had a satisfactory quality of delimbing. From the bottom part of trees, sawmill timber was processed and the top parts gave good quality pulp wood.

In the overall evaluation, the CTL 40HW head was useful in the birch stand in the thinning operation. This was possible due to a modification in construction: (1) the top knife was mounted as movable and hydraulically operated, (2) there were no bottom movable delimbing knives, (3) the trajectory of the arms with feeding rollers was changed and (4) the head frame was maximally shortened. Tests carried out in Poland showed that further improvement in delimbing could be achieved, as well as a correction of the length measurement system.

Soil disturbance and remaining stand damage

The increases in bulk density after single and double harvester passes were 0.16 $g \cdot cm^{-3}$ and 0.30 $g \cdot cm^{-3}$ respectively and were statistically significant. Penetration resistance after both harvester passes increased at all depths in both ruts. A statistically different high penetration resistance was on SP 01 at depths 5, 10 and 15 cm. After a double harvester pass, higher resistance was on both ruts at all depths, though a statistically significant difference was only at depths of 20, 25 and 30 cm. An increase in bulk density and penetration resistance after a double harvester pass showed similar final values. This can lead to the conclusion that the first pass of a harvester makes a dramatic change in the analysed type of soil due to stops and crane expansion deep in the stand. The crane moved out put significantly bigger pressure on the wheels, especially when pulling in cut trees. The second drive was without crane expansion and stops, and eventually previously compacted soil met lower pressure from the harvester. An increase in bulk density and penetrometer resistance of the soil suggests that heavy machines such us harvesters should only drive on limited areas within strip roads [Erler and Güldner 2002, Erler 2005].

Statistically significant differences of CPT showed maximal increase of 60% after a single drive and 40% after a double drive of the harvester. Ampoorter et al. [2007] after a single harvester pass, recorded a smaller increase in penetration resistance on sandy soil, from 0.65-0.94 MPa to 1.15-1.36 MPa at depth from 5-35 cm.

Trees with damage amounted to 5.3% and most of them were from 1 and 2 Kraft classes. In a birch stand Bembenek and Mederski [2005] recorded 6.4-9.4% of trees with damage in the remaining stand, in which a Rottne harvester was used with a head for coniferous species. A higher percentage of trees with damage is presented by Bacher [2003] and Bacher-Winterhalter et al. [2006]: 6.4-19.0% in mixed stands, where also mature trees were felled and extracted.

The results obtained in the paper are optimistic. In the authors' opinion, a set of a harvester with the CTL 40HW head and a forwarder, is feasible in thinning operations in birch stands in Central Europe.

CONCLUSIONS

1. Mean operational productivity was 13.40 $m^3 \cdot h^{-1}$ when thinning intensity was 62.24 $m^3 \cdot h^{-1}$. The mean volume of timber obtained from one tree was 0.32 m^3.
2. The increases in bulk density (statistically significant) after single and double harvester passes were 0.16 $g \cdot cm^{-3}$ and 0.30 $g \cdot cm^{-3}$ respectively.
3. Penetration resistance after both harvester passes increased at all depths in both ruts: a statistically different high penetration resistance was on SP 01 at depths 5, 10 and 15 cm.
4. After a double harvester pass, higher resistance was on both ruts at all depths, though a statistically significant difference was only at depths of 20, 25 and 30 cm.
5. Statistically significant differences of cone penetrometer test (CPT) showed maximal increase of 60% after a single drive and 40% after a double drive of the harvester.
6. Trees with damage amounted to 5.3% and most of them were from 1 and 2 Kraft classes.

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EFEKTY INNOWACYJNEGO ZASTOSOWANIA HARWESTERA W TRZEBIEŻOWYM DRZEWOSTANIE BRZOZOWYM

Streszczenie. Pozyskiwanie drewna gatunków liściastych harwesterem wiąże się z wieloma trudnościami oraz jest przedmiotem stosunkowo nielicznych badań. Celem artykułu było określenie efektów zastosowania harwestera UTC 150-6LS z głowicą CTL 40HW, zaprojektowaną do pozyskiwania drewna gatunków liściastych. Badania przeprowadzono w trzebieżowym drzewostanie brzozowym w północnej Polsce (Nadleśnictwo Zaporowo). Określenie wyników innowacyjnego pozyskiwania drewna brzozy przeprowadzono z uwzględnieniem trzech parametrów: 1) wydajności operacyjnej, 2) uszkodzenia drzewostanu oraz 3) uszkodzenia gleby. Podczas pozyskiwania drewna brzozy harwesterem uzyskano średnią wydajność operacyjną 13,40 $m^3 \cdot h^{-1}$, a uszkodzenia drzewostanu wahały się od 4 do 7%. Analiza gleby na szlakach operacyjnych wykazała wzrost gęstości o wartości od 0,16 do 0,21 $g \cdot cm^{-3}$. Stwierdzono również zmniejszenie średniej wilgotności gleby po przejazdach harwesterem, różnice jednak nie były istotne statystycznie. Największą zwięzłość gleby obserwowano po dwóch przejazdach harwestera: wzrost o 50% na głębokości 30 cm oraz wzrost o 45% po jednokrotnym przejeździe na głębokości 10 cm.

Słowa kluczowe: harwester, drzewostan liściasty, trzebież, wydajność, uszkodzenia drzewostanu, uszkodzenia gleby

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