A Mobile Hydraulic Winch for Use in Small-Scale Forestry

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Abstract

Winches have recently been used to extract timber from forests. Winches are often components of tractors, but tractors cannot be used on difficult terrain and are generally too expensive for small forest owners. The current study considers the use of an experimental winch for the extraction of timber from small plots with difficult terrain. The mobile hydraulic winch used in this study weighs 50 kg and has a pulling force of up to 53 kN, a 12 V motor, and a 64x224 mm drum. The associated power unit is a gasoline, single-cylinder, four-stroke, air-cooled KIPOR KG 390D (400D), 389 cm^3 engine, with 7.7 kW of power, and a torque of 22.6 Nm at 2500 rpm. The engine powers a high-pressure oil pump with an output pressure of 3 MPa and a flow rate of 60 litres per minute. The input torque of the pump shaft is 25 Nm at 3000 rpm. The hydraulic winch can be fixed to tree trunks, stumps, or wooden pegs by lashings. The winch was tested at three locations with different assortments of wood. The results showed that the experimental winch was practical for timber extraction and that <250 kN of force was needed for successful extraction. At the test sites, the expense of lumber removal was on average 140% greater with the winch than with a horse but the advantage of the hydraulic winch is high pulling force. Because of its small size and low weight, the unit can be easily handled by two workers, easily moved at short distances in small plots with rough terrain, and easily transported among plots. With a one-man crew, the percentage of direct costs represented by wages dropped to 56%, and the percentage represented by fuel increased to 40%.

Keywords: farm-forestry, extraction, productivity, cost analysis

1. Introduction

The technology used to transport timber out of forests, i.e., to extract timber from forests, mainly depends on the type of timber and the terrain. The force required can be generated by gravity, machinery, or by humans or various animals. In contrast to aerial extraction by helicopter, ground extraction is done by pulling or towing (Zloch 1971).

In recent years, extraction from larger forests plots on relatively even terrain has often involved the use of winches (Akay 2005, Russell and Mortimer 2005, Gellerstedt 1997), which are usually located on universal farm tractors or forestry tractors (Laurier et al. 2002). Although tractors with winches can be very useful, their manoeuvrability is inadequate for use in small forest plots, and they cannot be used on steep slopes (Akay 2005). Moreover, the owners of small forest plots seldom own tractors.

In many countries, forest properties are often small and divided among multiple owners. Currently, about 150,000 individuals own forest land in the Czech Republic. The average area of forest land owned per person is about 3 ha. Only 0.3% of the owners owned more than 50 ha of forest in 1990s (Jánský 2000). For such small owners, the use of large machinery is not economical. Even when the owner belongs to a cooperative, the fragmentation of the land often precludes the economical use of large machinery (Ottaviani Aalmo et al. 2016). At least in other countries, banks do not want to lend to small owners, and if they do, the owner often has a big problem repaying the loan (Mitchell-Banks 2001). For these reasons, small owners have become interested in buying smaller, more versatile equipment.

An alternative to tractor-mounted winches, are small portable winches (Visser and Stampfer 2015). For example, the LD-52UV was introduced in 1952 and the VSKII was introduced in 1955. These winches,

which had drums that could hold 350–400 m of 8 mm thick rope, were gradually replaced by iron horses (KAPSEN, MULA) but with short ropes (Balcar 2004). As load manoeuvring is unimportant for thinning, modern mobile winches, such as the LPV-20 VNAD-2 VNAD-D, were developed. However, these machines cannot be used in areas with difficult terrain (Horek 1993). A basic limitation of portable winches is their low pulling force, which ranges from 7–10 kN (Neruda and Zemánek 2013). As a consequence, portable winches cannot be used to extract large logs or large bundles of timber.

For studying the resistance of trees to mechanical stress (Peltola et al. 1999, Gardiner et al. 2000), Macků et al. (2016) designed an experimental mobile winch with commonly available components. As assessing the resistance of full-grown trees to mechanical stress requires substantial force, the experimental winch had high power. The aim of the current study was to assess the use and costs of this experimental winch for timber logging in small-scale forestry.

2. Material and methods

2.1 Descriptions of the winch and power unit

The experimental hydraulic winch and its power unit are described in Fig. 1. The hydraulic winch can be fixed to tree trunks, stumps, or wooden pegs with lashings (Fig. 2).

The winch can generate a 53 kN pulling force. The drum is 64x224 mm. The winch, which is equipped with both wireless and wired controls, weighs about 50 kg. The power unit is a KIPOR KG390D (400D) one-cylinder, 389 cm^3, four-stroke gas engine. The engine has a torque moment of 22.6 Nm at 2500 rpm. The nominal engine power is 7.7 kW at 3600 rpm. The engine powers a high-pressure oil-pump with an output pressure of 3 MPa and a flow of 60 litres per minute. The input torque of the pump shaft is 25 Nm at 3000 rpm (Fig. 2).

The mobile winch and the power unit were constructed as prototypes (Macků et al. 2016). The total cost was about 2000 EUR. Other equipment included
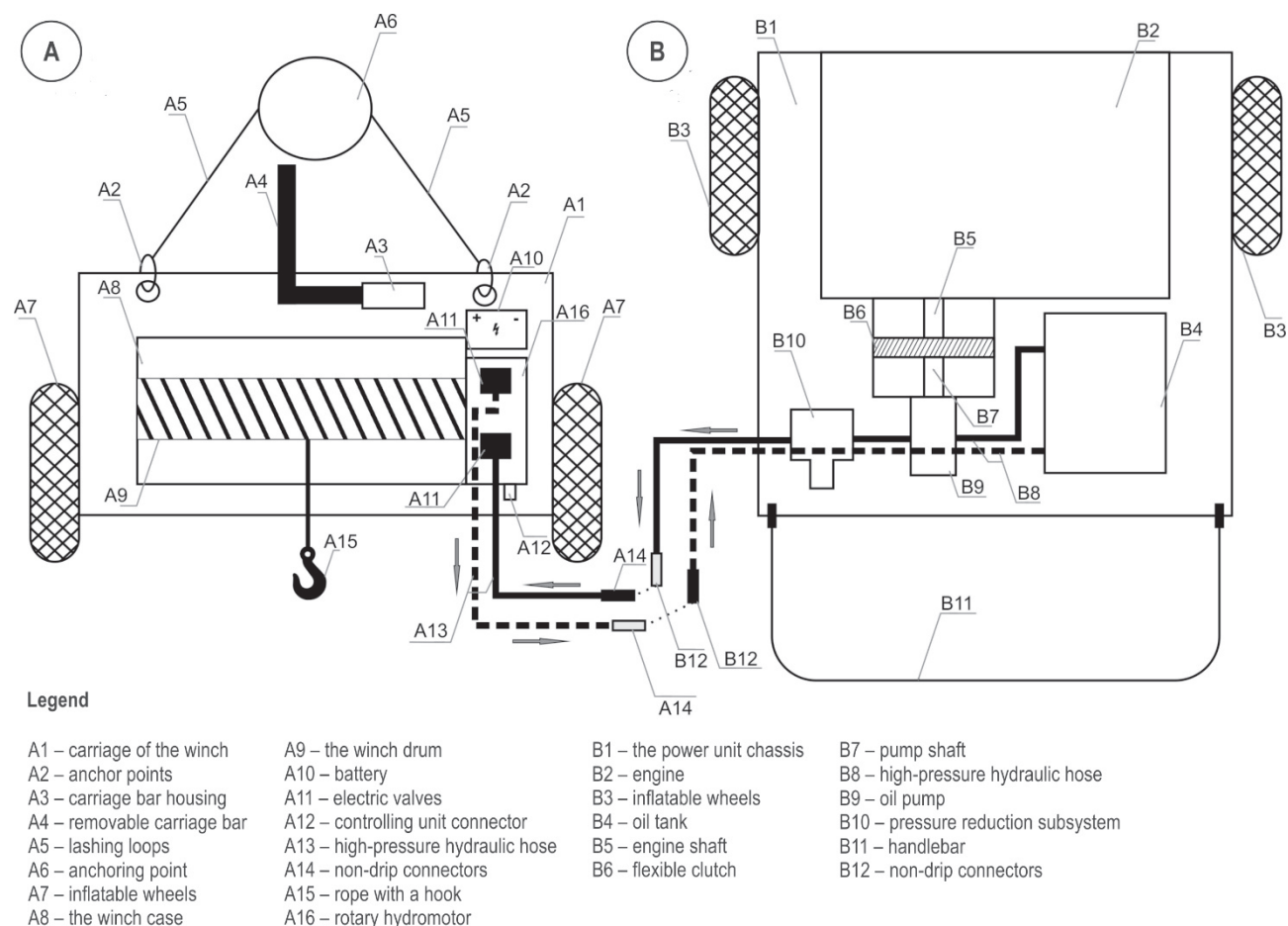

Legend

A1 – carriage of the winch
A2 – anchor points
A3 – carriage bar housing
A4 – removable carriage bar
A5 – lashing loops
A6 – anchoring point
A7 – inflatable wheels
A8 – the winch case

A9 – the winch drum
A10 – battery
A11 – electric valves
A12 – controlling unit connector
A13 – high-pressure hydraulic hose
A14 – non-drip connectors
A15 – rope with a hook
A16 – rotary hydromotor

B1 – the power unit chassis
B2 – engine
B3 – inflatable wheels
B4 – oil tank
B5 – engine shaft
B6 – flexible clutch

B7 – pump shaft
B8 – high-pressure hydraulic hose
B9 – oil pump
B10 – pressure reduction subsystem
B11 – handlebar
B12 – non-drip connectors

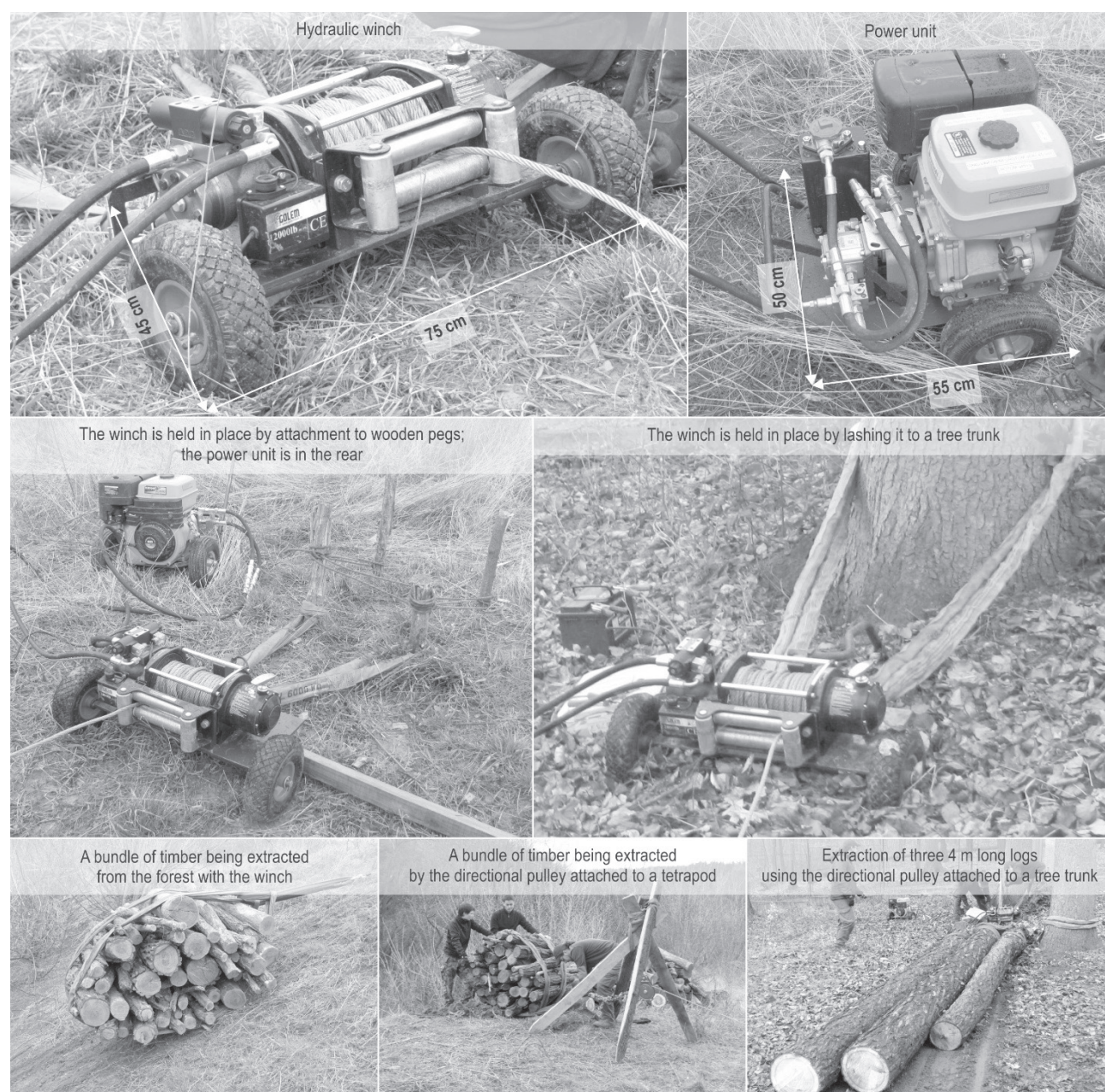**Fig. 1** Hydraulic winch (A) and power unit as seen from above (B)

Fig. 2 Photos of different ways of moving logs with the experimental winch

a wood splitting hammer, axe, chain saw, textile tie-down straps, strain gauge with datalogger, woodchuck, timer, notebook, and camera.

2.2 Study area

To assess the use of the experimental winch for log extraction, five tests were conducted at three locations (Únětice, Liboc, and Svatý Jan pod Skalou) in the central Czech Republic (Fig. 3). Each test consisted of 10 »work cycles« (10 independent extractions). All three locations are at 250–350 m a.s.l. The tests were con-

ducted in dry weather between 10:00 am and 3:00 pm and in parts of the forest where timber has been felled and left in place. Background information on the tests, terrain, and the properties of the extracted timber is provided in Table 1.

In test C, the timber was manually extracted. The pile of firewood was formed of bolts of black locust (*Robinia pseudoacacia*) with a length of 1 m, an average thickness of 16.5 cm (range = 10 to 28 cm), and a moisture content of about 25–30%. In the other four tests, the timber was extracted with the experimental winch.
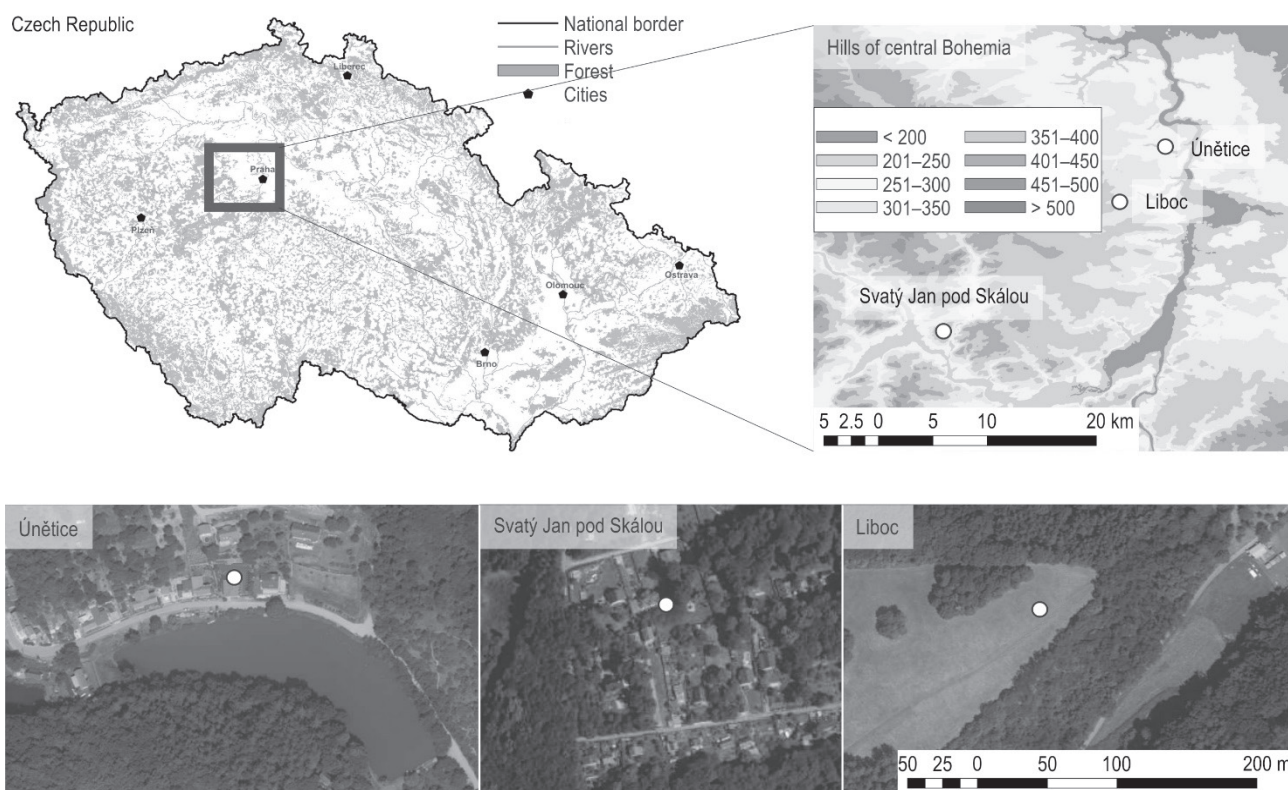
Fig. 3 Localities where the experimental winch was tested for timber extraction; location of the study area

Tests A and C, which involved the same location, slope, and timber properties, enabled a direct comparison of extraction by hand vs. by winch.

2.3 Data collection

As noted in the previous section, 10 work cycles were performed for each test. Each work cycle consisted of the following separate operations:

⇒ rope unreeling (from starting the engine to stopping the unwinding)
⇒ load assembly (from preparing the chokers to moving personnel from the unsafe space)
⇒ winching (from the start of winching by controls until the end of winching)

⇒ load release (from the release of chockers to the start of unreeling the rope again).

A strain gauge and datalogger were used to record the maximum and average pulling forces. The times required to perform all operations of the work cycle, from winch and power unit preparation to deposition of the timber at the roadside landing, were recorded.

2.4 Cost calculation

The cost of extracting timber with the experimental winch was calculated. A standard method was used to calculate fixed and operating costs (Miyata 1980) but it was also modified as needed for the winch. In

Table 1 Background information on the tests and localities used for assessing the experimental winch (extraction distances are listed in Table 2)

Test and locality	Latitude; Longitude	Slope, °	Tree species	Tree age	Length of timber, m	Date of experiment
A Únětice	50.1500703N, 14.3643139E	35	Black locust	60	1	March 29, 2016
B Únětice	50.1500703N, 14.3643139E	<5	Black locust	60	Bundle (Fig. 2 bottom left and bottom center)	March 29, 2016
C Únětice	50.1500703N, 14.3643139E	35	Black locust	60	1	May 19, 2016
D Svatý Jan pod Skalou	49.9709597N, 14.1193853E	<5	Larch	130	4 (Fig. 2 bottom right)	May 1, 2016
E Liboc	50.0991686N, 14.3172789E	<5	Spruce	120	8	June 10, 2016

these calculations, service time of the winch was set at 500 h per year, the depreciation period was set at 10 years, and the salvage value was set at EUR 100. As the winch and power unit are relatively inexpensive (acquisition cost was about EUR 2000), the purchaser was assumed to pay the entire purchase price. There is no need to pay insurance or taxes on this type of device.

Wage costs were based on the average wage of workers, including other employee payments, which, with all other required payments, was about EUR 5.77 per hour in the Czech Republic at the time of the study. That wage is lower than wages paid to workers in Western European countries (Eurostat 2017).

Fuel prices were based on the average prices in 2016. The average CZK exchange rate to EUR in 2016 was used (27 CZK = 1 EUR). Repairs and maintenance costs were obtained from logging machine operators and were set at 10% of the daily depreciation of the machine. General overhead expenses were set at 30% of direct expenses, which is the average value in forestry in the Czech Republic. The calculation includes both total costs and performance costs (total costs + profit) for other entities (with a 15% expected profit). A standard 8-hour shift was used.

Based on the average times of individual operations (Table 2), the total time required to extract 1 m^3 of timber was determined. The volume of timber extracted per shift was calculated based on the average time of extraction in each test. A 7-hour shift was assumed because 1 hour is required to prepare the equipment. The direct costs to extract 1 m^3 of timber was then calculated.

Costs were compared for extraction using the experimental winch vs. a horse. In the case of horse extraction, actual contract prices of timber extraction in forest enterprises were used (School Forestry Com-

pany in Kostelec nad Černými lesy, Vojenské lesy a statky ČR, s.p., Forests of the Czech Republic, s.p.).

Cost was also determined when the experimental winch was operated by two workers in accordance with Executive Order (Nařízení vlády 2002) and by one worker.

3. Results

Extraction distances ranged from 10–25 m (Table 2). Unreeling the rope was the least time consuming operation, followed by loading and forming the load. In most localities, the most time-consuming operation was winching the load. The time required for winching depended on the load and the terrain. Winching a 4 m long log required an average pulling force of about 2 kN when the terrain was flat (test D) but almost 7 kN on a slope with 1 m long log (test A); winching an 8 m long log required over 20 kN when the terrain was flat (test E) (Table 2).

The extraction of wood by hand in test C (10.5 m on a 35° slope) required an average of 55.5 min, which was almost 5 times longer than when using a winch at the same location in test A (Table 2).

The cost per hour calculations (averaged over the four tests with winch) show that over 70% of the direct costs were for wages and 26% were for fuel. Other direct costs were relatively insignificant. With a two-man crew, the direct costs were 16.16 EUR per hr, and cost price (full standard cost + profit) per hr of operation, was 24.16 EUR/hr (Table 3). With a one-man crew, the total direct costs dropped to 10.39 EUR per hr, and the performance-related price was 15.53 EUR per hr (Table 3). With a one-man crew, the percentage of direct costs represented by wages dropped to 56%, and the percentage represented by fuel increased to 40%. The costs

Table 2 Time required for winching operations and pulling forces generated by the experimental winch in five tests

Test and locality	Extraction distance, m	Volume of load, m^3	Time of unreeling, min	Time of load assembly, min	Time of winching, min	Time of load release, min	Total extraction time, min	Logged pulling force, kN
	Average		Average/Minimal/Maximal					
A Únětice	10.3±2.5	1.075	0:50/0:45/0:55	4:30/4:05/5:10	4:20/3:45/5:10	1:50/1:30/2:15	11:30/10:05/13:30	6.56/4.44/10.96
B Únětice	16±2	1.191	1:05/1:02/1:09	4:52/4:10/5:45	7:05/6:50/7:32	2:10/2:50/3:01	15:12/14:52/17:27	6.72/4.53/7.82
C Únětice	10.5±0.5	1.079	ns	ns	ns	52:10/55:05/58:20	ns	ns
D Svatý Jan pod Skalou	15.1±2	0.4	1:02/0:56/1:07	2:10/1:50/2:44	7:02/6:55/7:25	0:33/0:30/0:35	10:47/10:11/11:51	2.37/1.5/3.4
E Liboc	25.2±4.4	0.6	1:33/1:24/1:39	2:05/1:41/2:36	9:10/8:43/10:15	0:35/0:30/0:40	13:23/12:18/15:10	17.35/16.16/20.15

ns – non studied

Table 3 Direct costs and operational costs of the experimental winch with one or two workers

Economic indicator	One worker	Two workers
Investment costs, EUR	2000	2000
Salvage value, EUR	100	100
Lifespan, years	0.37	0.37
Expected yearly usage, hours	18.50	18.50
Fuel consumption, litres/hr	0.14	0.14
Fuel costs, EUR/litre	1.09	1.09
Gross pay-out, EUR/hr	4.31	4.31
Yearly depreciation, EUR/year	190	190
Depreciation, EUR/hr	0.38	0.38
Fuel, EUR/hr	4.15	4.15
Lubricant, EUR/hr	0.04	0.04
Repairs, EUR/hr	0.05	0.05
Pay of operators including mandatory fees, EUR/hr	5.77	11.54
Total direct costs, EUR/hr	10.39	16.16
Overhead expenses (30% of direct cost total), EUR/hr	3.12	4.85
Full standard cost, EUR/hr	13.51	21.01
Expected profit (15%), EUR/hr	2.03	3.15
Cost price (full standard cost + profit), EUR/hr	15.53	24.16
Cost price per work shift, EUR/shift	124.28	193.29

of logging one timber pile by one worker are comparable to logging with a horse (on average only 9% higher). On average, timber extraction was 136% more expensive with the winch than with a horse (Table 3).

The calculations indicate that the cost price of extracting a 1 m³ bundle of timber is 70% higher with the experimental winch than with a horse (4.93 vs. 7.73 EUR/m³). The cost price of horse extraction was not calculated

for extracting bundles of timber because extraction of bundles by horse is not a common practice mainly because of occupational safety regulations (Executive Order Nařízení vlády (2002)) (Table 4).

For extraction of logs, cost price would be 3.5 times higher with the experimental winch (with a two-man crew) than with a horse (Table 4).

4. Discussion

The results of our tests indicate that the mobile winch described here is practical for extraction of timber from small forest plots. In addition to its manoeuvrability, the main advantage of the winch is that it has sufficient pulling force to extract logs from difficult-to-access sites and to extract large logs. The tests confirmed that the winch can extract both individual logs and bundles of logs.

Under extreme conditions (when the lumber is large, the total volume of extracted timber is small, or the plot has very steep slopes), it is usually necessary to involve winches for extraction. The construction and use of an aerial cable system is not practical for the extraction of small volumes of timber, and the use of animal (horse) power is limited by the small pulling force (Neruda and Zemánek 2013), which is 25–50 times lower than that of the experimental winch described here.

Due to its pulling force, the experimental winch used in our tests can extract bundles of timber uphill, although doing so it could damage roots and disturb the soil (Conway 1976). Soil disturbance can be eliminated by using a sulky (Spinelli and Magagnotti 2012).

The cost of extracting a bundle of timber is only 9% higher with the mobile winch than with a horse. On average, extraction of logs is 136% more expensive with the winch than with a horse. One reason why costs are higher with the winch is that the winching speed is low. For winching only 10.3 m, for example, required 11.5 minutes in test A (Table 3). Winching

Table 4 Direct costs and the cost price of the experimental winch per cubic meter of extracted timber and comparison with logging by horse

Test and locality	Extraction distance m	Volume m³	Time total min	Volume per work shift m³	Direct cost EUR/m³	Cost price EUR/m³	Cost price using a horse EUR/m³
A Únětice	10.3	0.62	11:30	22.78	4.97	7.43	4.93
B Únětice	16.0	0.69	15:12	19.09	5.93	8.86	4.70
D Svatý Jan pod Skalou	15.0	0.40	10:47	15.58	7.26	10.86	2.70
E Liboc	25.0	0.60	13:23	18.83	6.01	8.98	2.70
Mean	16.6	0.6	12:43	19.1	6.0	9.0	3.8

could be more efficient if winch speed was increased by the use of a different gearbox. Another reason why costs are higher with winching is that two persons are generally needed for practical and safety reasons. Although only one worker is needed to operate the winch, two workers are needed for preparing the winch and power unit.

A steel rope was used in the current study. The time and effect spent unreeling the rope could probably be reduced, and the distance of extraction increased, by replacing the steel rope with a synthetic rope (Magagnotti and Spinelli 2012). A DynaForce®plastic rope, for example, is lighter than a steel rope but has a higher load capacity (https://www.grube.eu/forestry/timber-harvesting/heavy-timber-felling/1596/ dynaforce-tree-hoist-rope). It is also safer than a steel rope. On the other hand, the purchase price is higher for a plastic rope and the working life may be shorter.

According to Spinelli et al. (2010), the purchasing cost for a tractor, a tractor-powered cable system (like the Savall 1500), and a self-powered cable system is about € 35,000, € 20,000, and € 16,000, respectively. The purchasing cost of the winch and power unit used in the present study was only about 2000 €.

According to Spinelli et al. (2016), managers of small forest plots are increasingly purchasing smaller, less expensive, and more versatile machines rather than heavy industrial equipment (Spinelli et al. 2016).

In addition to being useful for owners of small forest plots, the winch described here would also be useful for arborists. The arborist is usually transporting only a few logs and only for short distances but the logs are often large and, therefore, require a high pulling force (Neruda and Zemánek 2013). Farmers would also find the winch useful for both forestry and non-forestry jobs.

The advantages of the experimental winch and power unit tested here are their small size, low weight, and high pulling force. The power unit alone can be used to operate a small cable system or as a source of hydraulic pressure for a number of hydraulically powered tools and adapters such as chain saws, delimbing devices, woodsplitters, hydromanipulators, etc.

5. Conclusions

The results indicate that the experimental winch described here will be useful for extraction of timber from small forest plots. Because of its small size and low weight, the unit can be easily handled by two workers (tree feller and winch operator), it can be easily moved at short distances in small plots with rough terrain, and easily transported among plots. The winch has sufficient power to extract logs substantially larg-

er than those that can be extracted with conventional portable winches. It can be used for extraction at distances up to 50 m without moving the winch.

For owners of small forest plots, the described winch should be useful not only for timber extraction but also for the transport of other loads. Relative to a tractor, the winch costs less to purchase and can be used in plots with steep slopes. Compared to other mobile winches, the described winch has considerably greater power but remains easy to handle and transport.

The wages of the two workers present over 70% of the direct costs in operating the experimental winch. At the test sites, the expense of lumber removal was on average 140% greater with the winch than with a horse. When the winch is not being used, however, it does not require any additional costs (except for depreciation), while the horse must be fed, stabled, and cared for every day. The winch is, therefore, an excellent choice for small cooperatives with irregular work in the woods.

Acknowledgements

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