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Comparing the productivity and costs of extraction of long and short wood

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Abstract: *Comparing the productivity and costs of extraction of long and short wood.* The aim of the study was compare the effectiveness of extraction long and short wood, carried out on the same felling area. LKT 80 (set 1) and a Valtra 8050 farm tractor with Palms 10D forestry trailer equipped with Palms 4.70 hydraulic crane (set 2) were used for the experiment. Set 1 transported long timber (> 6.0 m) on an average distance of 365 m with an average load of 3.44 m^3. Set 2 transported short timber 2.5 m long, an average distance of 500 m, with an average load of 6.90 m^3. The unit cost per hour of extracting long timber with set 1 was € 38.93 h^{-1}, and short timber with set 2 - € 31.68 h^{-1}. In the order given, the efficiency of skidding for a distance of 500 m was: 7.05 m^3h^{-1}, 7.19 m^3h^{-1}; and direct costs of timber extraction was: 5.52 €m^{-3}, 4.41€m^{-3}. At distances >170 m, short timber extraction is more cost-effective than long timber extraction.

Keywords: farm tractor, forest trailer, skidding, timber extraction, wood harvesting

INTRODUCTION

Recently, costs of wood harvesting have increased significantly by the increase in fuel prices, equipment servicing services and statutory minimum wage. Simultaneously, they may not always be sufficiently compensated by the amount of rates for forestry work.. Hence the need to look for appropriate solutions aimed at increasing efficiency combined with the profitability of the services provided. The profitability of the use of specific means for timber harvesting depends on the size of the cut area, load accumulation, fragmentation and distribution of forest complexes (Goychuk et al. 2011, Nurek and Gendek 2016). A very important factor influencing the effectiveness of skidding sets is also the type of cuts made in the stand. On open areas (clearcut), machines will show greater efficiency than during partial cuts (Maksymiak and Grieger 2008), and with higher efficiency, lower direct costs of skidding of 1m^3 can be counted on (Adebayo et al. 2007, Kaakkurivaara and Kaakkurivaara 2018). A study by Soman et al. (2019) in the USA shows that the total cost of harvesting with partial harvest was 54% higher than with clear-cut, and the largest part of the costs (52-70%) was incurred by timber extraction. This is related to difficulties in accessing subsequent pieces of loaded wood. Difficult terrain effectively slows down work, and inadequate equipment aggravates this problem. Currently, tractors with four-wheel drive are becoming a certain standard when working in the forest. This feature improves their off-road capabilities and allows them to transport larger loads of wood. Even better parameters have a set in which the trailer also has driven wheels. This translates into an increase in skidding efficiency. Such machines will be particularly useful in difficult terrain conditions, e.g. with larger slopes. Dudek (2010a) showed an increase in the single load of the set with all-wheel drive by

45%, compared to the set without drive on the trailer axle, using the same model of farm tractor. Harvesting in Poland is mainly carried out using two systems: the long-lenght-system LLS and cut-to-lenght CTL, together with the increase in the share of mechanized logging observed in the countries of Central and Eastern Europe (Mederski et al. 2016, Moskalik et al. 2017), the share of short timber is constantly growing. In Poland, the most commonly used technology in final felling is semi-suspended log skidding with the use of LKT skidders (Maksymiak and Grieger 2008) supplemented with pull inward skidding of short wood with a farm tractor with a self-loading trailer. It is possible to carry out trailed log skidding with the use of horses, but its percentage share was clearly decreasing several years ago (Dudek 2010b), and currently the importance of horse skidding is marginal. Long beams skidding can also be performed farm tractors with appropriate equipment. An additional possibility of semi-suspended skidding is the use of the cable logging system, but they generate high costs, and their use is justified in extremely difficult conditions: swampy areas, very steep slopes (Dudek 2010a,b), hence their importance in timber skidding in Poland is insignificant.

The abovementioned problems mean that very popular means of skidding in the mountain and sub-mountain areas in this part of Europe are skidders LKT 80 used for long timber skidding, and agricultural tractors with self-loading trailers used for transporting short timber, which are a cheaper alternative to specialized forwarder forestry tractors (Dudek and Janas 2022). The advantage of agricultural tractors is their versatility, which allows them to be used with many devices for each type of skidding and various types of plows, used during preparatory work for forest renewal. This allows for a faster return on equipment purchase costs (Naskrent et al. 2019).

The aim of the study was to compare the efficiency and direct costs of semi-suspended long timber skidding with a specialized skidder-type forestry tractor and skidding short timber with a farm tractor with a self-loading trailer.

MATERIAL AND METHOD

Study area

The study was carried out in one research area located in south-eastern Poland, in the Kolbuszowa Forestry Inspectorate - compartment 151b. In the tests, a specialized cable skidder - LKT 80 (set 1) was used for skidding long timber, and a Valtra 8050 farm tractor aggregated with a Palms 10D self-loading trailer (set 2) was used for skidding short timber. Both skidding sets moved along the same, designated skidding trails. The wood was harvested with chain saws, and both tractors were operated by the same operator. Throughout the study period, the trails were in good condition, dry and passable. Small ruts were created as a result of repeated passage of skidding machines, which, however, did not affect the speed of the extraction. There were no obstacles along the entire length of the trails. Timber was stored at the ends of two main logging trails, on both sides of the compartment 151b. Both log yards were located near a public road with an asphalt cover.

Compartment 151b has an area of 9.78 ha. A group felling was carried out there, currently it was the last cut-clearing. The habitat type of the forest is a moist forest, a flat plain area. The species composition was mostly European beech (*Fagus sylvatica* L.) (30%), common hornbeam (*Carpinus betulus* L.) (30%) and oak (*Quercus robur* L. and *Q. petraea* Liebl.) (20%) aged 101 years old. Beech aged 61 years (10%) and black alder (*Alnus glutinosa* Gaertn.) (10%) aged 81 had a smaller share. The average DBH for beech was 59 cm, and for oak 48 cm (the wood of these two species was harvested).

Stand valuation class: I and II, tree cover 0.8, moderate intermittent crown cover (Forest Management Plan 2020).

Characteristics of timber extraction sets

The set 1 is a specialized LKT 80 skidder forest tractor. This tractor is characterized by a two-piece frame. This tractor does not have swivel wheels. The change of direction is possible thanks to the articulated frame, controlled by hydraulic cylinders. On the front part of the frame there is a driver's cabin with protective nets, an engine and a blade. The drive unit is a naturally aspirated Zetor 8001 diesel engine with a power of 60 kW at 2200 rpm (Table 1). The rear part of the frame is equipped with a stop plate and an electro-hydraulic winch. The single-drum winch has a pulling force of 59 kN. The rope wound on the drum can be 75 m long at 14 mm in diameter.

Table 1. Characteristics of the machines used in the study

Machine	LKT 80	Valtra 8050	Machine	Palms 10D forest trailers
Configuration	4 × 4 wheel drive	4 × 4 wheel drive	Weight/loaded weight (tonnes)	1.7/11.3
Weight (tonnes)	6.4	5.0	Length (mm)	3975 (4825*)
Power (kW)	60	81	Width (mm)	2165
Tires	16,9/14-30-10	14.9R28 front 18.4R38 back	Number of stanchions	6 pairs
Transmission	5 + 1	36 + 36	Loader	Palms 4.70
Max. speed (kmh)	25	50	Weight (tonnes)	0.7
Length (mm)	5300	4860	Crane reach (mm)	7000
Height (mm)	2580	2800	Lifting moment (kNm)	47
Width (mm)	2230	2560	Rotation angle (°)	370

* The trailer model is equipped with a special extension attachment

The set 2 is a Valtra 8050 agricultural tractor aggregated with a Palms 10D self-loading trailer equipped with a Palms 4.70 hydraulic crane. The tractor has been equipped with a hydraulic winch, which helps the machine to get out of the mud during difficult working conditions or can be used to pull hard-to-reach pieces of wood. Guards mounted on the front and underside of the machine are also important elements. In addition, a safety cage made of steel profiles was installed.

Determination of time consumption and efficiency of timber extraction

Extraction performance tests were carried out in October and November 2022. The weather conditions did not affect the work efficiency. While performing research activities and elaborating the results, the methodology proposed in the works of Dudek (2009) and Dudek and Janas (2022) was used. Using the timing method, the efficiency of the skidding operation was determined by wood volume and time of individual transport activities: driving for the load, loading, in the first case (set 1) loading consists in unrolling the required length of the winch rope, attaching it to the logs, pulling the wood to the machine and lifting one end of the piece (semi-suspended position). In the second case (set 2), the loading consisted of activities such as: unfolding and folding the trailer supports, loading timber with a hydraulic crane and moving the set on the surface (access to subsequent pieces of timber so as to enable loading of the entire trailer), loaded driving and unloading - this operation includes such activities as: the set's journeys near the piles containing the appropriate assortments of wood, unfolding and folding the trailer supports, unloading the timber from the trailer to the appropriate pile (set 2), unfastening the winch ropes and stacking wood in piles (set 1).

The time of individual skidding activities was measured with an accuracy of 1 s. Within the study, the time of 18 individual full cycles of timber skidding was measured. The length of the path from the cutting area to timber yard was measured using the Geoportal application and GPS location. The volume of the load with the LKT tractor was read from the forester's recorder based on the registration numbers of the collected wood, separately for each cycle. In contrast, the volume of the load to be torn off by the Valtra was assumed based on volume of the load trailer, then assigned a value of 6.9 m^3 for each tearing cycle, because each time the trailer was full and carried an assortment of the same length. Having data on the length of the skidding trail, the volume of the load and the time of the full cycle, the time consumption of each of the 4 skidding operations (loaded and unloaded driving, loading and unloading) was calculated, and then the skidding efficiency was determined, in accordance with the methodology described by Dudek and Janas (2022).

Determining the costs of timber extraction

For this purpose, the methodology proposed in the work of Dudek and Janas (2022) was used. Unit costs of timber skidding were calculated on the basis of annual prime costs.

In order to calculate the costs of extraction, a market analysis was conducted and literature data were used (Sosnowski et al. 2004, Gil and Zaborski 2005, Sosnowski and Porczak 2005, Dudek and Janas 2022).

Loan interest rate, minimum wage, fuel price, exchange rate (1 Euro = 4.78 PLN) and purchase price of funds deriving fees were adopted according to their amounts in force on February 17, 2023. The price of fuel without VAT was used to calculate the costs.

RESULTS

Evaluation of the time consumption and efficiency of timber extraction

Extraction set 1 transported long timber (> 6.0 m, beech and oak). The average size of the skidded load was 3.44 m^3 and the average skidding distance was 365 m. The extraction set 2 transported short timber 2.5 m long (beech and oak). The average size of the hauled load was 6.90 m^3, and the average hauling distance was 500 m.

The results of the time consumption of timber extraction are summarized in Table 2.

Table 2. Average time-consumption of timber extraction with the tested sets

Extraction set	Time consumption by unit			
	Unloaded driving [hm^{-1}]	Loading [hm^{-3}]	Loaded driving [hm^{-1}]	Unloading [hm^{-3}]
1	0.000234	0.051499	0.000276	0.016080
2	0.000228	0.067737	0.000286	0.034079

Based on the data from Table 2, the unit time consumption of driving (A) and loading work (B) was calculated for set 1 (1) and set 2 (2):

$$A1 = 0.000234 + 0.000276 = 0.000510\ hm^{-1}$$
$$B1 = 0.051499 + 0.016080 = 0.067579\ hm^{-3}$$
$$A2 = 0.000228 + 0.000286 = 0.000514\ hm^{-1}$$
$$B2 = 0.067737 + 0.034079 = 0.101816\ hm^{-3}$$

Grouped in the above manner, the unit time consumption of driving (A) at the distance (L) and loading work (B) at the load (Q) allowed to determine the equation of cycle time consumption for set 1 (Tc_1) and set 2 (Tc_2):

$$Tc_1 = 0.000510L + 0.067579Q1$$
$$Tc_2 = 0.000514L + 0.101816Q2$$

Using these equations, the efficiency of timber extraction was calculated with a specialized LKT 80 skidder forestry tractor and a Valtra 8050 farm tractor with a Palms 10D trailer equipped with a Palms 4.70 hydraulic crane (Table 3).

Table 3. Efficiency of timber extraction with the tested sets

Extraction set	Extraction distance [m]	Volume of a single load [m^3]	Time consumption of the cycle [h]	Cycle frequency [number h^{-1}]	Productivity of extraction [m^3h^{-1}]
1	100	3.44	0.2837	3.53	12.13
	200		0.3348	2.99	10.28
	300		0.3858	2.59	8.92
	400		0.4369	2.29	7.88
	500		0.4880	2.05	7.05
	600		0.5389	1.86	6.38
2	100	6.90	0.7539	1.33	9.15
	200		0.8053	1.24	8.57
	300		0.8567	1.17	8.05
	400		0.9081	1.10	7.60
	500		0.9595	1.04	7.19
	600		1.0109	0.99	6.83

The conducted research shows that set 1 is more efficient up to a distance of 400 m, while set 2 is more efficient above this distance. Such results were influenced by a 100% higher average load in the case of set 2 and shorter loading time (by 163%) and unloading (by 324%) for set 1 (Fig.).

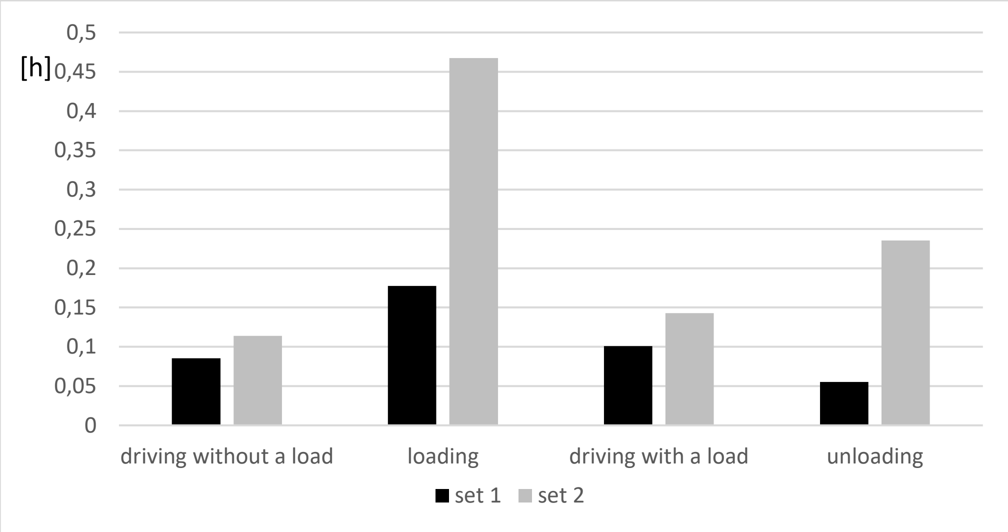

Figure. Time of individual transport operations in an average of timber extraction cycle

Analysis of direct costs of timber extraction

The data collected in Table 4 was used to calculate the costs of timber extraction with the tested sets. The unit hour cost of long timber with set 1 was 38.93 €h^{-1}, and for short timber with set 2 - 31.68 €h^{-1} (Table 5).

Table 4. Input data for calculating the costs of timber extraction

Parameter for cost calculation (behind the study of Dudek and Janas 2022)	LKT 81*	Valtra G105 HiTech + Palms 10D with crane 4.70*
Purchase price, €	137 030	82 500 + 30 020
Depreciation period, yrs	8	8
Value after the depreciation, % of the purchase price	10	10
The loan interest rate per year, %	8	8
Equipment insurance, % of the purchase price	2.5	2.5
Fuel consumption, dm^3h^{-1}	8.5	6
Oil and lubricant consumption, % of the fuel price	10	10
Fuel price without VAT (22%), €dm^{-3}	1.25	1.25
Number of service people	1	1
Employee wages, €h^{-1}	5.96	5.96
Number of working hours per year	1680	1680
Repair cost index, % of depreciation costs	70	70

* This is the most similar to the tested set available in the companies' offer.

Then the cost of one cubic meter of wood was calculated with the tested sets in the distance range of 100-600 m. Higher direct costs of skidding 1 m3 at a distance of 100 m were recorded for set 2 - 3.46 €m-3, which was caused by 33% lower extraction efficiency of the tested set. On the other hand, at extraction distances of 200 m and more, higher direct costs were recorded for set 1 - from 3.79 to 6.10 €m-3 (Table 6), which at shorter distances from 200 to 400 m resulted mainly from higher hourly extraction costs, and at longer distances (500-600 m) from lower extraction efficiency.

Table 5. Calculation of annual and hourly direct costs of timber extraction

Cost items	LKT 81		Valtra G105 + Palms 10D with Crane 4.70*	
	€ year^{-1}	€h^{-1}	€ year^{-1}	€h^{-1}
Depreciation	15 416	9.18	12 659	7.54
Loan interest	6 117	3.64	5 022	2.99
Insurance	3 426	2.04	2 813	1.67
I. Fixed costs - total	24 959	14.86	20 494	12.20
Fuel	17 850	10.63	12 600	7.50
Oils and lubricants,	1 785	1.06	1 260	0.75
Wages	10 013	5.96	10 013	5.96
Repairs	10 791	6.42	8 861	5.27
II. Variable costs - total	40 439	24.07	32 734	19.48
Extraction costs total (I + II)	65 398	38.93	53 228	31.68

Table 6. Direct costs [€] of timber extraction 1 m^3 of wood at a distance of 100-600 m

Timber extraction set	Timber extraction distance [m]					
	100	200	300	400	500	600
	Timber extraction cost [€m^{-3}]					
Set 1	3.21	3.79	4.36	4.94	5.52	6.10
Set 2	3.46	3.70	3.94	4.17	4.41	4.64

DISCUSSION

Analyzing the performance results of the two tested timber extraction sets, it can be concluded that over short distances, the extraction with the LKT 80 shows higher efficiency, and at a distance of ≥ 500 m, the extraction with a farm tractor with a forestry trailer turns out to be more efficient. Both tested methods of extraction are characterized by a decrease in efficiency with increasing distance, but the downward trends are different. In the case of the LKT 80 skidder, there was a sharper decrease in productivity with the distance of the extraction. The results obtained in the work are consistent with the conclusions of Grodecki and Stempski (2002), who stated that at a short transport distance, the extraction of long wood is better, and a greater distance, the extraction of short wood is more beneficial.

In both sets, the most time was spent on loading. Especially in the case of forwarding short wood, loading determines the longer time of a single extraction cycle. Naskrent et al. (2019) in their work also found that loading is the most time-consuming. This is due to the repeated need to drive up to subsequent pieces of wood and degree of scattering of the material over the surface of the cuts. The study by Stempski (2012) shows that loading on an ordered clearcut is 1/3 faster than on an unordered one. Also Kulak et al. (2017) report that loading a John Deere 548G skidder takes the most time during one skidding cycle - from approx. 25% to 52% (average distance 124-246 m). Kulak et al. (2023) also found that loading in the case of forwarding of short wood with a tractor with a forestry trailer equipped with a hydraulic crane consumes the most time, from 37% to 40% of the full cycle, depending on the extraction set and the average extraction distance (461-1317 m). However, Proto et al. (2018) found that driving with a load in the case of the John Deere 548H skidder is the most time-consuming element of timber extraction and takes up 30% of the entire cycle (average distance 276 m). Similarly, for extraction with an farm tractor equipped with a cable winch, Cataldo et al. (2020) reports that driving with a load takes the most time - 42% of the full cycle (average distance 276 m).

The loading for both tested extraction sets is a similar percentage share of the full extraction cycle: set 1 - 42%, set 2 - 49%. The unloading works of the extraction of long wood account for 13% of the whole cycle, and the extraction of short wood - 25%. Loading and unloading are variables that will determine efficiency for the same extraction distance, therefore, with shorter loading times, set 1 achieves higher efficiency at a distance of up to 450 m, despite a much smaller average load size (Table 3). The study yielded the extraction productivity of the LKT 80 forest tractor - 8.92 m^3h^{-1} over a distance of 300 m. A 29% higher yield for the extraction distance of 300 m and the same tractor was obtained in the work Dudek (2010b) - 11.49 m^3h^{-1} in mountain felling stands. However, in this case, the average load was 32% higher - 4.54 m^3. The smaller size of the load in these tests resulted from the short length of the wood with very large diameters - wide butt ends made it difficult to connect a larger number of pieces - forming a larger load. On the other hand, the extraction performance for the LKT 81T tractor and the distance of 300 m, which is lower by 14% than that obtained in this study, is reported by Orlovský et al. (2020) - 7.66 m^3h^{-1} with a higher average load - 5.45 m^3. Even lower values for skidding in winter conditions are given by Acar and Dinç (2001) – 5.87 m^3 h^{-1}, with an average distance of 250 m. These differences confirm that the efficiency of extraction (at the same distance) is influenced not only by the average load, but also by a whole range of other factors, e.g.: greater intensity of cuts on a given surface increases the efficiency of extraction (Leszczyński et al. 2021), as well as well-developed forest infrastructure (Enache et al. 2016). In turn, the increasing inclination of the terrain affects the longer time of individual treatments of timber extraction operations, which results in lower efficiency (Diniz et al. 2019, Ezzati et al. 2021). Extraction performance is also affected by the number and size of trees per cycle (Hejazian et al. 2013), machine type and size (Mohammad 2020), operator skills and experience (Suhartana and Yuniawati 2023).

Similarly, a large differentiation in the efficiency achieved is noted in the case of extraction of short timber with the use of farm tractors with trailers. The performance of a tractor with a forest trailer is primarily determined by the size of the loading volume of the trailer and the power of the tractor. During the experiment, the trailer was used to its full potential, fully loaded. The tested set obtained an efficiency of 8.05 m^3h^{-1} at a extraction distance of 300 m. A similar set in a felling stand was examined by Dudek and Janas (2022), and its efficiency for a distance of 300 m was equal to 5.66 m^3h^{-1}, but the trailer had a lower 19% average cargo volume (5.57 m^3). Spinelli et al. (2015) report an average efficiency of a tractor with a forest trailer combination of 6.8 m^3h^{-1} (transport distance 5.5 km). Whereas Spinelli et al. (2004) report that a farm tractor with a trailer on a eucalyptus plantation obtained a capacity of 13.4 m^3h^{-1} (skidding distance 174 m). This is 54% more than obtained in this study for the same distance (8.71 m^3h^{-1}). Whereas Kormanek and Fiszer (2018) obtained a yield of 4.98 m^3h^{-1} for a extraction distance of approx. 500 m, carried out with snow cover, which in turn is a value lower by 31% than that obtained in this study.

The hourly cost of extraction calculated in the paper was described in the case of set 1 (LKT 80) - € 38.93 h^{-1} (Table 5), it is 47-106% lower than the John Deere 548H skidder (Proto et al. 2018, Bernardi et al. 2022), by 72% from the John Deere 848H skidder (Miyajima et al. 2021), and by 19-31% from the Timberjack 450C skidder (Hejazian et al. 2013).

The hourly cost of extraction in set 2 (Valtra 8050 + Palms 10D) calculated in the paper amounted to € 31.68 h^{-1} (Table 5) and is similar like in the paper by Leszczyński et al. (2021) for MTZ Belarus 952.2 Farm Tractor with FAO FAR 84 - 31.73-37.15 €h^{-1} and in the work of Dudek and Janas (2022) for a very similar extraction set: Valtra G105 HiTech with a Palms 10D - 30 trailer, 32€h^{-1}. On the other hand, Spinelli and Magagnotti (2010) for the Valtra 130 set with the Kronos 100 forestry trailer, calculated the hourly cost of extraction 114% higher (67.7 €h^{-1}) than for this study.

The cost of extraction 1 m^3 of timber calculated for the study in the range of 100-600 m was € 3.21-6.10 m^{-3} for set 1 and € 3.46-4.64 m^{-3} for set 2 (Table 6). A similar value was obtained for the Ecotrac 120 V skidder in the mountain forests of Croatia, Horvat et al. (2007) – € 4.88 m^{-3}, for the extraction distance of 300 m. Slightly higher costs for a similar extraction set were obtained by Dudek and Janas (2022) in lowland forests of Poland – € 4.78-6.13 m^{-3}, in from 100 to 500 m. Meanwhile, Proto et al. (2018) give a value of 5.80 €m^{-3} for the John Deere 548H skidder for the extraction distance of 276 m. This is 37% more than the value obtained in the work for this distance (4.23 €m^{-3}). Even higher, the cost of extraction 1 m^3 of wood was calculated by Mousavi et al. (2012) for the HSM-904 skidder – 13.2 €m^{-3} at the distance of 253 m. Also, high costs were calculated by Bernardi et al. (2022) for the John Deere 548H skidder in the variant with a cable winch, the rope Skidder was € 17.36 m^{-3} for mean extraction of 160 m, and in the variant with hydraulic claws, Grapple Skidder was € 8.67 m^{-3} for mean extraction of 185 m.

Spinelli and Magagnotti (2010) for mean extraction distance of 400 m, calculated the skidding cost for an farm tractor with a trailer – € 14.9 m^{-3}. This value is 3.5 times higher than that obtained in our study for set 2. This difference may be due to the fact that in the cited studies, extraction was carried out on very small areas and in younger stands. While Leszczyński et al. (2021) for a farm tractor with a trailer skidding short timber over an average distance of 700 m, they give 7.80-9.13 €m^{-3}. This is a value higher from 60% to 87% than calculated in the work for the same distance (4.87 €m^{-3}). From the review paper by Louis et al. (2022) shows differently from this study, namely that the costs of semi-suspended extraction with a skidder (6.89 ± 5.29 €m^{-3}) are lower than the costs of extraction with the use of a forwarder (8.76 ± 6.61 €m^{-3}). However, Louis et al. (2022) did not include in the review the results of studies on extraction with the use of a farm tractor with a self-loading trailer, and only specialized forwarder forestry tractors were taken into account. In addition, they do not provide the average hauling distance, and yet the distance is one of the main factors affecting the efficiency, and thus the direct costs of extraction.

Large butt diameters with a relatively short length of large-size timber had an impact on the small volume of the load formed by the LKT 80. In order to improve work efficiency and better use of the load capacity of the skidder, the handling of these logs should be carried out at the log yard, so that the whole trunks are removed from area of tree felling and then skidded to the timber yard – to manipulate the raw material in accordance with the needs of wood recipients. However, in this case, the less expensive set: a farm tractor with a self-loading trailer would have much less work. Therefore, before starting the extraction, the front of work for both sets should be determined. For this purpose, first of all, the timber extraction distances must be taken into account. In the case of longer skidding trails, a larger front of works should be planned for farm tractor with trailer with manipulation on the area of the cuts, while in the case of shorter trails for a skidder tractor, and then the manipulation of the raw material should be transferred to the timber yard.

Another solution to increase productivity may be the concept of an innovative winch enabling the use of the same tractor to skidding long timber using a rope winch and short timber using a trailer hitched to this winch. This solution can generate an increase in productivity by 12% (Gironimo et al. 2015).

CONCLUSION

Comparing the 2 technologies of timber extraction performed on the same felling area, with distances greater than 170 m, short timber extraction with set 2 (Valtra 8050 farm tractor with Palms 10D trailer and Palms 4.70 hydraulic crane) turns out to be more profitable (lower direct costs) than the long timber extraction set 1 (LKT 80 skidder). This result was influenced by a 100% increase in the collected one-off load and lower costs of extraction in the case of a cheaper farm tractor with a self-loading trailer. Therefore, for shorter distances, it would be recommended to extract long wood using the semi-suspended method, and for longer distances, to transport short wood using a trailer. With the market demand for various assortments and hand-machine harvesting with the use of chainsaws, the manipulation of wood in order to reduce the costs of timber extraction should be partly transferred to the timber yard.

The largest part of the extraction time, in the case of both tested technologies, is consumed by loading. Stacking short timber into groups during harvesting can improve extraction performance. However, when harvesting with chainsaws, such practices can extend increase the logger’s working time, reducing his productivity.

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Streszczenie: *Porównanie wydajności i kosztów zrywki drewna długiego i krótkiego.* Celem badań było porównanie efektywności zrywki drewna długiego i krótkiego, prowadzonej na tej samej powierzchni zrębowej. Do doświadczenia wykorzystano ciągnik LKT 80 (zestaw 1) oraz ciągnik rolniczy Valtra 8050 z przyczepą leśną Palms 10D wyposażoną w żuraw hydrauliczny Palms 4.70 (zestaw 2). Zestaw 1 transportował długie drewno (> 6,0 m) na średnią odległość 365 m przy średnim ładunku 3,44 m^3. Zestaw 2 transportował krótkie drewno o długości 2,5 m, na średnią odległość 500 m, przy średniej wielkości ładunku 6,90 m^3. Jednostkowy koszt zrywki drewna długiego za pomocą zestawu 1 wyniósł 38,93 €h^{-1}, a drewna krótkiego za pomocą zestawu 2 - 31,68 €h^{-1}. Odpowiednio wydajność zrywki dla odległości 500 m wyniosła: 7.05 m^3h^{-1}, 7.19 m^3h^{-1}; a bezpośrednie koszty zrywki wyniosły: 5.52 €m^{-3}, 4.41€m^{-3}. Przy odległościach >170 m zrywka drewna krótkiego jest bardziej opłacalna niż zrywka drewna długiego.

Słowa kluczowe: ciągnik rolniczy, przyczepa leśna, zrywka, pozyskiwanie drewna, zrywka drewna

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