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ORIGINAL PAPER

The effect of timber harvesting in thinning of pine stands *Pinus sylvestris* L. on efficiency of extraction using an agricultural tractor with a self-loading trailer

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ABSTRACT

The aim of this study was to compare basic efficiency parameters in forwarding of logs felled using a harvester and chain saws. Logs of 4.0 m in length came from late thinnings of pine stands and they were extracted with an 86 kW agricultural tractor with a self-loading trailer of 9500 kg load capacity. Analyses included the load, extraction distance, organizational structure of operation time, duration of the extraction cycle, as well as productivity in the operation time. It was also verified whether there is a relationship between the distance covered to collect log loads and the duration of the extraction cycle and the duration of the loading operation. These values were recorded during 27 extraction cycles for logs felled using a harvester and 25 extraction cycles for logs felled using chain saws. The extraction distance for logs felled using a harvester was 250 m, while for chain saw-felled logs it was 200 m. The mean load of logs felled using a harvester and those chain saw-felled was comparable (6.2-6.4 m^3). The distance covered to collect the load of logs felled using a harvester was statistically significantly shorter than that for chain saw-felled logs. Within the structure of operation work time the greatest share accounted for loading time (almost 50 and 60% for logs felled using a harvester and chain saws, respectively). The duration of the extraction cycle for chain saw-felled logs was almost 33 min. and it was statistically significantly longer than the duration of the extraction cycle for logs felled using a harvester (24.5 min.). Extraction productivity in the operation time for logs felled using a harvester was over 15 $m^3 \cdot h^{-1}$ and it was statistically significantly greater than extraction productivity recording for chain saw-felled logs (almost 12 $m^3 \cdot h^{-1}$). In the case of both log harvesting technologies a weak, statistically non-significant correlation was found between the distance covered to collect the load and the duration of the extraction cycle. A similar situation was observed in the case of the distance and duration of loading for chain saw-felled logs, whereas for logs felled using a harvester no correlation between these variables was recorded.

KEY WORDS

cut-to-length method, forwarding, late thinning, time study, work cycle, work productivity

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Introduction

Timber harvesting in Poland is increasingly often performed using the cut-to-length method. This method has been commonly applied for many years in Scandinavia (Nurminen *et al.*, 2006; Asikainen *et al.*, 2009 cited after Malinen *et al.*, 2016; Nordfjell *et al.*, 2010; Proto *et al.*, 2018; Lundbäck *et al.*, 2021), while recently it has been adopted not only in Poland, but also in the Baltic countries (Moskalik *et al.*, 2017). The method started to be used in Poland in mid-1990s, when the State Forests purchased 15 Timberjack 1010 forwarders (Grodecki, 1996; Jodłowski, 1997). At that time the introduction of these machines resulted in greater interest in productivity and environmental impact of various timber harvesting technologies, including the cut-to-length method involving timber extraction using forwarders (Paschalis and Porter, 1994; Porter, 1998; Suwała, 1999; Suwała and Rzadkowski, 2001). In the cut-to-length method technological operations (felling, delimbing, bucking) may be performed using chain saws or harvesters. Since the early 2000s the number of harvesters in Poland has been increasing steadily (Mederski *et al.*, 2016). At present it is estimated at approx. 1000 machines (Więsik, 2022), with timber harvesting using harvesters accounting for almost 50% (Bodył, 2022). The growing number of harvesters is accompanied by a systematic increase in the share of large timber logs, which since 2015 has grown 2.5-fold (from 2.8 to 7.1 million m^3). Moreover, since 2020 logs have been predominating over long timber in the structure of large-sized pine timber sales (in 2020 the difference amounted to approx. 0.2 million m^3, while in 2022 it was as much as 2.7 million m^3) (Portal, 2023).

In the cut-to-length method using a combination of manual and machine operations medium-sized timber assortments bucked immediately after felling are manually transported to strip roads, where they are accumulated as bundles, typically composed of several, and less frequently around a dozen rollers. In the case of much heavier logs such an accumulation is hindered and it is usually reduced to the necessary minimum (transferring those more distant from the strip road to be within the reach of the extraction machine crane), or it is not performed at all. In a situation when felling and bucking operations are performed by a harvester, both rollers and logs are accumulated at the strip road. At present timber extraction in the cut-to-length method is performed typically with the use of forwarders, while agricultural tractors with self-loading trailers are also used for this purpose (Mousavi and Naghdi, 2014; Grieger *et al.*, 2016; Stańczykiewicz *et al.*, 2016; Kormanek and Fiszer, 2018; Leszczyński *et al.*, 2021). Traction parameters of agricultural tractors are definitely less advantageous compared to specialist vehicles; however, thanks to their lower price and adaptability they have been commonly used in many European countries (Akay, 2005; Magagnotti and Spinelli, 2011; Proto *et al.*, 2018; Taş and Akay, 2020). In Poland they are presently used mainly in timber forwarding (in combination with self-loading trailers); in other countries they are often used in skidding in the tree-length method or the full-tree method (Macri *et al.*, 2017; Gülci *et al.*, 2018; Cataldo *et al.*, 2020; Gülci, 2020; Ghaffariyan, 2022a).

As it was stated by Więsik (2017), when the market for services in Polish forestry was initially privatized, it comprised numerous economically weak entities, in which an agricultural tractor was the primary machinery. These firms, in order to meet the technological and environmental challenges, were eager to purchase self-loading trailers, together with their previously acquired tractors constituting extraction units much cheaper than professional forwarders. Such units are particularly useful when extracting timber from small, scattered forest complexes (Rzadkowski, 1995), while they may also be used to transport timber over substandard roads, inaccessible for regular transport vehicles (Spinelli *et al.*, 2015).

While at present contractors providing forestry services in Poland increasing often decide to purchase forwarders, extraction units composed of an agricultural tractor and a trailer equipped with a crane continue to be used in timber extraction in the cut-to-length method.

The aim of this study was to determine the structure of operation time and productivity in extraction of pine logs using a set of an agricultural tractor and a self-loading trailer. Analyses covered extraction of timber felled using either chain saws or a harvester in late thinnings of pine stands. A hypothesis was proposed that extraction productivity for logs felled using a harvester exceeds that for chain saw-felled logs, and that for both technologies there is a relationship between the distance required to collect the load of logs and the duration of the extraction cycle and loading time.

Material and methods

Investigations were conducted in the Tuchola Forest (Polish: Bory Tucholskie) in the Osie Forest District (the Regional Directorate of the State Forests in Toruń) in four pine stands *Pinus sylvestris* L. aged from 89 to 104 years (Table 1).

In subcompartments 306c and 320b medium-sized timber assortments – rollers 2.0 m and 2.5 m in length, as well as large-sized timber – logs of 4.0 m in length, were harvested using chain saws. Rollers were prepared for extraction by being manually transported towards strip roads and arranged into bundles. In that case logs were not transferred due to their considerable weight. In subcompartments 320d and 320f timber (identical assortments as in subcompartments 306c and 320b) was felled and collected using a John Deere 1070d forest thinning harvester with a Waratah 745 head. The harvester bucked and at the same time accumulated next to the strip road not only medium-sized timber assortments (rollers), but also logs. In all the four stands the strip roads were arranged approx. 20 m apart.

Timber was extracted using a set of an Ursus 1224 4×4 tractor, equipped with an 86 kW engine and a Palms 9s trailer, load capacity of 9500 kg, with a Palms 670 crane, max. radius of 6.7 m and lifting capacity of 780 kg to 4 m. In all the experimental sites the extraction unit was operated by the same operator with several years of experience in such work. The extraction distance was assumed based on the specification of essential terms of the contract for forestry services in the subcompartments investigated in this study and it was 200 m for saw-felled logs and 250 m for logs felled using the harvester.

Table 1.
Characteristics of experimental sites

	Subcompartment			
	306c	320b	320d	320f
Area [ha]				
Stand	Scots pine	Scots pine	Scots pine	Scots pine
Stand age [years]	104	104	89	89
Density	0.8	0.9	1.1	1.0
DBH [cm]	36	30	33	36
Height [m]	27	23	24	27
Volume [$m^3 \cdot ha^{-1}$]	232	340	397	418
Forest habitat type	fresh mixed coniferous forest	fresh coniferous forest	fresh coniferous forest	fresh mixed forest

Field studies included continuous time study for operation time T_{02} (BN-76/9195-01), which was the time of the extraction cycle (C_t) including driving without a load (t_1), loading (t_2), driving with a load (t_3) and unloading (t_4) (Więsik, 2017):

$$C_t = t_1 + t_2 + t_3 + t_4 \text{ [s]} \tag{1}$$

Time was measured using a timer accurate to 1 s. Limit points for individual extraction stages were determined by:

a) the extraction unit stopping at the first logs on a strip road – end of travel without load/start of loading,
b) placement of the crane arms on loaded logs – end of loading/start of travel with the load,
c) the extraction unit stopping at the stack – end of travel with the load/start of unloading,
d) placement of folded crane arms between stakes in the travel position – end of unloading/start of travel without load.

Operation times were measured for 25 extraction cycles for chain saw-felled logs and 27 extraction cycles for logs felled using a harvester.

Apart from continuous time study the numbers of logs in each extraction cycle were recorded on site, while the length of strip roads was also measured (with a Walktax thread meter distance measurer). The numbers of logs were used to calculate the load volume in each extraction cycle, which was the product of the number of logs and mean volume of one log. Mean log volume was calculated by diving the volume of all logs from a given subcompartment by their number. Volume of all logs from each subcompartment was calculated based on measurements of their top log diameters (in pieces jointly) (Zarządzenie, 2019) after extraction at the extraction road. The lengths of strip roads were used to calculate distance (d) travelled to collect a load of logs in each extraction cycle:

$$d = \frac{l \cdot Q_d}{\sum Q_d} \text{ [m]} \tag{2}$$

where:

l – total length of strip roads,
Q_d – timber volume in an extraction cycle,
$\sum Q_d$ – total timber volume from all extraction cycles.

Productivity in operation time (W_{02}) was calculated by dividing the volume of load in each extraction cycle by the duration of the cycle (Więsik, 2017):

$$W_{02} = \frac{3600 \cdot Q_d}{t_c} \text{ [m}^3\cdot\text{h}^{-1}\text{]} \tag{3}$$

where:

t_c – duration of the extraction cycle.

Next basic descriptive statistics were calculated for durations of individual stages and the entire extraction cycle, the number of logs in a single load, volume of a single load, distance covered during loading and productivity in operation time. After the normality of distribution for the above-mentioned extraction parameters was verified applying the Shapiro-Wilk test, the significance of differences between the log harvesting technologies (chain saws, harvester) was determined. Student's t-test or the Mann-Whitney U test were applied. The effect of distance covered to collect the load on the duration of the extraction cycle and loading time was assessed using Spearman's correlation coefficient. Significance of the correlation coefficient was evaluated applying Student's t-test. All statistical analyses were conducted using the Statistica 13 package (TIBCO Software Inc., 2017), with the hypotheses tested at the significance level α=0.05.

Results

The total operation time of 25 extraction cycles for chain saw-felled logs was 14 h, 12 min. and 2 s, while that for 27 extraction cycles for logs felled using a harvester it was 10 h, 59 min. and 23 s. During that time the extraction unit transported 160.92 m^3 of chain saw-felled logs and 167.37 m^3 of logs felled using a harvester. Mean numbers of logs extracted within one extraction cycle were comparable (Table 2), while the load of logs felled using a harvester was on average by almost two logs greater than the load of chain saw-felled logs. Mean volumes of loads extracted within one extraction cycle were also similar (6.2-6.4 m^3), with the load of logs felled using a harvester being slightly smaller than the chain saw-felled ones (Table 2). Both in the case of the number and volume of logs extracted in one extraction cycle the differences between the adopted timber harvesting technologies were statistically non-significant (the number of logs – t=0.029, p=0.308; load volume – t=1.044, p=0.302). Markedly greater, statistically significant differences (t=15.580, p<0.001) were recorded for the distance required to accumulate the mean load of logs. This distance in the case of logs felled with a harvester was by almost 43% smaller compared to that for chain saw-felled logs (Table 2). An important result given in this table is connected with greater values of the coefficient of variation for the technology, in which logs were felled using a harvester. This was of particular importance in the case of the number of logs per one extraction cycle, where at a comparable mean the difference between the minimum and the maximum for that technology amounted to 20 pieces, while for the technology using chain saws it was only 11.

The shares of durations of individual extraction stages in the operation time are given in Figure 1. Irrespective of the timber harvesting technology used, loading took markedly the longest time. The share of duration of that operation for extraction of logs felled using a harvester accounted for almost 50%, while in the case of logs felled with chain saws it was almost 60% operation time. The shortest duration was recorded for travel without load and travel with a load, as it was jointly slightly over 16% for logs felled with chain saws and almost 20% for those felled using a harvester. In turn, unloading took from 24 to 30% of the operation time (Fig. 1).

While the shares of time for most extraction stages (except for loading) for logs felled using a harvester were greater than those recorded for saw-felled logs, in the case of means and medians it was observed only for travel with a load. Figure 2 presents distributions of durations for extraction cycle stages depending on the extraction distance (A – travel to collect a load, B – travel with a load). The mean travel time with a load of logs felled using a harvester amounted to 2 min. and 55 s, while for logs felled using chain saws it was 2 min. and 23 s, with the differences being statistically non-significant (t=–1.770, p=0.083). In turn, the mean time of travel to collect saw-

Table 2.

Mean ($\bar{x}$), median (Me), minimum (Min.), maximum (Max.), standard deviation (SD) and coefficient of variation (CV [%]) for the number of logs/extraction cycle [pcs.] volume of logs/extraction cycle [m^3] and distance travelled to collect the load/extraction cycle [m] depending on timber harvesting technology

		$\bar{x}$	Me	Min.	Max.	SD	CV
CS	pcs.	40.04	40.00	34.00	45.00	2.94	7.33
	m^3	6.44	6.59	4.99	7.66	0.74	11.43
	m	201.94	206.80	156.63	240.30	23.08	11.43
H	pcs.	41.52	43.00	22.00	52.00	6.60	15.90
	m^3	6.20	6.24	3.81	7.68	0.89	14.41
	m	115.49	116.19	71.00	143.03	16.64	14.41

CS – chain saw, H – harvester

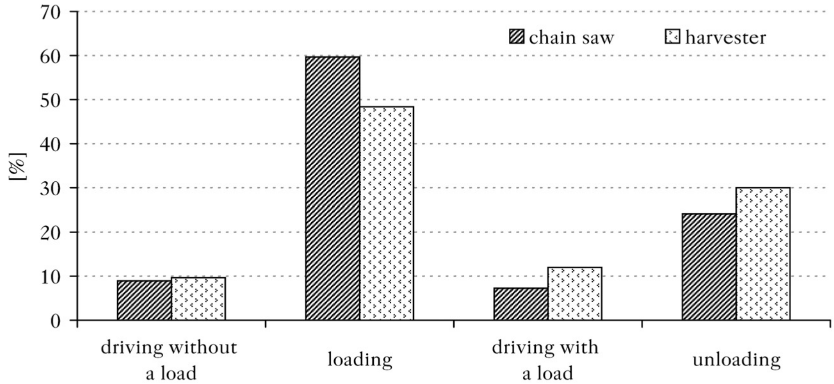

Fig. 1.

Structure of operation time for an extraction unit depending on timber harvesting technology (chain saws, harvester)

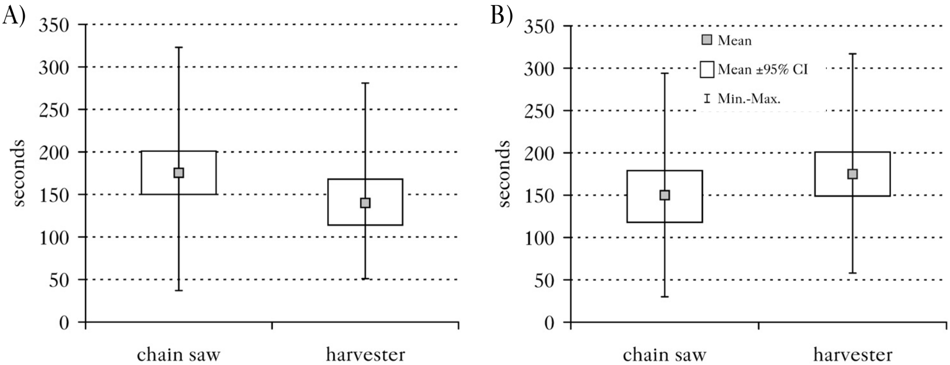

Fig. 2.

Distributions of times of travel to collect a load (A) and travel with a load (B) depending on timber harvesting technology

felled logs was 2 min. and 56 s, whereas for those felled using a harvester it amounted to 2 min. and 22 s, with the differences in this case being statistically significant (Z=2.98, p=0.022).

Distributions for durations of extraction cycle stages irrespective of the extraction distance are presented in Figure 3 (A – loading, B – unloading). The mean loading time for logs felled using chain saws was 19 min. and 36 s, while for those felled using a harvester it was markedly shorter at 11 min. and 49 s. A statistically significant dependence was observed between the duration of log loading and the adopted timber harvesting technology (Z=5.961, p<0.001). The mean unloading time for logs felled using a harvester was 7 min. and 20 s, whereas for those felled with chain saws it was 7 min. and 55 s. Differences between the durations of this extraction stage were small (Fig. 3B) and statistically non-significant (Z=1.951, p=0.051).

The mean duration of the extraction cycle for logs harvested with chain saws amounted to 32 min. and 51 s (at extreme values ranging from 25 min. 47 s to 43 min. 12 s), while for logs felled using a harvester it was 24 min. and 25 s (at extreme values ranging from 16 min. 47 s to 33 min. 14 s), with the differences being statistically significant (t=7.463, p<0.001).

Productivity in the operation time for extraction of logs felled using a harvester was over 15 $m^3 \cdot h^{-1}$, while for logs harvested with chain saws it was almost 12 $m^3 \cdot h^{-1}$ (Table 3), with the differences being statistically significant (t=–6.007, p<0.001).

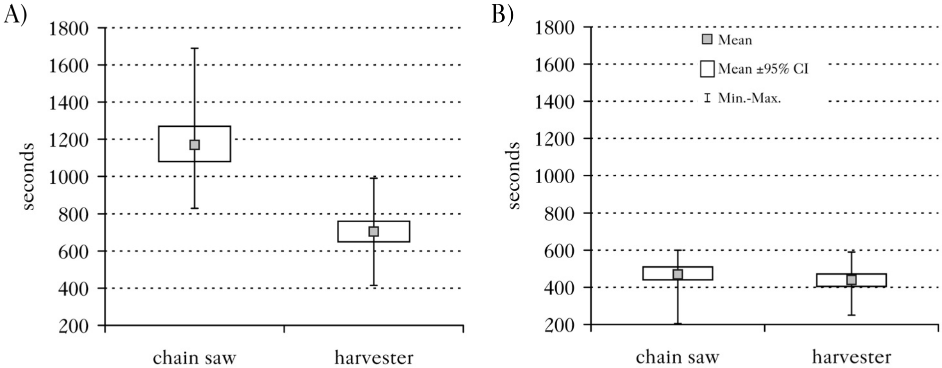

Fig. 3.
Distribution of durations of loading (A) and unloading (B) depending on timber harvesting technology

Table 3.
Mean ($\overline{x}$), median (Me), minimum (Min.), maximum (Max.), standard deviation (SD) and coefficient of variation (CV [%]) for hourly productivity of log extraction [$m^3 \cdot h^{-1}$] depending on timber harvesting technology

	$\overline{x}$	Me	Min	Max	SD	CV
CS	11.92	11.62	9.10	15.12	1.81	15.16
H	15.39	15.30	10.55	20.69	2.31	14.98

CS – chain saw, H – harvester

Both in the case of extraction of logs harvested with chain saws and with a harvester a weak, statistically non-significant correlation was found between the distance traveled to collect a load and the duration of the extraction cycle (chain saws: R=0.28, p=0.175; harvester: R=0.274, p=0.167). The situation was slightly different for the distance and log loading time, where for logs felled using a harvester there was no correlation between these variables (R=0.192, p=0.337), while for chain saws a weak, statistically non-significant correlation was observed (R=0.252, p=0.224).

Discussion

In this study the mean load of logs felled using a harvester was 6.20 m^3, while for that harvested with chain saws it was 6.44 m^3. At pine wood density of 740 $kg \cdot m^{-3}$ (Rozporządzenie, 2012) it was approx. 4600-4800 kg, *i.e.* slightly over 50% maximum load capacity of a Palms 9s self-loading trailer of 9000 kg. Literature data indicate that wood of Scots pine *Pinus sylvestris* L. may have greater density. For example, Tomczak *et al.* (2016) reported 844 $kg \cdot m^{-3}$, which would amount to a load of 5200-5400 kg. In turn, results of inspections conducted by the Inspectorate of Road Transport indicate that standard density of pine wood of 740 $kg \cdot m^{-3}$ is underestimated by approx. 180-220 kg (Szymaniak, 2020). Including these values would increase a single load to 5800-6000 kg, while the utilization of load capacity would increase to 65-67%. The utilization of load capacity amounting to 66% (at pine wood density of 750 $kg \cdot m^{-3}$) was reported by Kulak *et al.* (2023) for a Palms H92 trailer with load capacity of 9000 kg during extraction of 3 m long logs. In that study logs were arranged on the trailer in two stacks, resulting in the length of the load markedly exceeding the length of the loading space of the trailer (slightly less than 5.2 m), while nevertheless the utilization of load capacity did not exceed 70%. A similar situation was observed when conducting analyses within this study, as load length (4 m) was also greater than the length of the loading space (3.9 m); nevertheless, the utilization of trailer load capacity only slightly exceeded 50%.

Such an underutilization of load capacity in self-loading trailers has also been indicated by other researchers. For example, in a study very similar to these investigations, for loads of medium-sized timber assortments (almost 6.5 m^3) harvested during late thinnings of pine stands Naskrent *et al.* (2019) reported 40% load capacity utilization. In turn, a much better result (over 80%) was obtained by Kormanek *et al.* (2018) during extraction of hardwood assortments of 1 m in length using a Belarus 820 agricultural trailer with a PD 80 trailer. Underutilization of load capacity is also observed in the case of professional vehicles (forwarders). In a study by Laitila *et al.* (2007) during extraction of fuel wood during thinning operations performed with a forwarder of 8500 kg load capacity approx. 60% utilization of load capacity was recorded (at wood density of 850 $kg \cdot m^{-3}$). In turn, in a study of Proto *et al.* (2018) the mean load for a forwarder of 13200 kg load capacity was 10.1 m^3, while for a forwarder of 20200 kg load capacity it ranged from 14.3 to 14.8 m^3 (results from cutting areas). For pine wood density of 740 $kg \cdot m^{-3}$ this would correspond to utilization of load capacity for these forwarders amounting to 57 and 53%, respectively.

Forwarding of timber (using an agricultural trailer with a self-loading trailer, a forwarder) is cyclic in character (Nurminen *et al.*, 2006). The operation cycle consists of four stages – travel to collect a load, loading, travel with a load, and unloading. For the operator of the extraction unit in this study loading accounted for the longest time, as – in the case of logs felled using chain saws – it amounted to almost 60% of operation time. A similar share of loading time for medium-sized timber harvested during late thinning of pine stands (also harvested using chain saws) was recorded by Naskrent *et al.* (2019). The greatest share of loading time during timber extraction using an agricultural trailer with a crane trailer was also reported by Kormanek and Fiszer (2018) and Kulak *et al.* (2023). Forwarding using professional machines (forwarders) is also characterized by the greatest share of loading time in the extraction cycle. For example, Proto *et al.* (2018) in their studies on factors affecting extraction productivity for pine timber harvested during thinning with the use of a John Deere 1110E forwarder and from two cutting areas using a John Deere 1910E forwarder recorded loading time shares amounting to 40.1%, 35.6% and almost 50%, respectively. In that study unloading ranked second, as the share of its time was 32.6%, 23.3% and 27.5%, respectively. Manner *et al.* (2016) based on TimberLink data from two John Deere 1910E forwarders recorded during almost 8900 extraction cycles found the greatest, 45% share for loading time. An even higher share of that time (50-55%) was given by Gagliardi *et al.* (2020) in their investigations concerning extraction efficiency for pine logs *Pinus patula* Schiede ex Schltdl. & Cham. of varying length with the use of two forwarders – a smaller one with load capacity of 15000 kg, and a larger one with load capacity of 20000 kg. In their study the smaller forwarder, for which a slightly greater share of loading time (55%) was recorded, loaded timber from both sides of the strip road, while the larger performed the operations from one side of the road.

Analyses, which results are presented in this paper, showed a smaller share of loading time for logs felled using a harvester compared to chain saws. A similar regularity for fuel wood extraction (load volume of 6 m^3) with the use of a harvester and with chain saws was reported by Laitila *et al.* (2007).

According to literature on the subject (Ghaffariyan, 2022b) extraction productivity for a unit composed of an agricultural tractor and a trailer may range from less than 4 $m^3 \cdot h^{-1}$ up to over 19 $m^3 \cdot h^{-1}$. In this study operation productivity for extraction of logs harvested using chain saws was almost 12 $m^3 \cdot h^{-1}$. A slightly lower productivity (11.3 $m^3 \cdot h^{-1}$) was obtained by Naskrent *et al.* (2019) for extraction of medium-sized industrial and fuel timber, also harvested using chain saws during late thinning of pine stands. Generally literature sources typically give lower forwarding productivity for operations performed with an agricultural tractor with a self-loading trailer, as a rule amounting to max. 10 $m^3 \cdot h^{-1}$. For example, Zychowicz and Kasprzyk (2014) obtained effective productivity of 5.72 $m^3 \cdot h^{-1}$ for extraction of medium-sized hardwood timber of 2.5 m in length over a relatively small distance of 174 m. An even lower extraction productivity for hardwood rollers of 1 m in length harvested from a clear cutting area, amounting to 4.8 $m^3 \cdot h^{-1}$, was reported by Kormanek and Fiszer (2018). In that case such a low productivity could have been caused by a long extraction distance of 770 m. Dudek and Janas (2022) in their studies on extraction of pine logs of 2.5 m in length over a distance of 475 m recorded productivity of approx. 6.5 $m^3 \cdot h^{-1}$. A greater extraction productivity (almost 7.5 $m^3 \cdot h^{-1}$) for slightly longer pine logs (3 m) was obtained by Kulak *et al.* (2023). In their study logs were arranged on a trailer in two stacks, which should have increased productivity, although extraction operations were performed over a long distance of more than 1300 m. Leszczyński *et al.* (2021) in their analyses concerning timber harvesting efficiency using an Arbro 400s harvester head mounted on a Kubota excavator for medium-sized pine timber of 2.5 m in length recorded extraction productivity slightly over 4 $m^3 \cdot h^{-1}$. In that case such a low productivity could have been affected by the very small dimensions of felled trees (timber was harvested in the first commercial thinning of a pine stand). Operation efficiency recorded in this study for extraction of logs felled using a harvester exceeded that of logs felled using chain saws and it amounted to almost 15.5 $m^3 \cdot h^{-1}$. Available literature shows that it one of higher efficiencies (Ghaffariyan, 2022b). Still an even higher productivity for forwarding performed using an agricultural tractor with a crane trailer, amounting to 19.2 $m^3 \cdot h^{-1}$ from final yields in a eucalyptus plantation in Spain was given by Spinelli *et al.* (2004). That result could have been influenced by the greater timber accumulation in the clear cutting area and a smaller extraction distance (mean of 174 m) than it was in this study.

Analysis of the correlation between the distance travelled to collect a load and the duration of the extraction cycle for both timber harvesting technologies showed a weak, statistically non-significant correlation, at very similar values of Spearman's correlation coefficient (0.27-0.28). Similar values of this coefficient for both technologies may result from the similar duration of the extraction cycle per unit length of the strip road (5.8-6.1 $s \cdot m^{-1}$). In turn, analysis of dependencies between the distance travelled to collect a load and loading time showed no such dependency in the case of extraction of logs using a harvester and a weak dependency in the case of logs felled using chain saws. This lack of correlation for extraction of logs using a harvester may have resulted from greater timber accumulation at strip roads in that technology (0.054 $m^3 \cdot m^{-1}$) compared to logs felled using chain saws (0.032 $m^3 \cdot m^{-1}$).

Conclusions

- Results of the study confirmed the hypothesis on greater extraction productivity for logs felled using a harvester compared to the use of chain saws. Both in the case of extraction of logs harvested with chain saws and with a harvester no relationship was found between the distance travelled to collect a load and the cycle duration, or the distance and loading time.
- Operation efficiency for extraction of logs felled using a harvester was by almost 30% greater than that for extraction of logs felled using chain saws. At the same time, the duration of the extraction cycle for these logs was by over 25%, and the distance required to collect a load by almost 43% shorter than it was for logs felled using chain saws.
- Analyses confirmed the structure of operation time characteristic of forwarding with the greatest share of loading time, while the share of this time for logs harvested with the use of chain saws was by over 20% greater than it was for logs felled using a harvester.

Authors' contributions

W.S. – conceptualization, methodology, material collection, statistical analyses, investigation, writing – original draft preparations; M.T. – conceptualization, material collection, formal analysis, writing.

Conflict of interest

The authors declare no conflict of interest.

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STRESZCZENIE

Wpływ technologii pozyskiwania drewna w trzebieży drzewostanów sosnowych *Pinus sylvestris* L. na efektywność zrywki kłód ciągnikiem rolniczym z przyczepą samozaładowczą

Pozyskiwanie drewna w Polsce odbywa się coraz częściej metodą drewna krótkiego (*cut-to-length*, CTL), w której wyrobione przy pniu sortymenty są w sposób nasiębierny zrywane do drogi wywozowej. W metodzie drewna krótkiego operacje technologiczne (ścinka, okrzesywanie, przerzynka) mogą być wykonywane pilarkami lub harwesterami. W przypadku zastosowania pilarek sortymenty drewna średniowymiarowego są ręcznie transportowane do szlaków, przy których następuje ich koncentracja w pakietach zawierających kilka, rzadziej kilkanaście wałków. Koncentracja znacznie cięższych kłód jest w tym przypadku utrudniona i ogranicza się z reguły do przemieszczenia tych bardziej oddalonych od szlaku w zasięg żurawia maszyny zrywkowej. Gdy ścinkę i operacje obróbcze wykonuje harwester, dokonuje on także koncentracji całości drewna przy szlaku operacyjnym. Zrywka drewna w metodzie drewna krótkiego realizowana jest obecnie z reguły forwarderami, ale wykorzystywane są do tego celu także ciągniki rolnicze z przyczepami samozaładowczymi. Celem badań było porównanie podstawowych parametrów efektywności nasiębiernej zrywki kłód pozyskanych harwesterem i pilarkami. Kłody o długości 4,0 m pochodziły z trzebieży późnych drzewostanów sosnowych *Pinus sylvestris* L. w wieku 89 i 104 lat (tab. 1). Zrywkę wykonano ciągnikiem rolniczym Ursus 1224 o mocy 86 kW z przyczepą samozaładowczą Palms 9s o ładowności 9500 kg. Analizowano wielkość ładunku, dystans niezbędny do jego zgromadzenia, strukturę operacyjnego czasu pracy, czas cyklu zrywkowego oraz wydajność w czasie operacyjnym. Zbadano także, czy istnieje związek między dystansem do zebrania ładunku kłód i czasem cyklu zrywkowego oraz między dystansem i czasem załadunku. Pomiarami objęto 27 cykli zrywkowych kłód pozyskanych harwesterem i 25 cykli zrywkowych kłód pozyskanych pilarkami. Odległość zrywki kłód pozyskanych harwesterem wynosiła 250 m, a pozyskanych pilarkami 200 m. Średnie ładunki kłód pozyskanych pilarkami i harwesterem były podobnej wielkości (tab. 2). Dystans, który musiał przejechać zestaw zrywkowy, żeby zgromadzić ładunek kłód pozyskanych pilarkami, był dłuższy (statystycznie istotnie) niż kłód pozyskanych harwesterem (tab. 2). W strukturze operacyjnego

czasu pracy największy udział miał czas załadunku, przy czym dla kłód pozyskanych pilarkami udział ten był o ponad 20% większy niż dla kłód pozyskanych harwesterem (ryc. 1). Udziały czasów większości faz zrywki (poza załadunkiem) kłód pozyskanych harwesterem były większe niż pozyskanych pilarkami (ryc. 1), natomiast w przypadku wartości średnich sytuacja taka dotyczyła jedynie jazdy z ładunkiem (ryc. 2 i 3). Średni czas jazdy z ładunkiem kłód pozyskanych harwesterem był o około 0,5 min dłuższy niż z ładunkiem kłód pozyskanych pilarkami (ryc. 2B). W przypadku jazdy po ładunek sytuacja była odwrotna: o około 0,5 min dłużej trwała jazda po kłody pozyskane pilarkami (ryc. 2A). Średni czas załadunku kłód pozyskanych harwesterem był o około 40% krótszy (różnica była istotna statystycznie) niż kłód pozyskanych pilarkami (ryc. 3A), natomiast średnie czasy rozładunku były zbliżone (nieco dłużej trwał rozładunek kłód pozyskanych pilarkami) (ryc. 3B). Średni czas cyklu zrywkowego kłód pozyskanych pilarkami był statystycznie istotnie dłuższy od czasu cyklu zrywkowego kłód pozyskanych harwesterem. Wydajność operacyjna zrywki w obu technologiach pozyskiwania drewna przekroczyła 10 $m^3 \cdot h^{-1}$ (tab. 3), przy czym większa (statystycznie istotnie) była w przypadku kłód pozyskanych harwesterem. Badanie związków korelacyjnych wykazało generalnie słabe, statystycznie nieistotne korelacje, a w przypadku dystansu do zebrania ładunku i czasu załadunku kłód pozyskanych harwesterem nie wykazano korelacji.