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Productivity and cost of biofuel in ditch cleaning operations using tracked excavator based harvester

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Abstract. Forest ditches is one of the poorly utilized sources of biomass for energy production and timber industry. Increase of productivity and reduction of cost of extraction of biomass from the ditches, retaining at the same time high quality standards, are the key issues of mechanization of harvesting operations in this area. The scope of the study was to evaluate productivity and cost of biomass delivered from forest ditches, when tracked excavator based harvester and different work methods are used. New Holland 215B excavator with Ponsse H7 felling head was used in trials. The machine was operated by experienced operators. The study was implemented in drainage systems managed by Joint stock company „Latvia state forests". Total extracted area 12 ha, extracted biomass – 734 m^3. Duration of the study including harvesting and forwarding – 4 months. Average cost of roundwood production including road transport to 50 km distance in the trials was 27 EUR m^{-3}, average cost of biofuel – 11 EUR m^{-3} (4.5 EUR LV m^{-3}). The study approved advantages of excavators in ditch cleaning operations; however, several improvements are possible. The machine should be equipped with smaller accumulating felling head, delimbing and bucking should be done in parallel to a ditch direction, number of assortments should be reduced, as well as extraction of trees with diameter below 6 cm should be avoided.

Key words: excavator, ditch cleaning, productivity, biofuel, prime cost.

INTRODUCTION

Drainage is one of the most important forest management measure in Latvia contributing to increase of economic value of forests, sequestration of carbon from atmosphere and implementation of social functions of forests. In Latvia 32% of forests grows on drained organic or mineral soils and the improvement of soil water regime in combination of use of improved (bred) plant material, had notably and significantly improved forest productivity and financial value (Jansons et al., 2015; 2011). Forest drainage ditches may become a considerable source of solid biofuel in Latvia. According to results of the study implemented in cooperation with the Joint stock company 'Latvia state forests' (LVM) in 2012 total area of drainage ditches in fertile forest stand types in the state forests is 23 kha. The average above ground biomass of trees on drainage ditches in the fertile forest stand types is 46 tonnes ha^{-1}, and the total stock corresponds to 1.1 mill. tonnes of biomass or 5.4 mill. LV m^3 (LV – loose volume) of chips. If the extraction is repeated every 30 years the annual production capacity is 0.2 mill. LV m^3

of chips or 0.07 mill. m^3 of roundwood. Biofuel (firewood and tops) is about 23 % of the output of roundwood, respectively annual production of wood chips is 0.04 mill. LV m^3, which is about 10 % of chips delivered by the LVM directly from forest operations (Lazdiņš & Zimelis, 2012).

Excavator based harvester is not a common phenomenon in forest management in Latvia in spite this type of machines is well known in forestry since several decades, for instance John Deere produces heavy duty harvesters on tracks. Usually these harvesters are heavy (above 25 tonnes) and are more adapted to extraction of large dimension trees, which is not a case in Nordic and Baltic states (Bergroth et al., 2006). Cranes of tracked harvesters are usually massive and short (7–8 m) to demonstrate the best performance in regenerative felling. In Finland there are studies approving suitability of excavators in thinning of forests on organic soils (Väätäinen et al., 2004); however, excavators are more common in stump extraction and forest regeneration, where tracked excavators approved their reputation of durability and cost effectiveness (Laine & Rantala, 2013; Persson, 2012). Theoretically this type of the machines can be utilized also in ditch cleaning, but they are too costly to operate in conditions, where the most of output is low grade biomass and cost efficiency of the machine is critical (Lazdiņš et al., 2014).

An alternative to the expensive tracked harvester is rebuilding of standard tracked excavator into forest harvester by replacing or extending the crane, installation of a felling head and harvester control system, as well as by adding an external frame around cabin and other safety equipment. This solution costs half of a standard harvester price, but it is not commonly used in harvesting practice due to insufficient durability of standard excavators and worse working environment (mainly vibration) in the tracked machines. Ditch cleaning provides completely different working conditions in comparison to a regenerative felling or thinning – flat landscape, no large stumps, no accessibility issues. These conditions are native to excavators and to their operators providing significant advantages for broader utilization of excavators in forest operations. Smaller excavators (10–15 tonnes) with smaller felling heads can be selected for ditch cleaning; however, the reach length of the crane is still important in the ditch cleaning operations. A standard crane with extension rod (increases reach length up to 11 m) can be used instead of complete replacement of the crane. In this case the excavator can be easily adopted for different operations – digging, harvesting, soil scarification and stump extraction (Lazdiņš & Thor, 2009; Lazdiņš et al., 2014; Zimelis et al., 2015).

According to Finnish studies utilization of tracked excavators instead of standard harvesters is more beneficial than the use of standard middle size wheeled harvesters mainly due to smaller investments and operational costs. The main drawbacks are low clearance, large dimensions of machines and short crane (Väätäinen et al., 2004). The questionnaire of Finnish entrepreneurs using excavators in forest harvesting, constructing companies and producers of the equipment for harvesters resulted with the conclusion that the most important drawbacks are small driving speed (and restrictions to access certain types of roads) and problems to operate in rocky areas. However, constructing companies in Finland proposed interest about utilization of their machines in forest harvesting in winter season (Bergroth et al., 2006).

The clearance and size of the machine have no critical technical value in the ditch cleaning operations, and accessibility of the felling sites can be solved by temporal bridges from low grade roundwood assortments. The most significant benefits of excavators in the ditch cleaning operations are smaller investments and ability to use a machine for different purposes. Reduced environmental impact due to smaller pressure on a ground can be of importance; however, this issue is more related to machines utilized in forwarding of roundwood and biofuel. Ditches usually characterizes with low visibility during harvesting, which is one of the most often mentioned problem in small tree harvesting (Lazdiņa et al., 2012) and there is another benefit of excavators, because the crane is mounted beside a cabin and operator is always looking to the same direction where an operation takes place and there are no obstacles between the cabin and the felling head. Excavators are usually heavier than standard harvesters and the additional weight is another benefit, because it allows to use a crane to the maximum reach length, as well as to use accumulating function for bigger trees and in a larger distance from the machine (Zimelis & Lazdiņš, 2015).

MATERIALS AND METHODS

New Holland 215B excavator (total weight 26 tonnes) with Ponsse H7 felling head was used in trials. Accumulating function was secured by feed rollers. The machine was operated by experienced operators; however, they didn't used accumulating function before the trials. A training period of 3 days was used to adopt to the work methods. The study was implemented in drainage systems managed by Joint stock company „Latvia state forests" nearby Glāzšķūnis and Lēdmane villages. Off-road transport of roundwood was done by John Deere 810D forwarder; harvesting residues were transported by Logset F5 forwarder (no tracks was used during transportation). Forwarder operators were less experienced and demonstrated lower productivity than average in a specific conditions (Lazdiņš et al., 2014; Zimelis et al., 2015). Total extracted area 12 ha, extracted biomass – 734 m^3. Duration of the study – 4 months (May to August, 2015).

Four harvesting methods were compared in the study:

5. full tree biofuel method – production of standard set of roundwood assortments, harvesting residues and non-delimbed undergrowth trees (up to 6 m long) in one pile nearby or across a ditch, accumulating unit utilized for undergrowth trees not suitable for standard assortments;

6. partly delimbed biofuel method – production of standard set of roundwood assortments, harvesting residues and partly-delimbed undergrowth trees; harvesting residues and partly delimbed trees (up to 3 m long) in separate piles nearby or across a ditch, accumulating unit utilized for undergrowth trees not suitable for standard assortments;

7. merged firewood and partly delimbed biofuel method – production of standard set of roundwood assortments (excluding firewood), partly-delimbed undergrowth trees with firewood (up to 3 m long) in one pile and harvesting residues in separate pile; roundwood and biofuel is piled nearby or across a ditch, accumulating unit utilized for undergrowth trees and trees suitable for firewood production;

8. **partly delimbed firewood and undergrowth tree method** – production of standard set of roundwood assortments, harvesting residues, partly delimbed firewood, partly-delimbed undergrowth trees and harvesting residues; firewood (2.7–3.3 m long),

undergrowth trees (up to 3 m long) and harvesting residues in separate piles nearby or across a ditch, accumulating unit utilized for undergrowth trees not suitable for standard assortments and trees suitable for firewood production.

Schematic structure of the work methods is provided in Fig. 1. Assortments specific for certain method are highlighted with darker lines.

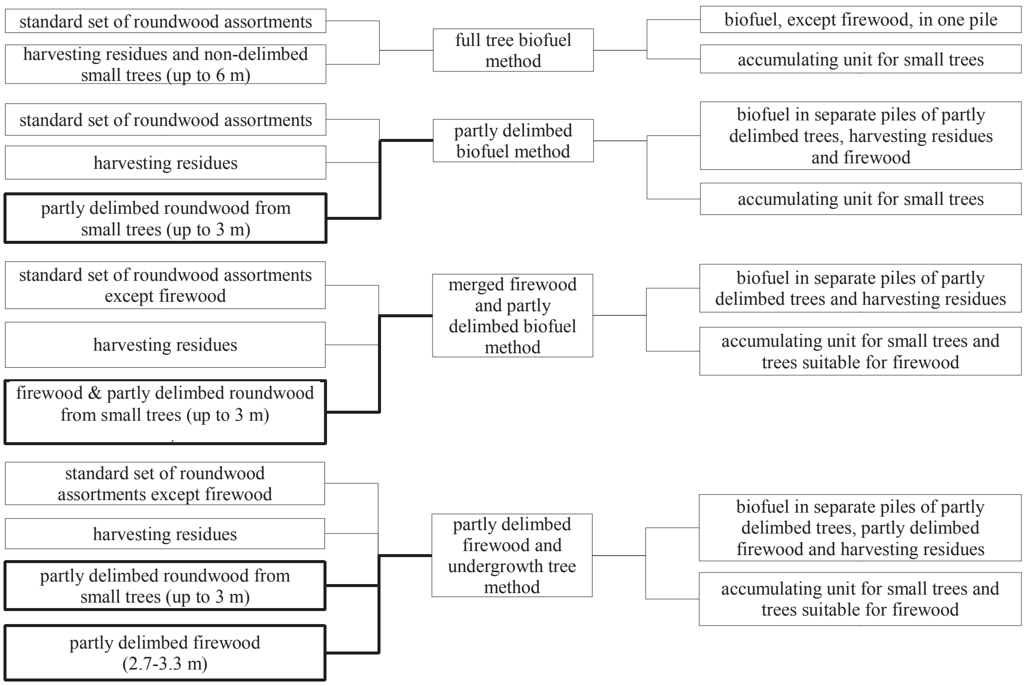

Figure 1. Schematic structure of work methods.

The 4th method is separated to utilize to a maximum extend capacity of the harvester and the accumulating unit while working with large dimension trees.

Time studies of all operations were done by the LSFRI Silava team. Calculation of prime cost was based on information delivered by dealers of New Holland, John Deere and Logset in Latvia.

Calculation of productivity and cost of biofuel is based on time studies of the harvesting and forwarding (roundwood and harvesting residues separately). Figures on productivity and cost of chipping and road transport of roundwood was borrowed from earlier studies (Zimelis and Lazdiņš, 2015).

The work time was accounted using shock- and humidity-resistant field computer Allegro CX with time tracking software SDI. During hauling, the driving speed of the forwarder was determined using GPS measurements within the SDI software. The time studies of the excavator included automated accounting of fuel consumption using an AIC-904 VERITAS unit. For other machines average values provided by the contractors were used. The work time of the machines was matched with accounting of the engine hours, i.e. the time study was stopped when the engine was switched off and resumed when the engine was started again.

The work time elements are shown in Table 1. Volume of every load forwarded to roadside were estimated by operators and verified by the harvester accounting system for every ditch.

Table 1. Work time elements in harvesting and forwarding

Harvesting		Forwarding	
Category	Explanation	Category	Explanation
Informative fields	work cycle number	Informative fields	various notes on breaks, passages, change of ditches etc.
	average diameter of gripped trees D1.3, mm	Productive work time	driving to stand
	qty. of gripped trees		reaching logs or branches when loading
	felled half-trunks		gripping logs or branches when loading
	various notes, especially on manipulations with chain or chain bar		loading logs or branches in the bunk
Productive work time	reaching tree		arranging logs or branches in bunk
	time for gripping tree		driving during loading
	cutting tree		putting logs or branches into strip-road
	drawing the trunk and placing in the assortment stack		driving out of stand
	clearing the undergrowth		reaching log or branches when unloading
	bucking the tree		
	time consumed to enter the stand		unloading logs or branches (from gripping till releasing in the yard)
	time consumed to exit the stand		gripping logs or branches when unloading
	other non-standard operations, inter alia clearing the undergrowth and machine service		moving when unloading
Non-productive time	activities not related to work		other work-related operations
		Non-productive time	activities not related to work

The ditches were surveyed before and after the operations and surrounding stands were surveyed after the operations to estimate rate of damages. Square sample plots (20 m long with a ditch dependant width, average area 400 m^2) were equally distributed across the ditch and at least 100 trees per ha were measured (species, diameter and height of about 10% of the measured trees) in the sample plots. Damages of trees were accounted in all stands across the ditches in a 20 m wide band after harvesting and forwarding of roundwood and harvesting residues.

RESULTS AND DISCUSSION

Duration of harvesting time studies was 174 hours, average productivity of harvester was 6.2 m^3 per efficient hour at the average tree volume of 0.28 m^3. The most of the produced assortments was firewood and pulp-wood (78 % in total, Fig. 2). A share of high grade logs produced in the trials was only 13 %; the most of them only 1 % from the total stock (0.6 m^3 ha^{-1}). The efficient work time (work cycles resulting with logs) was 76 % of the planned work time. The most important issue was regular problems with the chain due to lack of automatic tensioning system in the felling head.

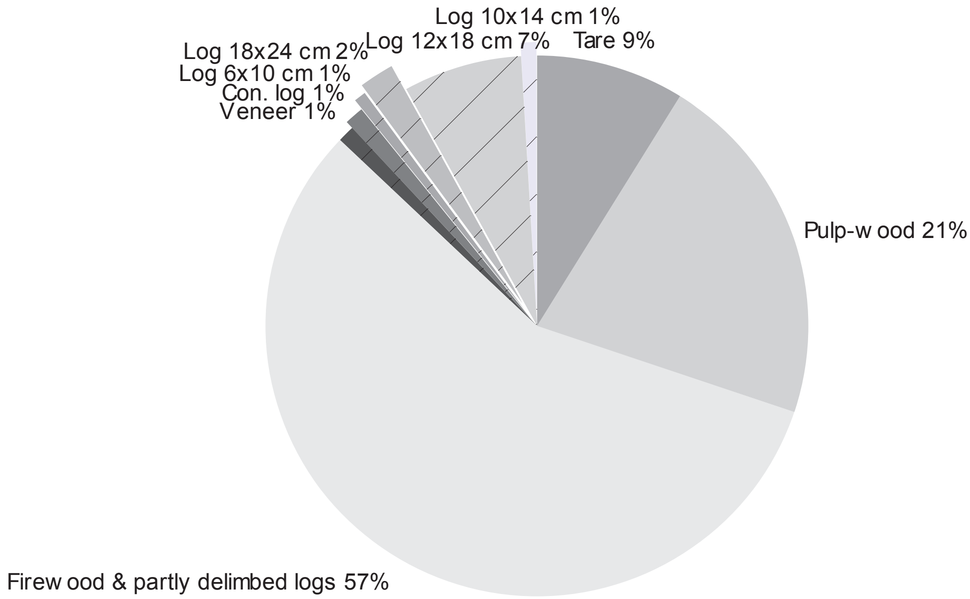

Figure 2. Structure of roundwood assortments (numbers in labels, for instance 18x24 cm, means minimum top and bottom diameter, con. log means other coniferous logs).

Productivity of harvesting depending from a diameter of extrated tree follows to a power regression (Fig. 3). Accumulating function was used mostly for trees with diameter at 1.3 m height below 8 cm; however, accumulating was used rarely.

Fig. 4 demonstrates the reason for comparably low productivity of the harvester – the most of the productive time was spent to cut undergrowth trees with diameter below 8 cm contributing to less than 10% of the produced assortments. Small trees was cut to free up space for the assortment piles and to improve visibility conditions during harvesting. Considerable improvement of the productivity, especially during forwarding, was reached when operators put logs and residues into ditches and left undergrowth trees untouched.

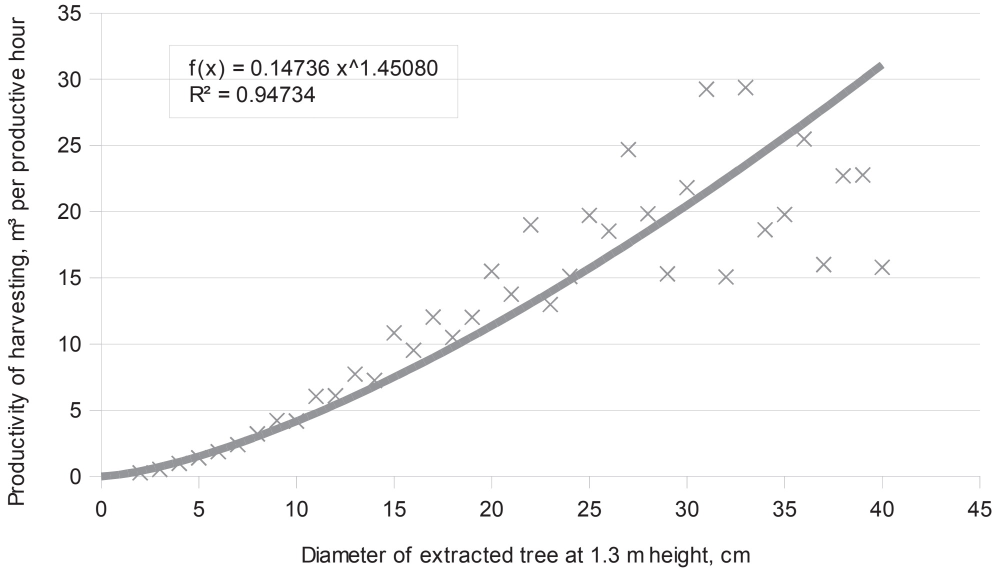

Figure 3. Average productivity of harvester.

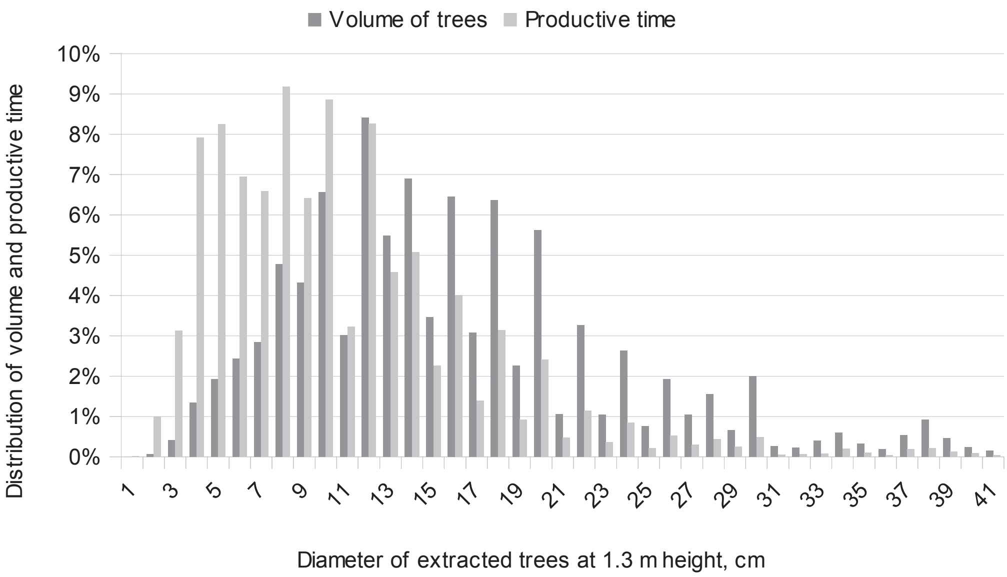

Figure 4. Distribution of productive harvesting time and volume of extracted trees.

Average fuel consumption of the harvester was 15.2 L per hour and it was not significantly affected by the work method. Higher fuel consumption in comparison to a wheeled harvester can be explained by less adaptive regulation of the engine RPM (it works with constant RPM), higher total mass of the machine and higher engine power of the excavator.

The best results were obtained using the 1st work method (full tree biofuel method); however, weighing of the results by diameter of the extracted trees approved that 3rd method (merging of firewood and partly delimbed logs) demonstrates the best performance (Fig. 5).

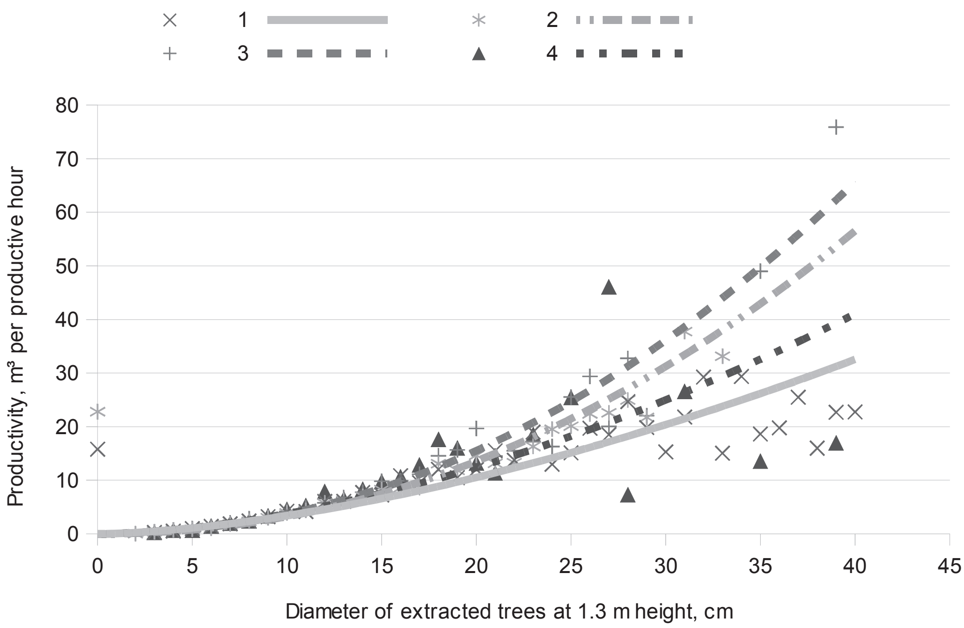

Figure 5. Harvesting productivity (m3 per direct work hour) depending from diameter of tree and work method.

During the time studies species (pine, spruce, deciduous) and dimensions of extracted trees were noted; however no statistically significant difference were found in productivity of extraction of the deciduous and coniferous trees.

Average load of roundwood in the trials was 6.9 m^3; loading took in average 49 minutes, unloading – 16 minutes, which is about twice more than in earlier trials (Lazdiņš et al., 2012). Forwarder driving speed due to excellent conditions was 175 m $min.^{-1}$, which is close to a maximum speed of the machine. The worse performance of the roundwood forwarder can be explained by lack of experience (all operations were slower) and by inappropriate work method – operators tried to make a single assortment loads instead of mixing assortiments. As a result of this approach the total driven distance was at least twice longer than it should be. Productivity of forwarding significantly decreased if 4th method was applied; however, this result is less related to the method than to other factors (dimensions of trees and driving conditions, location of assortments piles).

Average load of harvesting residues was 13 m^3 LV (loose volume), loading time 12 minutes, unloading time – 3 minutes per load. Average load of partly delimbed logs was 16 m^3 LV, loading time 20 minutes, unloading – 5 minutes per load. Operators were experienced and reduced driving distance considerably in comparison to the roundwood forwarding. Average driving speed with harvesting residues was 156 m min. and with partly delimbed logs – 188 m min.

The quality requirements in state forests proposes that the whole ditch channel should be cleaned from woody vegetation, and in our trials it was done using chainsaw. Extracted trees and bushes were piled above the harvesting residues. Time consumption to clean the whole channel was 12 hours ha^{-1} and to clean roadside only – 6 hours.

The cost and income analysis demonstrated that cash flow of mechanized ditch cleaning using the 3rd method can be positive if average extracted tree is at least 8.6 cm in diameter and the areas harvested during the study are close to this threshold (Fig. 6). Avoiding of cutting of trees with diameter below 6 or even 8 cm would increase net income considerably having at the same time negligible impact of the output of roundwood and biofuel.

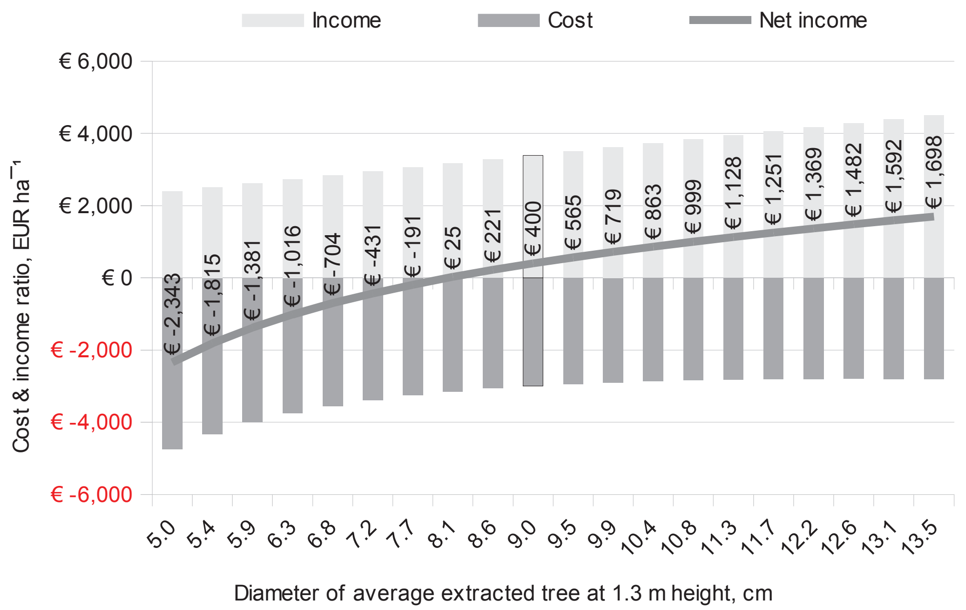

Figure 6. Ratio of harvesting cost and income.

According to the study results biofuel, including firewood, harvesting residues and undrgrowth trees contributes to 67% of the potential income if the produced biomass is sold according to the market price. Inrease of the diameter of the average extracted tree would increase the share of biofuel in the income according to the average conditions in different ditches extracted during trials; however this assumption can be wrong if the species composition is changing, for instance, if share of birch and spruce is increasing.

CONCLUSIONS

1. The study results approves hypothesis that excavator, euqipped with accumulating felling head and long crane is efficient solution for extraction of biomass from the forest drainage ditches. It is important to prioritize biofuel production in extreme harvesting conditions to secure efficient and continuous utilization of the machine, because, in contrast to other roundwood assortments, biofuel can wait in a stand for favourable forwarding conditions. In a good conditions it is reasonable to produce more valuable assortments and biofuel.

2. To reduce fuel consumption and to improve quality of the operations it is reasonably to equip the excavator with smaller felling head (Ponsse H5, Moipu 500 or similar). Significant benefit would be additional guillotine unit below the chain bar to be able to cut trees close to water level or in bad visibility conditions.

3. The fuel consumption of the excavator used in the trials was considerably higher than of the conventional wheeled harvesters (respectively, 15.2 L per hour and 9–12 L per hour); however, the impact of fuel consumption on prime cost of the production is smaller than the potential impact of work method improvements.

4. The most beneficial work method in the trials was production of the standard set of roundwood assortments, harvesting residues and merged assortment of partly delimbed logs and firewood. The whole tree harvesting method do not inceases productivity, mostly because of the tree lenght restrictions requiring to pull through the feed rollers the most of the trees.

5. Considerable increase of productivity can be reached by more intensive use of accumulating unit – for pulp wood, firewood and partly delimbed logs, and by avoiding extraction and processing of small trees and bushes (diameter below 6–8 cm). These improvement requires different bucking instructions (reduced number of assortments) and reconsidering of quality requirements for firewood, pulp-wood and tare (longer branches allowed, less restrictive rules for lenght and top diameter of logs). The changes in work method will also improve performance of roundwood forwarding.

6. It is also reasonably to reconsider quality requirements for ditch cleaning, because cutting of undergrowth trees before or after mechanized harvesting usually have no practical reasons behing. Remaining trees and bushes will hamper development of the ground-floor vegetation in ditches and will use nutriets leaching out of the surrrounding stands. The silvicultural and environmental aspests of the ditch cleaning should be evaluated further.

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REFERENCES

Bergroth, J., Palander, T. & Kärhä, K. 2006. Excavator-based harvesters in wood cutting operations in Finland. *Forestry Studies|Metsanduslikud Uurimused* **45**, 74–88.

Jansons, A., Donis, J., Danusevičius, D. & Baumanis, I. 2015. Differential Analysis for Next Breeding Cycle for Norway Spruce in Latvia. *Baltic Forestry* 21, 285–297.

Jansons, A., Gailis, A., Donis, J. 2011. Profitability of silver birch (Betula pendula Roth.) breeding in Latvia. In: *Annual 17th International Scientific Conference Research for Rural Development Proceedings*. 2, Jelgava, Latvia, pp. 33–38.

Laine, T., Rantala, J. 2013. Mechanized tree planting with an excavator-mounted M-Planter planting device. *International Journal of Forest Engineering* **2**4, 183–193.
Lazdiņa, D., Lazdiņš, A. & Zimelis, A., Lazdāns, V. 2012. Productivity of tending depending on intensity of overgrowth. In: *Mežzinātne. Special Issue. Abstracts for International Conferences Organized by LSFRI Silava in Cooperation with SNS and IUFRO*. LSFRI Silava, Riga, Latvia, pp. 134–136.
Lazdiņš, A., Kalēja, S. & Zimelis, A., 2014. Factors affecting productivity and cost of solid biofuel in mechanized forest ditch cleaning. In: *Annual 20th International Scientific Conference Research for Rural Development Proceedings* **2**, Jelgava, Latvia, pp. 90–96.
Lazdiņš, A., Lazdāns, V. & Zimelis, A. 2012. *Enerģētiskās koksnes sagatavošanas tehnoloģijas kopšanas cirtēs, galvenās izmantošanas cirtēs un meža infrastruktūras objektos* (Research report No. 3. 5.5-5.1-000p-101-12-8, Technologies for production of biofuel in thinning, regenerative felling and forest infrastructure harvesting operations). LSFRI Silava, Salaspils, 143 pp. (in Latvian).
Lazdiņš, A. & Thor, M. 2009. Bioenergy from pre-commercial thinning, forest infrastructure and undergrowth – resources, productivity and costs. In: *Annual 15th International Scientific Conference Research for Rural Development Proceedings.* Jelgava, Latvia, pp. 147–154.
Lazdiņš, A. & Zimelis, A. 2012. *Biokurināmā sagatavošanas darba ražīgumu un izmaksas ietekmējošo faktoru izpēte meža infrastruktūras objektu apaugumā* (Research report No. 3. 5.5-5.1-000p-101-12-8, Evaluation of factors affecting productivity and cost of biofue; production in forest ditch cleaning). LSFRI Silava, Salaspils, 93 pp. (in Latvian).
Persson, T. 2012. Tree stumps for bioenergy – harvesting techniques and environmental consequences. *Scandinavian Journal of Forest Research* **27**, 705–708.
Väätäinen, K., Sikanen, L. & Asikainen, A. 2004. Feasibility of Excavator-Based Harvester in Thinnings of Peatland Forests. *International Journal of Forest Engineering* **15**, 103–111.
Zimelis, A. & Lazdiņš, A. 2015. *Biokurināmā un apaļo kokmateriālu sagatavošana grāvju trašu apaugumā ar mežizstrādes darbiem aprīkotu ekskavatoru* (Research report No. 2015/16, Production of biofuel and roundwood assortments with excavator adopted for the forest operations). LSFRI Silava, Salaspils, 78 pp. (in Latvian).
Zimelis, A., Lazdiņš, A., Spalva, G. & Saule, G. 2015. Results of evaluation of different methods and technologies of solid biofuel production in ditch cleaning harvesting operations. In: *Proceedings the International Scientific Conference Knowledge based forest sector*, Riga, Latvia, p. 29.