PRELIMINARY DATA ON THE PRODUCTIVITY OF STUMP LIFTING HEAD MCR-500

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Abstract
The first published studies on stump extraction for bioenergy in Latvia are dated with second half of the 19th century. In the 3rd decade of the 20th century, stump extraction was identified as one of the most prospective and challenging tasks of forest sector to secure sustainable deliveries of solid biofuel. In that time, stump extraction using explosives was considered to be a conventional forestry technology. Now we are returning to the same challenges; however, mechanical power is used instead of explosives to pull and to crash stumps.
MCR-500 is the first prototype of combined stump extraction and mounding head for a caterpillar excavator produced in Latvia by joining forces of the LSFRI Silava and engineering company Orvi SIA. The device is supposed to be used for extraction of stumps with a diameter up to 50 cm in coniferous and deciduous tree stands. Additional benefit of the device is ability to prepare soil by making mounds for the following forest regeneration. The article summarizes results of productivity trials of stump extraction and preparation of soil using the MCR-500 head. In total, 3.5 ha were extracted during the studies. The harvested amount of stumps was estimated using biomass equations; therefore, it might be corrected in further forwarding and comminution studies when an actual amount of biomass is estimated. Average stock of extractable biomass (stumps and coarse roots) in the experimental sites was 28 tons ha^{-1}. Productivity of stump extraction was 2.4...3.4 tons per efficient hour (2.5 tons in case of optimal rate of scarification of soil). Consumption of efficient time for scarification of soil is 3.4...4.3 hours per ha. Figures of productivity of stump extraction are comparable with the ones obtained with similar stump extraction heads. Scarification of soil with stump lifting head consumes twice more time than conventional trenching; however, in wet sites, productivity figures become closer making the excavator competitive.
Key words: stump extraction, excavator, productivity, biofuel.

Introduction

In spite stump extraction for bioenergy seems to be advanced and new technology arose some decades ago, the first scientific evidence of stump extraction research are dated back to the 19th century when stump harvesting was already well known and commonly used for solid biofuel production and just like now researchers studied an effect of stump extraction on productivity of forest stands (Bode, 1840). After Latvia become a free country in the beginning of the 20th century, questions on independence from external energy sources arose with a new power and researchers returned to stump extraction and the relevant forest regeneration issues. Just like now, opposite viewpoints were declared. For instance, O. Ceichner proposed that blowing up stumps is facilitating leaching of nutrients and erosion of soil. He recommended not to practise blowing up stumps in the state forests (Ceichners, 1929). At the same time, he and other researchers agreed that stump extraction is facilitating natural regeneration of pine stands and does not affect in any harmful way trees of the next generation (Vasiļevskis, 2007). K. Lange was one of the most active advocates of stump extraction. He declared that leaving of stumps in clear-felling areas for decaying is wrong, particularly in less forested regions suffering from lack of firewood (Lange, 1925). Before the World War Two, a production of firewood from stumps reached 7...30 thousand m3 annually. In 1939, the Forest Administration recommended to utilize all clear-felling areas for stump extraction. At that time the most conventional method for stump extraction was blowing up; however, mechanical extraction using special heavers including the ones invented and produced in Latvia became more and more common. Average productivity of stump extraction using heavers was 1,6...2 m3 per day (Vasiļevskis, 2007).

After retrieval of independence, stump extraction and stump biomass for long time did not reach the field of interests of forest practitioners and energy companies because other resources of woody biomass (firewood, residues from sawmills and harvesting remaining) were available in abundant amounts and nearly for free. Significant changes in attitude to stump biofuel happened at the beginning of the 21st century due to constantly growing demand for solid biofuel in local and foreign markets. Since 2006, stump biofuel is produced mainly in forest road construction and utilized as admixture to wood chips from harvesting remnants or sawmill residues. Stump biofuel is not sold as a separate assortment in Latvia yet (Andis Lazdiņš, 2006). The first studies of productivity of mechanized stump extraction in clear-felling areas were implemented in 2006 in cooperation with the Forest Research Institute of Sweden Skogforsk (M. Thor et al., 2008). A caterpillar excavator with a specialized stump lifting head produced by CBI was used in these studies. Average productivity of stump extraction was 10,4 m3 per hour; respectively, 40 times higher than 60 years ago (Andis Lazdiņš and Magnus Thor, 2009); however, these studies did not solve the issues relevant to forest regeneration after stump extraction because the device used was not suited for soil preparation during stump extraction. Additional scarification increases costs of forest regeneration and makes stump extraction unprofitable.

To contribute to improved forest regeneration after stump extraction, the Latvia State Forest Research Institute Silava in cooperation with the engineering and production company Orvi SIA in 2011 invented a new stump lifting device MCR-500, which was aimed to combine the best available knowledge in stump extraction and mounding as a soil scarification method. The device can lift and split stumps and prepare soil with an auxiliary plough producing mounds (initially, an area of mound is 0.25 m^2, in the second prototype – 0.36 m^2). The experimental trials with the first prototype of this device were established in 2011 nearby Riga in Daugava Forestry of the Riga city forest management company Rīgas meži Ltd. Different parameters, like productivity of harvesting and forwarding of stumps, quality of site preparation, and measures relevant to forest regeneration are studied in these trials.

Materials and methods

Stump extraction was done during September, 2011 in Riga forests of Daugava Forestry in 3 forest stands harvested in clear-felling in the winter of 2010/2011. Stand characteristics are provided in Table 1. Stands are sorted in the same sequence they were extracted. Further in the text, codes of the stands consisting of the compartment and block number are used. The stands were split into 4 (forest blocks No. 176 and 98) and 2 (forest block No. 104) experimental sites. Half of the stands were treated in a conventional way (site preparation with a forest trencher) and remaining half – with a stump extraction device doing simultaneous stump extraction and site preparation. All stumps with a diameter more than 20 cm in areas supposed for the stump extraction were measured (determining an average height, diameter, presence of decay and tree species) and marked with visible signs noting the number of the stump.

The stump extraction device MCR-500 was mounted on a New Holland 215B excavator (Figure 1) during the studies. The operator did not have previous

Table 1

Experimental stands

State forest district	State forestry	Forest block	Compartment	Area, ha	Dominant tree species	Stand type	Harvested roundwood volume, m^3
Riga	Ogre	176	18	2.3	Pine	*Myrtilloso-sphagnosa*	949
Riga	Ogre	98	4	3.8	Birch	*Hylocomiosa*	1542
Riga	Ogre	104	9	1.5	Spruce	*Myrtillosa mel.*	293

Source: calculation of the authors

Source: made by the authors

Figure 1. **Stump extraction head MCR-500 on an excavator New Holland 215B**

experience; therefore, the first site (176-18) can be considered as a training place.

All operations were recorded using special tools (Allegro field computer with SDI program). Time consumption was measured separately for every stump. During the time studies, an engineer recording time consumption wrote down the number of treated stump for each record; therefore, it is possible to estimate time consumed for a particular stump with a known height, diameter and species.

The working time was split into eleven operations: (1) turning of tower; (2) driving in a stand; (3) reaching a stump, relevant manipulations with the crane; (4) catching of stump; (5) lifting of stump; (6) splitting of stump; (7) shaking to get rid of soil; (8) dropping to get rid of soil or split a stump; (9) scarification – site preparation; (10) other unexpected operations; (11) other operations not relevant to efficient working time (phone conversations etc.).

The engineer doing time studies also noted the number of mounds prepared between each stump lifting operation. Everything except other operations not relevant to efficient working time was considered as the efficient time.

The five working rules implemented in the last two stands was:

1. extraction of stumps being in a diameter range of 20...50 cm, except spruce, which did not have an upper limit of the diameter;
2. stumps of black alder, ash and other relatively rare tree species important for biological diversity should not be extracted;
3. no stumps should be harvested on strip-roads to avoid problems during forwarding, an exception is dry sites with excellent soil bearing capacity;
4. extracted stumps should be piled in narrow rows alongside the existing strip-roads, an excavator should not use strip-roads during extraction;
5. soil should be prepared in front of the excavator below the stump storage areas and behind the excavator in the rest of area.

Fuel consumption was determined by measurement of refilled volumes of diesel. Average fuel consumption was applied to all trials.

Extracted biomass was estimated using biomass expansion equations published by different researchers in Nordic countries (Marklund, 1988; Repola, Ojansuu, and Kukkola; Hakkila, 1975). Above- and below-ground parts of stumps, coarse roots (diameter above 5 cm) and fine roots (diameter below 5 cm) were considered in calculations. The biomass expansion equations of the dominant tree species in the stand are assumed for rare tree species like aspen and black alder. Average density of wood was considered from the greenhouse gas inventory guidelines (Penman, 2003). The aboveground part of stumps was treated in formulas as cylinder. Fine roots are excluded from measurement of extracted volume (extractable biomass), assuming that they will stay in the ground.

Results and discussion

Total area extracted during trials was 3.5 ha; the total number of extracted stumps – 1235 (74 % of total number of stumps in all trials); an average diameter of extracted stump – 33 cm; biomass extracted during trials according to the biomass equations applied in the study – 96.8 tons (64 % of total extractable biomass); average dry weight of a single stump – 78 kg; the number of prepared mounds – 1997 (Table 2).

In calculation to area units (per ha), the average number of extracted stumps was 353, extracted biomass – 27.7 tons ha^{-1}, all extractable stumps (except stumps marked as too small, too big, belonging to species important for biological diversity as well as stumps of strip-roads) – 43.1 tons ha^{-1}, the average number of prepared mounds – 571 per ha^{-1} (from 315 to 1496), total efficient time – 9.5 hours ha^{-1} including 7.6 hours for stump extraction and 1.9 hours for mounding (Table 3). Notably that in the last stand (104-9), time consumption for soil scarification was 3.3 hours (more by 73 %), but the number of produced mounds – greater than average by 162 %. Similarly, productivity of stump extraction in the last stand was by 20 % higher than in the first stand. Difference between the first and second stand was not so significant. It means that an operator gets used to the working method within 4 days (time consumed for the first 2 stands). However, the average size of stumps in

Table 2

Characteristics of experimental trials and stumps

Object	Area, ha	Extracted stumps	Share of extracted stumps	Average diameter of extracted stumps, cm	Biomass of extracted stumps, kg	Share of extractable biomass	Biomass of average stumps, kg	Prepared mounds
176-18	1.1	415	90%	30	25197	72%	61	346
98-4	1.7	550	71%	36	54108	66%	98	604
104-9	0.7	269	63%	32	17479	53%	65	1047

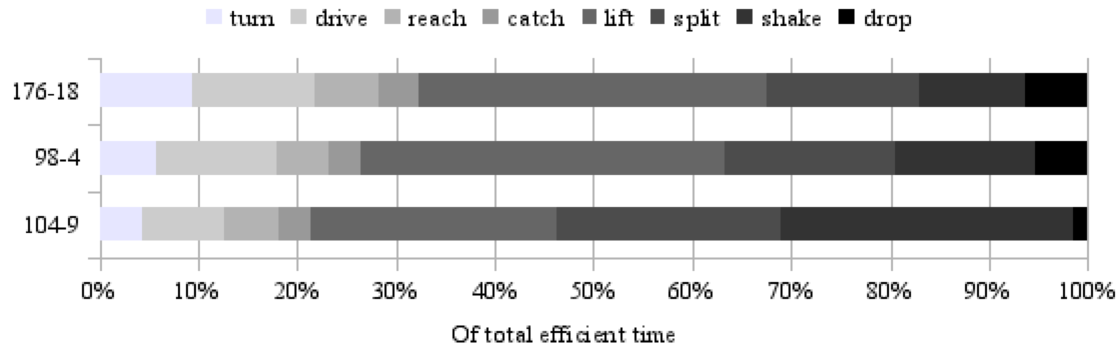
Source: calculation of the authors

Table 3

Productivity figures recalculated to area units

Object	Number of extracted stumps, per ha	Extractable biomass, kg ha^{-1}		Number of prepared mounds per ha^{-1}	Efficient time, hours ha^{-1}			
		extracted stumps	all stumps		total	for stump processing	for mounding	for soil preparation
176-18	377	22907	31774	315	9.4	8.3	1.0	3.0
98-4	324	31828	48511	355	10.4	8.5	1.9	3.4
104-9	384	24970	47242	1496	9.8	6.6	3.3	4.3

Source: calculation of the authors



Source: calculation of the authors

Figure 2. **Share of different operations**

the second stand (98-4) was considerably bigger than in other stands; therefore, decrease in productivity may be explained by unfavourable working conditions. The second stand also characterizes by larger share of birch stumps (27 % of total extracted biomass in comparison with 16 % on average).

If not measuring operations relevant to stump extraction only, average time for soil preparation would be 3.4 hours ha^{-1}. In the last stand, where the number of prepared mounds was optimal or even too big, scarification took 4.3 hours. The disc trenching in a control plot in the same stand took 1.8 hours ha^{-1}. Assuming that stump extraction does not take place and the excavator prepares 2200 mounds ha^{-1} having the same productivity as in the trials, it would take 6.4 hours ha^{-1} to prepare soil. The disc trenchers have 2...3 times higher prime cost of production; therefore, the service price for the both technologies is comparable.

The share of different operations in different stands is shown in Figure 2. The chart clearly shows that in every next stand an operator spends less time on turning, driving in a stand, lifting of stumps; and spends more time on splitting and shaking. In contrast to the first stand, where the operator tried to drop stumps to get rid of soil, at the end of the study he mostly used shaking. This switch in the working method led to considerable visual improvement of quality of extracted biomass; although this method is not healthy both to machine and to the operator. The problem with dropping arose from too slow movement of the splitting knife of the MCR-500 because of technical issue with pressure in hydraulic system – during all the study, the splitting knife got only 65 % of the necessary pressure. In case of shaking, the operator does not have to open the splitting knife several times per stump in contrast to dropping and in contrast to recommendations, the operator completely abandoned dropping as a cleaning method at the end of the study. However, in normal working conditions we would recommend to stick on multiple dropping instead of shaking.

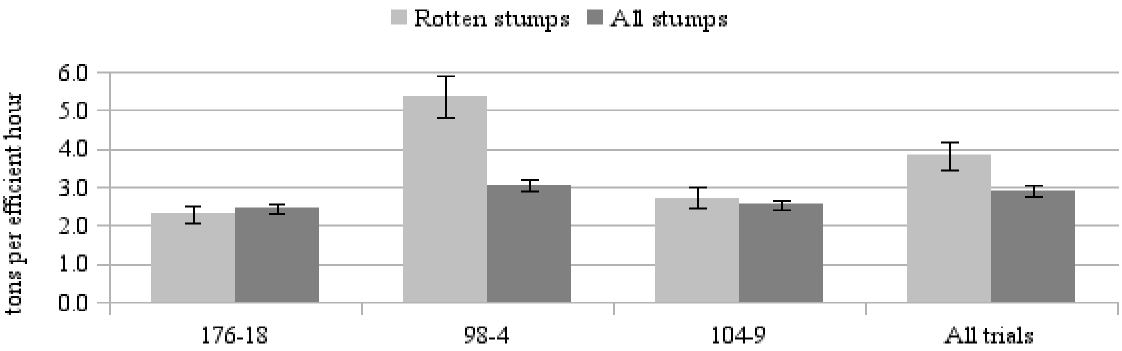
The number of multiple operations was studies to understand if it is reasonable to try to extract several closely located stumps at once or it does not have an effect on productivity. Summarizing results in 14 % of extraction cycles, the operator lifted more than 1 stump, which contributed to 21 % of extracted biomass. Average biomass of stumps extracted in multiple operations was considerably bigger (by 63 %) than of stumps extracted in single operations (Table 4). Time consumption per stump in the multiple and single operations does not differ, but in calculation to biomass, the difference becomes significant – in multiple operations time consumption

Table 4

Extraction of several stumps

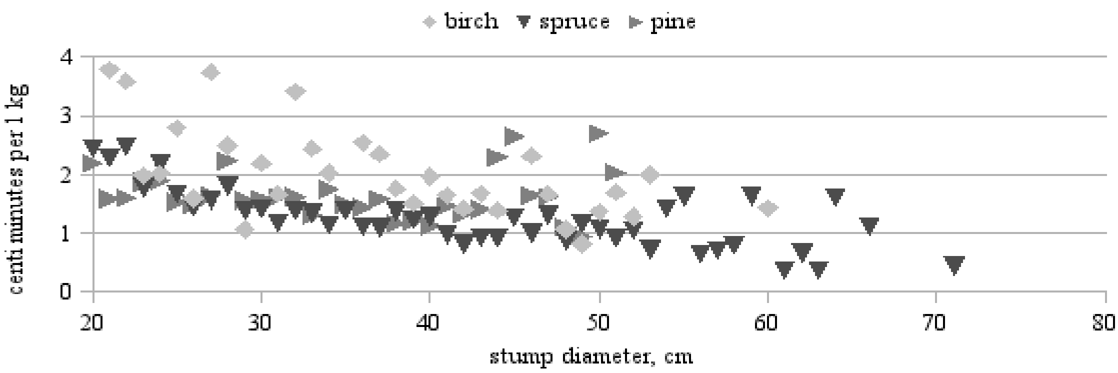
Several stumps in one operation	Percentage of total extracted stumps	Percentage of total biomass	Average biomass of stump, kg	Average time per stump, sec.	Average time, sec. kg^{-1}
1 stump	85.9%	78.9%	70	62	0.89
2 stumps	12.4%	19.2%	117	60	0.51
3 stumps	0.9%	0.8%	62	58	0.94
4 stumps	0.3%	0.2%	41	27	0.66
5 stumps	0.4%	1.0%	200	87	0.44

Source: calculation of the authors



Source: calculation of the authors

Figure 3. **Productivity depending on presence of decay**



Source: calculation of the authors

Figure 4. **Productivity depending on diameter of stump**

per kg is by 41 % smaller (0.53 in comparison with 0.89 sec kg^{-1} in single operations). Obtained results demonstrated that the operator does not have to keep off multiple operations, especially if 2 stumps can be lifted at once.

Another important point to study is the impact of root rot on productivity of stump extraction. The average number of stumps having visual presence of root rot damages was 17 %; in the first trial (176-18), it was only 2 %, in the second an third – 23 %. Harvestable biomass of rotten stumps was 18 %, on average. Figure 3 shows that there is significant difference in productivity working with rotten and healthy stumps – the last takes considerably more time on average, but especially in the second stand.

Evaluation of time consumption for the stump extraction depending on a diameter of stump shows that the diameter significantly affects productivity (Figure 4). For birches, productivity continues to grow for stumps reaching a diameter of approximately 45 cm; then productivity remains relatively constant. For pines, the productivity slightly increases for stumps reaching approximately 43 cm in diameter. For spruces, slight increase in productivity continues even if stumps are more than 60 cm in diameter.

Conclusions

The average extracted stump biomass in the trials according to the biomass equations was 27.7 tons ha^{-1}, (7.6 % of extracted roundwood expressed in m^3); real figures will be known only after comminution because the equations used are known for underestimation of the biomass. Total efficient time – 9.5 hours ha^{-1} including 7.6 hours for stump extraction and 1.9 hours for mounding.

Training of an inexperienced operator to reach a high level of productivity and quality of soil scarification takes 3...4 days. The most of effect relates to quality of soil preparation.

If the evaluated technology is used only for soil preparation (production of 2200 mounds ha^{-1} having the same productivity as in the trials), scarification would take 6.4 hours ha^{-1}. The disc trenching in a control plot in the same stand took 1.8 hours ha^{-1}; however, the disc trenchers have 2...3 times higher prime costs, which might equalize the service price in practice.

The study results demonstrated that the multiple operations are beneficial, especially if 2 stumps can be lifted at once; therefore, operators should always evaluate ability to extract 2 or more stumps at once.

There is significant difference in productivity when lifting rotten and healthy stumps – rotten stumps are easier for extraction; however, it is hard to predict if the same biomass expansion factors can be applied to healthy and rotten stumps.

The species and size of stumps affect productivity; for birches, productivity grows for stumps reaching 45 cm in diameter, for pines, the productivity slightly increases for stumps reaching 43 cm in diameter, for spruces, productivity grows even if stumps are more than 60 cm in diameter.

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