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DAMAGES TO THE SURFACE LAYER OF SOIL DURING TIMBER HARVESTING USING THE EQUIPMENT AGGREGATED WITH FARM TRACTORS*

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Abstract. In the study, impact of three devices aggregated with farm tractors on forest soil was compared – FRANSGARD 6000 GS cable winch and two processors – NIAB 5-15 and HYPRO 450. The basic difference between the above mentioned machines consists in the fact that the cable winch skids debranched tree stems while processors skid the whole trees, including their tree-tops. The percentage of soil injured in late pine stand thinning reached, respectively: 1.2%, 2.2% and 5.5%. The analysis of significance of differences in Ug indicators characterising the damages induced has shown that only the indicator computed for HYPRO processor is significantly higher than the others. However, as the simulation performed has confirmed, appropriate thickening of skidding routes enables to achieve a comparable level of damages for all the machines examined. Taking into account the impact on forest soil, application of processors aggregated with farm tractors can be recommended for thinning stands.

Key words: harvesting damages, processor, cable winch, thinning

INTRODUCTION

The forestry services market in Poland is dominated by small companies, of limited financial resources [Kocel 2003]. They do not possess highly-efficient and very expensive multi-operational machines, instead, they are mostly equipped with universal farm tractors whose number has been recently increasing dramatically in Poland [Gil 2003]. The increased level of mechanisation of harvesting works, due to equipment which can be even available for medium-sized forestry service companies, is possible, among

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others, through application of processors aggregated with farm tractors [Walczyk 1997]. Operating of such machines is associated with relatively low inconvenience from the point of view of the working environment [Giefing 1994 b, Leszczyński et al. 2011], and they also demonstrate considerable efficiency [Giefing 1994 a, Sowa and Szewczyk 2008] and satisfying economic effectiveness [Sowa et al. 2007].

According to Giefing's claim [1995], the comprehensive assessment of timber harvesting technology should currently cover areas specified by "3 × E" rule – economics, ergonomics and ecology. Equipment and working methods can be used in forest ecosystems only of they are acceptable in all these areas. The studies conducted have just focused on one the ecological aspects of application of processors for tree harvesting purposes.

The aim of the study was to compare the extent of impairments of the soil cover occurring during the performance of timber skidding using three types of devices aggregated with farm tractors – two different processors and a cable winch. The scope of the studies was limited to late thinning treatment, performed in lowland pine stands.

MATERIAL AND METHODS

Research location

The testing areas were located in southern Poland, within the territory of Dąbrowa Tarnowska and Rybnik Forest Inspectorates. The basic features of stands in which the study was conducted, including characteristics of the thinning harvesting, are summarised in Table 1.

Table 1. Description of stands in which the study was conducted
Tabela 1. Opis drzewostanów, w których wykonano badania

Forest inspectorate – Nadleśnictwo	Dąbrowa Tarnowska	Rybnik
STL	BMspruce BMśw	BMspruce BMśw
GTD	Oak-Pine Db-So	Beech-Pine Bk-So
Species composition – Skład gatunkowy	9 Pine 1 Beech 9 So 1 Brz	Pine So
Age, years – Wiek, lata	45	77
Standing timber – Zadrzewienie	0.7	0.7
Density – Zwarcie	moderate umiarkowane	full pełne
Evaluation – Bonitacja	Ia	Ia
Diameter at breast height, cm – Pierśnica, cm	22 29	31
Height, m – Wysokość, m	20 22	24
Roundwood, $m^3 \cdot ha^{-1}$ – Grubizna, $m^3 \cdot ha^{-1}$	228	269

The equipment applied and harvesting technology

The BELARUS MTZ 100 model was used as the basic farm tractor. The basic parameters of the machines integrated with it, processors and the cable winch, are summarised in Table 2.

Table 2. General technical data of the processors and cable winch
Tabela 2. Ogólne dane techniczne procesorów i wciągarki

	Unit Jednostka	Processor Procesor NIAB 5-15	Processor Procesor HYPRO 450	Cable winch Wciągarka FRANSGARD 6000 GS
Control Sterowanie	–	lever dźwigniowe	lever dźwigniowe	pilot
Mass Masa	kg	1 030	1 130	550
Chainsaw gauge Podziałka piły łańcuchowej	”	0.404	0.404	–
Speed of timber shifting Prędkość przesuwu drewna	$m \cdot s^{-1}$	1.5	3-3.5	–
Minimum tractor capacity Minimalna moc ciągnika	kW	30	50	50
Maximum diameter of timber processed Maksymalna średnica obrabianego drzewa	mm	500	450	–
Length of winch cable Długość liny wciągarki	m	50	35	80
Winch towing power Siła uciągu wciągarki	kN	25	20	60

The harvesting works using the NIAB 5-15 processor were performed in stands located within the territory of Forest Inspectorate while the works using the HYPRO 450 processor – within the territory of Rybnik Forest Inspectorate. The activities were carried out according to the following outline:

- The chainsaw operator performed felling of the trees indicated for removal by the State Forests employees. While performing the felling, he kept the knocking down direction opposite to the skidding route.
- The processor operator was spreading the cable of the winch and attaching tree-stumps. Then he performed skidding of the whole trees, with tree-tops. Next to the skidding route he unhooked the load and debranched the timber, cutting it to 1.25 m long logs. Following the skidding and processing of the trees, the change of position of the processor within the range of the cable took place on the operational route.
- In case of the technology with skidding by FRANSGARD 6000 cable winch, used for tree stands of the Dąbrowa Tarnowska Forest Inspectorate, the major differences consisted in the fact that the chainsaw operator was not only felling the trees

but also debranching them with a chainsaw. The timber was skidded in the form of long timber towards the operational route on which cutting using the chainsaws was performed.

The second stage of skidding, to landing, was not covered by the analysis conducted under this study. The logging works were performed during the summer months (June--July).

For further description of the machines used and the related technology, the names NIAB, HYPRO and WINCH were adopted.

Field tests

For each of the three technologies, the assessment of soil damages was performed in two stages. At the first stage, on each rectangular manipulation plot of dimensions 50 × 100 m, 96 circular plots with a radius of 3.99 m were established in the network of squares with the side length of 12.5 m. The middle of each plot was marked with a wooden stake, and the number of the plot was written down on the nearest tree. The circular plots were situated in 4 rows, in order to obtain the skidding distance of up to 50 metres. At the second stage, after the logging was completed, the inventory of the occurring soil injuries was performed, by measuring their length, width and depth with a tape, at precision to 0.01 m.

In-house studies

Damages to the surface soil layer occurring as a result of the analysed technological processes were compared applying the indicator developed by Suwała [1999], computed according to the formula:

$$Ug = G_{ko} + G_{bp} + 2\ G_{bg} \qquad (1)$$

where:

- Ug – synthetic indicator of damages to the surface soil layer,
- G_{ko} – percentage share of the grooves volume in the soil layer of 10 cm thickness,
- G_{bp} – percentage share of shallow ruts volume of average depth to 5 cm, in the soil layer of 10 cm thickness,
- G_{bg} – percentage share of deep ruts volume of average depth above 5 cm, in the soil layer of 10 cm thickness.

The Ug indicator values obtained were subject to statistic processing using the Statistica 9.0 PL software [Statistica... 2009].

RESULTS AND DISCUSSION

The technologies analysed demonstrated relatively limited noxiousness towards the surface layers of soil. The general share of injured soil for individual variants is shown in Figure 1.

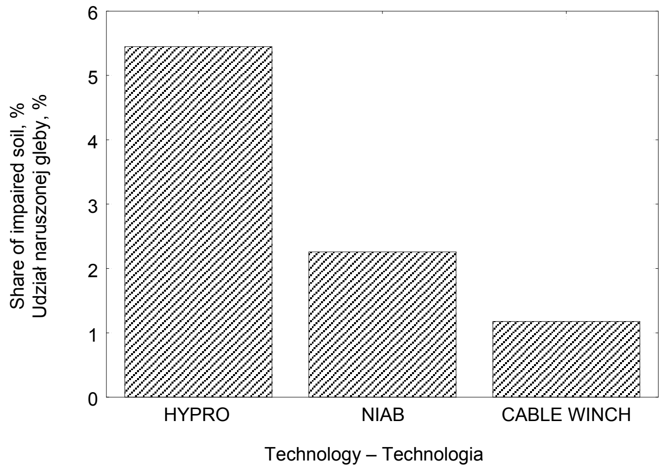

Fig. 1. Soil injuries under application of individual technologies
Rys. 1. Naruszenia gleby z zastosowaniem poszczególnych technologii

The lowest share of injuries was recorded for the cable winch – about 1.2%, for the NIAB processor the level was slightly above 2.2%, while for HYPRO processor – almost 5.5% of the study area. Studies concerning the impact of skidding performed using farm tractors equipped with cable winches generated similar results to those obtained in this study. Porter [1997] reports that in pine thinning stands this skidding method, depending on the model of the winch applied, results in damages at the level from 2.8 to 3.3%. However, this author has also considered the movement of the litter as damage, which has not been evaluated in this study. Disregarding this effect, he obtained results at the level of 1.3 to 1.5%, thus, close to the results observed for FRANSGARD cable winch, which caused damages at the area of 1.2% of the tree stand.

The values of Ug indicators obtained for circular plots in accordance with the methodology presented, were subject to Shapiro-Wilk test in order to determine their compliance with the standard distribution. Such distribution was obtained only after the logarithmic transformation of Ug indicators. The results of the tests performed are presented in Table 3.

Table 3. Results of Shapiro-Wilk tests – compliance of the Ug indicators with the standard distribution
Tabela 3. Wyniki testów Shapiro-Wilka – zgodność wskaźników Ug z rozkładem normalnym

	Before transformation Przed transformacją			After logarithmic transformation Po transformacji logarytmicznej		
Technology Technologia	HYPRO	NIAB	CABLE WINCH	HYPRO	NIAB	CABLE WINCH
Value of W statistics Wartość statystyki W	0.677	0.832	0.688	0.942	0.927	0.932
Calculated significance level p Obliczony poziom istotności p	0.000	0.002	0.000	0.236	0.107	0.185

Due to the distributions obtained, further statistical analyses were possible with the use of parametric tests. Basic descriptive statistics of Ug indicators is shown in Figure 2.

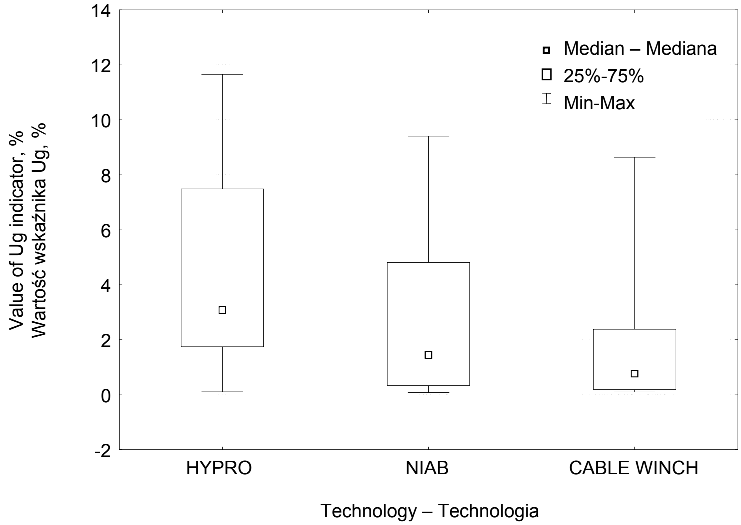

Fig. 2. Level of damages to the surface soil layer under application of the technologies analysed
Rys. 2. Poziom uszkodzeń wierzchniej warstwy gleby z zastosowaniem analizowanych technologii

In terms of increasing values of Ug indicators, identical arrangement of the technologies analysed was obtained, as in case of the share of the injured soil. The highest value of the indicator was demonstrated by the HYPRO technology (me = 3.07), medium – by NIAB (me = 1.45), whereas – by the CABLE WINCH (me = 0.73). In similar, pine thinning stands, while skidding the whole tree stems by hauling, depending on technology and distance between the routes, Suwała [1999, 2004] determined the values of Ug indicators at the level from 2.4 to 6.5%. Skidding of short timber using a farm tractor with a trailer moving outside the routes in the 40-year-old pine stand resulted in damages of the average value of Ug indicator = 1.42%, while in case of its moving in the vicinity of the route, Ug = 3.4% was noted and 100 metres away from the route the Ug indicator of only 0.1% was obtained [Kulak and Seńczyszyn 2011]. Similarly, in fir stands, however, for skidding of long timber by hauling using the light cable winch powered by the chainsaw engine, Sowa et. al [2008] determined the value of the Ug indicator at the level of 1.28%.

The analysis of variance conducted for the logarithmized Ug indicators has shown that at the significance level $\alpha = 0.05$, the average values of Ug indicators differentiate the technologies compared in statistically significant way ($F = 4.101$, $p = 0.021$). For precise comparison of the differences between the averages obtained for individual technologies, the NIR test was applied. Results of the test are presented in Table 4.

The analysis of the table of results shows that the damages occurring for skidding using the HYPRO technology are significantly bigger than in case of CABLE WINCH technology. Soil damages occurring during skidding with the NIAB processor do not

Table 4. Results of the NIR test on differences of the average value of Ug indicators for comparable technologies
Tabela 4. Wyniki testu NIR różnic średniej wartości wskaźników Ug porównywanych technologii

Technology Technologia	HYPRO	NIAB	CABLE WINCH
HYPRO		–	+
NIAB	0.095		–
CABLE WINCH	0.007	0.240	

Legend: – statistically insignificant difference, + statistically significant difference.
Legenda: – różnica nieistotna statystycznie, + różnica istotna statystycznie.

differ from damages occurring while applying other devices. Observations made during the field studies and the analysis of the results obtained allow for assumption that such result could have been influenced by the grooves occurring only on the plots where the HYPRO 450 processor was working. This machine was equipped with the shortest, 35-metre long line and it order to be able to skid the timber from more distant parts of manipulation areas, and it had to drive off the route inside the tree stand. When disregarding this form of soil damages, the Ug indicator calculated for HYPRO technology reached me = 2.55%. Descriptive statistics of Ug indicators, calculated without considering the grooves, is shown in Figure 3.

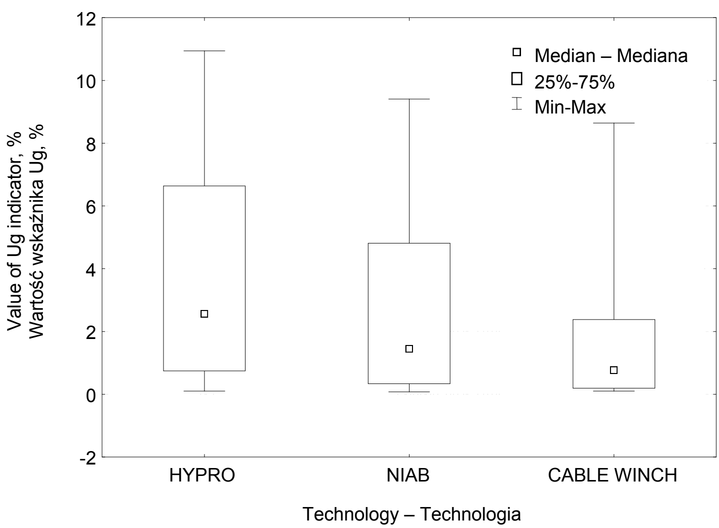

Fig. 3. Level of damages to the surface soil layer calculated only for grooves under application of the technologies analysed
Rys. 3. Poziom uszkodzeń wierzchniej warstwy gleby obliczony tylko dla bruzd z zastosowaniem analizowanych technologii

The damages occurring when applying the HYPRO technology are still the biggest, however, the repeated analysis of variance did not demonstrate any more significant differences between the indicators characterising the comparable technologies ($F = 2.135$, $p = 0.128$).

The measurements conducted on many 0.5-are plots allowed for determining probability of occurrence of soil surface impairments through computing the percentage of the areas where the grooves or guts were found. Results of such analysis are shown in Figure 4.

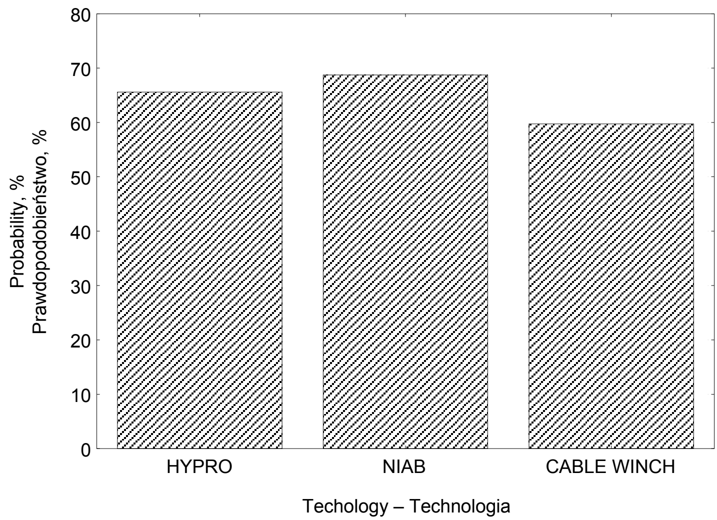

Fig. 4. Probability of soil injuries under application of individual technologies
Rys. 4. Prawdopodobieństwo uszkodzeń gleby z zastosowaniem poszczególnych technologii

The probability of occurrence of the surface soil layer damages under application of the technologies analysed was similar and it ranged from about 60-70%. Such share of areas with damages should be considered as average. Earlier studies show that in similar tree stands, depending on the harvesting technology, about 50% probability of occurrence of soil damages in case of horse skidding should be taken into consideration [Sowa and Kulak 2007], 70% – in case of machine timber harvesting technology using the harvester and forwarder [Kulak and Stempniak 2011] and 80% – in case of skidding with farm tractors using the hauling method [Sowa and Kulak 2008].

The study results presented did not confirm the information on particularly adverse environmental effects of timber harvesting within the system of the whole tree [Stajniak 1995]. In relation to the hauling skidding performed with the cable winch, skidding of the whole trees using the processors did not cause significantly higher damages. Taking into account the ergonomic advantages of this technology as well as its considerable efficiency, it should be recommended for wider implementation in Polish forests.

SUMMARY

1. The general share of the injured soil while applying the technologies analysed was not high. In case of skidding of long timber using the cable winch, 1.2% of the logging surface was damaged the share from 2.2% (NIAB) to 5.5% (HYPRO) was observed.

2. The values of Ug indicators ranged from 0.73% (CABLE WINCH) to 3.07% (HYPRO), at the same time, only these two technologies demonstrated statistically significant differences.

3. Larger damages in HYPRO technology were associated with the use of 35-metre line, which was too short, preventing timber skidding without driving off the operational route, inside the 50-metre width of the plots. Such way of operating involved generation of grooves, observed only on the surfaces where the HYPRO 450 processor worked.

4. For the Ug indicator calculated exclusively on the basis of the grooves, the differences between the three technologies compared were statistically insignificant. This indicates the need for proper adjustment of the distance between the operational routes, depending on the length of the skidding equipment cables in order to minimise the harvesting damages.

5. The probability of occurrence of the surface soil layer damages under application of the three technologies compared was similar and it ranged from about 60-70%.

6. Taking into account the impact on forest soil, while keeping proper distances between the skidding routes, application of processors aggregated with farm tractors can be recommended for thinning stands. This is further supported by the economic and ergonomic advantages of these machines.

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USZKODZENIA WIERZCHNIEJ WARSTWY GLEBY PRZY POZYSKIWANIU DREWNA Z UŻYCIEM URZĄDZEŃ AGREGOWANYCH Z CIĄGNIKAMI ROLNICZYMI

Streszczenie. W pracy porównano wpływ na glebę leśną trzech urządzeń agregowanych z ciągnikami rolniczymi – wciągarki linowej FRANSGARD 6000 GS oraz dwóch procesorów NIAB 5-15 i HYPRO 450. Zasadnicza różnica pomiędzy wymienionymi maszynami polega na tym, że wciągarka zrywa okrzesane strzały, a procesory całe drzewa, z koronami. Odsetek naruszonej gleby w trzebieżach późnych w drzewostanach sosnowych wyniósł odpowiednio: 1,2, 2,2 oraz 5,5. Analiza istotności różnic wskaźników Ug charakteryzujących powstałe uszkodzenia wykazała, że tylko wskaźnik obliczony dla procesora HYPRO jest istotnie większy niż pozostałe. Jednak odpowiednie zagęszczenie szlaków zrywkowych, co potwierdziła wykonana symulacja, pozwala na osiągnięcie porównywalnego poziomu szkód dla wszystkich badanych maszyn. Biorąc pod uwagę oddziaływanie na glebę leśną, stosowanie procesorów agregowanych z ciągnikami rolniczymi może być zalecane w drzewostanach trzebieżowych.

Słowa kluczowe: szkody pozyskaniowe, procesor, wciągarka, trzebież

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