

FACTORS AFFECTING PRODUCTIVITY AND COST OF SOLID BIOFUEL IN MECHANIZED FOREST DITCH CLEANING

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Abstract

The study represents results of productivity studies of mechanized ditch cleaning using Ponsse Fox harvester adapted to multi-tree handling H6 head in forest drainage systems managed by Joint stock company "Latvia state forests". The aim of the study is to evaluate productivity of extraction of biomass from ditches depending on working method and to estimate factors affecting prime-cost of biofuel in mechanized harvesting. The study results demonstrate that the 2nd method (mechanized extraction of roundwood and following motor-manual cleaning of remaining vegetation) is the most efficient solution for mechanized cleaning of ditches. Benefits of the 2nd method are smaller costs of undergrowth removal and bigger output of solid biofuel. Ponsse Fox harvester demonstrated sufficient work quality and productivity in the trials; however, it would be wise to use heavier harvesters or caterpillar excavator based harvesters in ditch cleaning. Using the 2nd method, a harvester can extract about 227 ha of ditches (23,000 m³) annually.

Key words: ditch cleaning, solid biofuel, mechanized harvesting.

Introduction

Biomass in roadside and ditch cleaning operations is an undervalued resource of solid biofuel in Latvia having considerable potential to grow. Considering fragmented land use and ownership structure, the amount of biomass growing in the forest infrastructure differs from case to case – it could be from some trees to several tens of thousands of trees per ha, resulting in complicated to estimate and to harvest type of biofuel. In most cases work with roadside and ditch cleaning means small dimensions of trees, where the height of average tree only sometimes exceeds 12 m (Skogforsk, 2011; Thor et al., 2008).

The latest studies on mechanized extraction of small size trees for solid biofuel production in ditch cleaning in cooperation among the Joint stock company "Latvia state forests", Latvia State forest research institute 'Silava' and Swedish forest institute Skogforsk were implemented in 2007...2008. The study approved that the average drainage ditch covered by woody vegetation can deliver about 100 LV m³ ha⁻¹ (LV – loose volume) of high quality solid biofuel applicable in pellet production as well as for plate wood production. The average age of trees in these ditches is 15...20 years (Thor et al., 2008).

According to results of the earlier studies woody vegetation on drainage ditches should be harvested once per 15...20 years, in conjunction with thinning or felling of neighbouring stands and reconstruction of drainage system if necessary. In state forests, every year 2,000...3,000 ha of drainage ditches should be harvested producing 0.2...0.3 mill. LV m³ of solid biofuel annually (Thor et al., 2008; Lazdiņš and Thor, 2009). Resources of solid biofuel in drainage systems of private forests have not been evaluated yet.

The studies in 2007...2008 demonstrated the average extraction productivity of 8.2 LV m³ per

productive hour. This is a relatively low value if compared with productivity in Sweden and prerequisites for feasible logging at roadsides. The Bracke C16.a harvester head secured 25% higher productivity, including forwarding of small trees in comparison to Ponsse guillotine type EH25 felling head. Both devices produced full tree assortment. The price of mechanized extraction and delivery of chipped solid biofuel in 2008 for EH25 installed on Ponsse Gazelle forwarder was 7.70 Ls LV m⁻³ and for Bracke C16.a installed on John Deere 970 harvester was 6.37 Ls LV m⁻³; respectively, 11 and 9.1 EUR LV m⁻³. At that time the market threshold for wood chips was about 8.5 EUR LV m⁻³. Thus, it was decided that it was too early to implement mechanized ditch cleaning due to low profitability. The study also demonstrated problems in skill of operators and maintenance of machinery (Lazdiņš and Thor, 2009; Thor et al., 2008). Studies on mechanized ditch cleaning were done in Sweden in 2009...2010 selecting objects, where the number of growing trees was 4,000...20,000 per ha with total growing stock of 40...110 tons ha⁻¹. The average productivity in the studies was 2.6...3.7 tons per hour using accumulating felling head (Skogforsk, 2011); it means twice higher than in earlier studies in Latvia. The profit before taxes was 1000 EUR ha⁻¹. However, the tested method can be applied only to 5% of roadsides in Sweden (10,000 ha), corresponding to 2 TWh of primary energy (Skogforsk, 2011).

Studies in Latvia and Sweden demonstrated that it is important to extract only the biggest trees, leaving small ones ($D_{1.3} < 4$ cm) on the ground or untouched. The extractable growing stock should be at least 40 tons ha⁻¹ (200 LV m³) to secure positive cash flow. If there are lots of trees with $D_{1.3} < 3$ cm, it is recommended to combine the harvester with

accumulating felling head and biomass mulcher to clean the roadside completely. The normal procedure would be to take larger trees with a harvester and then cut and crush remaining vegetation (Skogforsk, 2011).

In Latvian state forests valuable woody vegetation covers 10.8% of ditches and mixture of trees and bushes 43% of ditches with total biofuel production potential of 0.4...0.5 mill. LV m³ annually. The average growing stock ranges from 20 to 250 LV m³ ha⁻¹ (Lazdāns et al., 2008).

The aim of the study was to evaluate productivity of extraction of biomass from ditches depending from working method and to estimate factors affecting prime-cost of biofuel in mechanized harvesting.

Materials and Methods

The experiment was implemented in January – February, 2013. The studied working methods are:

- a harvester cuts all trees higher than 2 m, no manual operations necessary (method 1);
- a harvester cuts all trees and bushes thicker than 4 cm, then remaining bushes are removed manually (method 2);
- manual cut of deciduous having diameter (D_{1.3}) at 1.3 m height more than 10 cm and coniferous having D_{1.3} more than 8 cm with mechanized removal of remaining trees (method 3, standard).

Accumulating function was used in the 1st and 2nd method, because of quality requirements of pulpwood, which prohibits application of multi-tree handling in production of standard roundwood.

The harvester Ponsse Fox with H6 head equipped to be able to process simultaneously several trees was used in the study. Feed rolls were used for accumulation of trees; a harvester program was able to manage multi-tree processing. A logset 4F forwarder was used in forwarding of roundwood. Load capacity of the machine is 10 tons, weigh of fully loaded machine is 23.5 tons. Crane length is 7.2 m. Mostly

mixed loads were transported to roadside storage (up to 4 assortments per load). Every forwarder load was weighed with CAS RW-15P scales consisting of 2 platforms installed on separate steal or wooden base. Maximum weight that can be measured by each platform is 15,000 kg, uncertainty – 10 kg.

In total 32 ditches with the area of 16.4 ha and total length of 14.6 km were selected for the studies; harvesting trials were done in 16 ditches, a provider of harvesting and forwarding service was SIA “Betta serviss” company. Operators had previous experience with this type of operations.

The average diameter of trees higher than 2 m in all ditches was 9 cm, height 8 m, basal area – 15 m² ha⁻¹, number of trees – 1,761 per ha⁻¹, growing stock – 106 m³ ha⁻¹, above-ground biomass – 52 tons ha⁻¹. Additionally, 312 trees and bushes per ha⁻¹ being shorter than 2 m had to be cut down in all ditches (in case of mechanized extraction, 18% of all extractable trees would be 2 m high or shorter). The structure of vegetation differed between ditches and within a single ditch. Total growing stock in all measured ditches was 1,759 m³, above-ground biomass – 843 tons. Diameter distribution (Figure 1) shows that most of the trees on ditches have 3-5 cm diameter, but the growing stock is equally distributed in 10 – 30 cm diameter range; therefore, in case of mechanized extraction most of time would be spent on cutting trees that have a very small volume, and it is important to use accumulating function as much as possible with small size trees to increase volume of wood processed per crane cycle.

Wood samples were collected from each storage site right after forwarding by selection 10 logs of up to 4 of the most common species in the storage representing the smallest, the largest and moderate bottom diameter of logs. Wood chips samples were collected 17 days after forwarding during chipping of the material. Samples of wood chips were collected from every load, when it was full or after switching

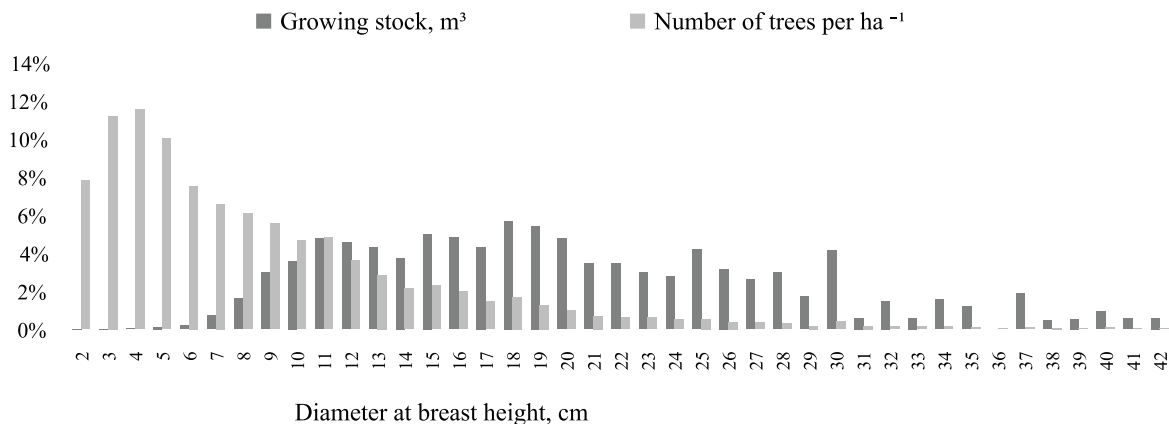


Figure 1. Diameter distribution of number and stock of trees on ditches.

to another storage yard. Biomass in all storage yards was chipped with EUROPE Chippers 1060 on an emergency truck base.

Standard analytical methods were used to determine particle size distribution in chips, moisture content in chips and logs, ash content in chips and logs, bulk density of chips as well as for sampling of chips during chipping operation (CEN, 2005; Swedish Standards Institute, 2005a; b, 2006a; b).

The outdoor temperature in February, 2013 (between forwarding and chipping) was by 3 °C higher than the average temperature of the last decade in this month. The amount of precipitation in the period between forwarding and chipping was 36 mm, no significant difference from previous decade was found.

Time studies were done for extraction, forwarding, manual cleaning of remaining vegetation and chipping of material. Productivity figures for roundwood and chip transport were taken from earlier studies (Thor et al., 2006; Thor et al., 2008; Lazdiņš and Thor, 2009; Kalēja et al., 2013). FLISS derived costing model was used in calculation of cost of biofuel and roundwood production and deliveries assuming that biofuel is delivered to a customer as chips (Thor et al., 2006; Skogforsk, 2009).

Results and Discussion

Direct productive time (time without driving into and out of the stand) for extraction of one tree in all methods on average is 44 sec., per 1 ha – 663 min. (11 hours), for 100 m of ditch – 75 min., for production of 1 m³ of logs – 9 min. (6.7 m³ per hour). The longest time per tree and per 100 m of ditches is characteristic for the method No. 3 (a harvester cuts trees after manual cleaning of undergrowth). The most efficient is the method No. 2. Smaller productivity in the 3rd method is the result of an increase of average diameter of mechanically extractable trees after removal of undergrowth; respectively, an accumulating function can be applied to limited number of trees, thus

significantly reducing productivity. Reduction of productivity in the 1st method is the result of more complicated quality requirements – the harvester had to manage very small stems spending time for removal of remaining undergrowth trees and bushes. Direct productive time is 82% of scheduled work time and 91% of total productive time, including driving into and out of the stand.

The greatest difference between working methods at harvesting stage derives from bucking operation, which is much more time consuming in the 3rd method (Figure 1). The 1st method requires considerably longer time for other operations (undergrowth removal). The longest tree processing time in the 3rd method can be explained by considerably larger dimensions of trees so that nearly all trees have to be processed using a single tree method to produce traditional assortments.

The exponential equations demonstrating impact of diameter of trees on productivity of harvesting are shown in Figure 2. The use of the 1st method is beneficial if a diameter of trees reaches standard conditions in the final felling, the 2nd method is more beneficial than the 1st in case of small size trees and more beneficial than 3rd method in all diameter classes.

The linear regression (Figure 3) characterizing this correlation can be used in practise to determine growing stock on ditches.

In total, 845 tons of material are forwarded (116 loads), average load – 7.3 tons. The biggest load – 13.2 tons (27 tons with a tractor). Biofuel (partially delimbed logs) loads were comparably smaller than other loads. The average load of biofuel 5.7 tons (2.6 tons of dry mass or 13 MWh). The average load is 3.3 tons of dry mass. On average, loading and unloading of 1 ton of naturally wet material took 7.2 minutes, but loading and unloading of 1 m³ – 1.6 minutes.

Considerably higher productivity figures were found in the 2nd method (Figure 4), because assortments are located more concentrated and extracted stock is larger, so driving and other operations takes less

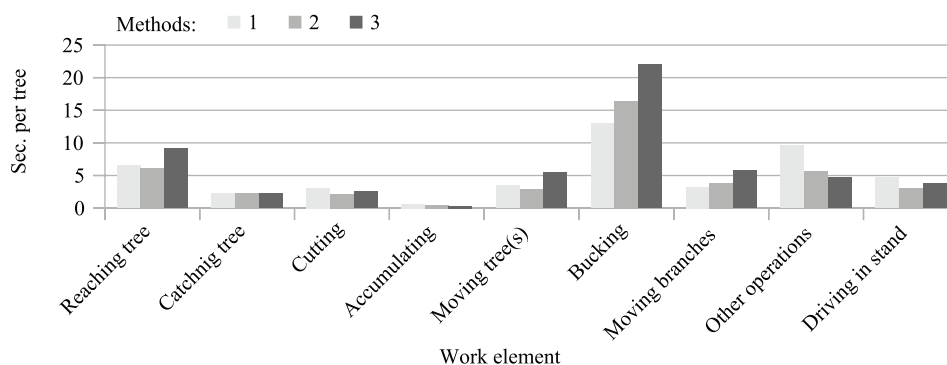


Figure 2. Duration of operations depending from work method.

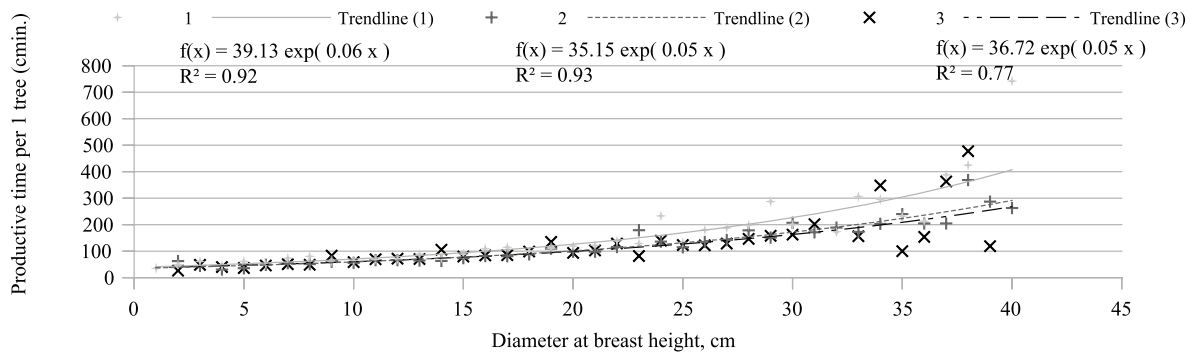


Figure 3. Equations to characterize harvesting productivity depending on work method.

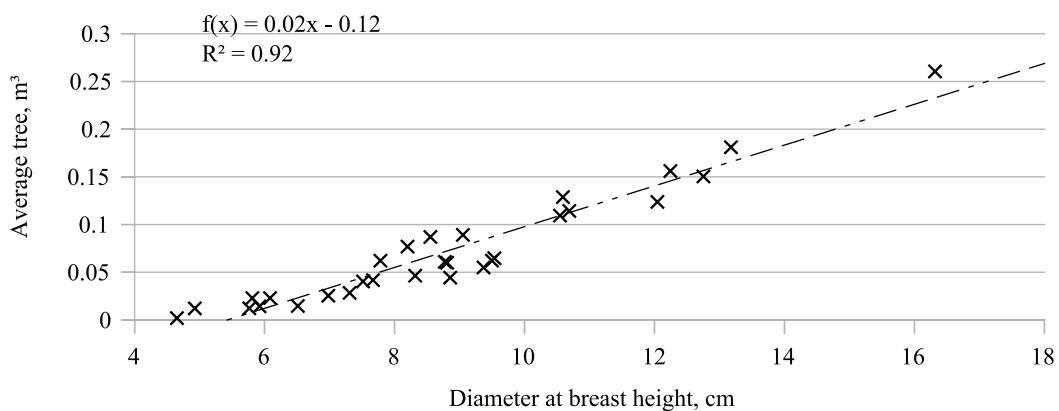


Figure 4. Equation to characterize diameter of average tree and stem volume.

time than for the 3rd method. Productivity goes down in the 1st method because of smaller dimensions of stems. However, no statistically significant difference was found in total forwarding time depending on the harvesting method; therefore, average figures were used in prime cost calculation.

Most time consuming operation was loading, followed by the other (including finding and separation of different assortments), driving in stand and unloading.

In total, 510 LV m³ of chips were produced and 7 loads delivered to a customer. The average load was 73 LV m³. Consumption of productive time for chipping was 37 sec. LV. m³, share of productive time 67% of scheduled work time. On average, the production of 1 ton of dry matter of solid biofuel requires 178 sec. of productive time. Productivity of chipping can be considerably increased by the reduction of delays and by the use of chipper with better carriage design (logs should not be pushed down to keep on carriage). On average, this operation took 28% of productive work time.

Besides solid biofuel 981 m³ (under bark) of roundwood assortments were produced in the trials

(2,363 MWh of primary energy). The output of solid biofuel equals to 555 MWh (23% of the amount of round-wood assortments). Every 100 m³ of roundwood assortments equal to 52 LV m³ of chips, corresponding to 57 MWh of primary energy.

The prime-cost of round-wood logs and wood chips with 5% profit margin depending on the selected working method, including delivery to 50 km distance, is:

- the 1st method – 1 m³ of saw-logs cost 26.0 EUR, but prime cost of 1 LV m³ wood chips – 14.3 EUR;
- the 2nd method – 1 m³ of saw-logs cost 19.3 EUR, but 1 LV m³ wood chips – 11.1 EUR;
- the 3rd method – 1 m³ of saw-logs cost 17.4 EUR, but 1 LV m³ wood chips – 10.1 EUR.

Manual operations – removal of undergrowth (3rd method) and cleaning of remaining woody vegetation (2nd method) is considered in calculation according to study data.

Volume of average tree is the main factor affecting prime cost – in the 1st and 2nd work method it is considerably smaller than in the 3rd work method; therefore, the average productivity in the 3rd method

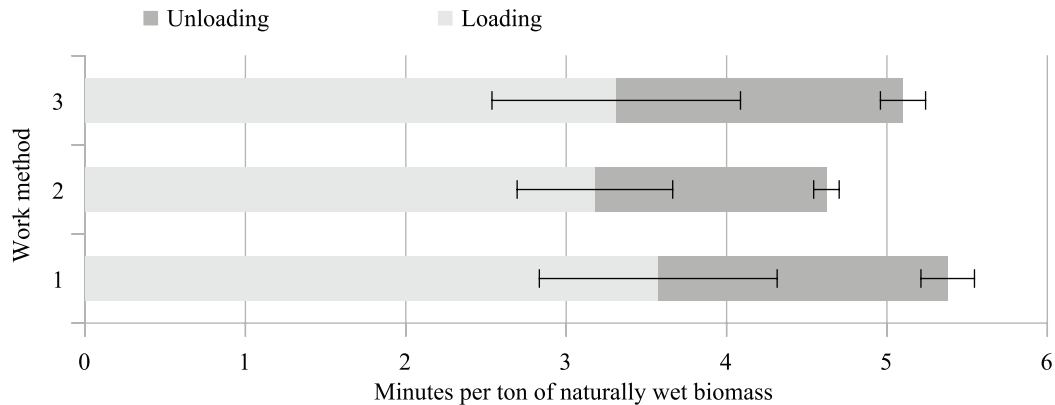


Figure 5. Productivity of loading and unloading.

is the highest in the experimental sites. Application of the 2nd method significantly reduces time consumption and cost for undergrowth removal after mechanized extraction.

The smallest cost using the 3rd method is determined by a larger volume of trees (after removal of undergrowth average diameter of extractable trees theoretically increased by 55%, but the number of extractable trees decreased by 58%). At the same time the undergrowth removal reduced extractable biomass only by 5%.

If compared, in equal conditions, the 1st method is more beneficial in case of small diameter of average tree (Figure 5). Productivity of the 2nd method can be raised by an increase of lower limit of extractable tree from 4 to 6 or 8 cm, so that smaller trees are extracted only in case if they can be cut and processed simultaneously with larger trees.

The best balance between income and expenses can be reached using the 2nd work method (Figure 6); however, it is determined largely by dimensions of trees and assortments' structure (ditches in the 2nd work method were characterized by large proportion of coniferous trees).

In practical work the 2nd method can be improved by increase threshold diameter value for extractable trees and by more intelligent selection of work method depending on the structure of woody vegetation in a particular object. It is also important that the 2nd method provides an opportunity to increase considerably the output of biomass from ditch cleaning in comparison to the 3rd method. The 1st method cannot be widely applied in practice using a standard harvester head, because it is not possible to meet internal quality requirements of the Joint stock company 'Latvia state forests', using this type of felling heads.

The average relative moisture of biomass directly after forwarding is 55%; the highest level of moisture is found in spruce wood (60%), then grey alder and black alder followed with, 57 and 56%, respectively. The driest is birch wood. The largest bulk density is found in birch logs (0.49 kg L⁻¹), the smallest – in spruce logs (0.38 kg L⁻¹). The average bulk density in all samples is 0.43 kg L⁻¹. The primary energy content of wood is 2.6...2.0 MWh m⁻³. Moderate correlation between bottom diameter and relative moisture found only for black alder (r=-0.59), but correlation between bottom diameter and bulk density – for birch (r=0.41).

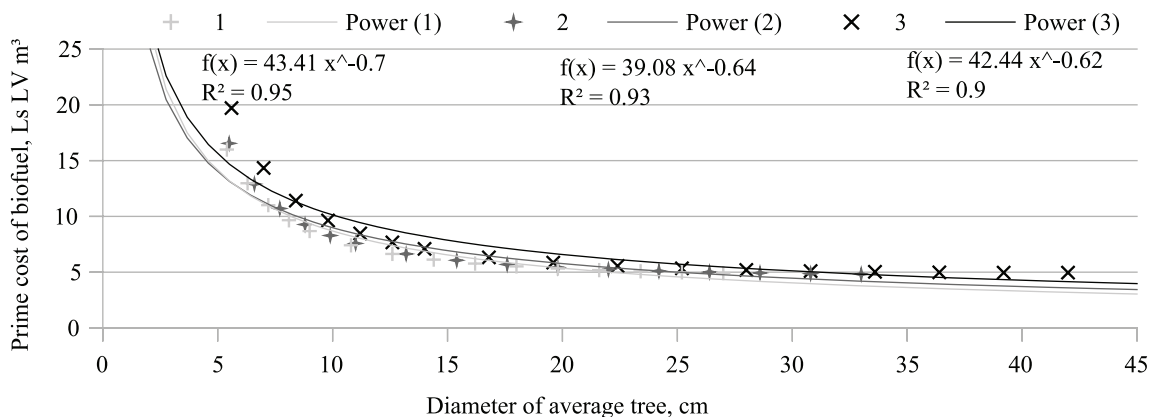


Figure 6. Comparison of different methods in equal conditions (the same $D_{1,3}$).

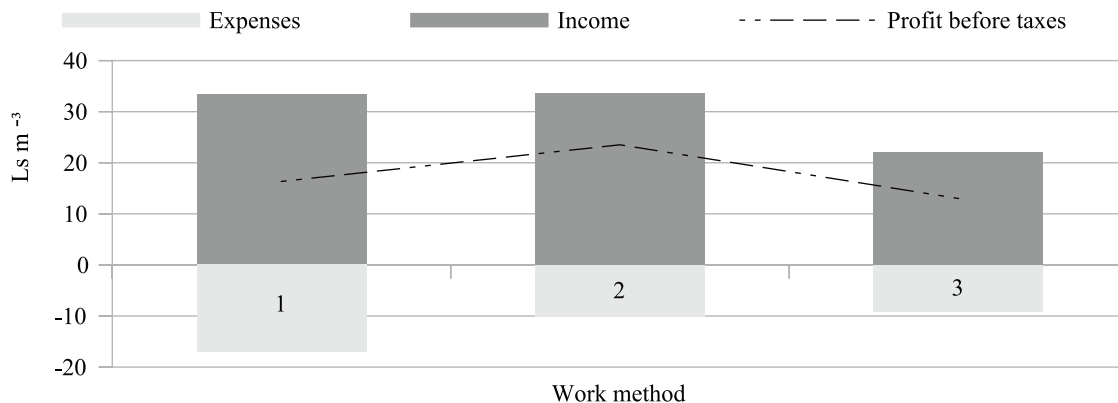


Figure 7. Comparison of income and expenses in different methods.

If compared to different storage yards, the driest wood is found in storages with the highest proportion of birch. No such correlation was found for bulk density. Different density of wood requires special attention to forwarder loads to avoid overloading, when birch dominant loads are transported.

Relative moisture of chips was 47%, it means that it is considerably smaller than during forwarding (from 55% or on average by 0.5% per day). Bulk density of naturally wet chips was 0.40 kg L⁻¹, but of absolutely dry wood – 0.21 kg L⁻¹ (weight of full load of chips in 90 m³ truck is about 36 tons). Primary energy content of chips is 1 MWh LV m⁻³. Largest fractions of chips are 45-16 mm and 16-3.15 mm (89% by mass), a small fraction below 3.15 mm is 8% by mass. Content of ash in produced chips is 0.68%. These chips can be used both, for industrial and premium class pellets; however, for production of premium class pellets the customer has to receive logs and not chips to debark them before crushing. Debarking most probably would decrease the amount of ash in raw material for pellet production; however, delivery of roundwood would considerably increase prime-cost of solid biofuel.

Conclusions

1. The 1st method cannot secure the implementation of quality requirements set by JSC “Latvia state forests”. The method can be utilized, if the number of undergrowth trees and bushes is insignificant,

specifically as a part of the 2nd method in suitable areas.

2. The 2nd method is the most efficient solution for mechanized cleaning of ditches, because it provides the best combination of assortments structure resulting in higher income and good productivity figures, both in harvesting and forwarding. Another benefit of the 2nd method is smaller cost of undergrowth removal. However, it would be wise to increase minimal diameter of mechanically extractable tree to 6...8 cm.
3. Working with the 2nd method, a harvester can extract about 227 ha of ditches (23,000 m³) annually. This means that 3 harvesters can be utilized to full extent in ditch cleaning in state forests.
4. Productivity of forwarder in ditch cleaning operations is considerably larger than average in commercial thinning and final felling. When using small forwarders in birch or black alder dominant vegetation, the loads should be considerably smaller than in coniferous stands to avoid overloading of the machine.

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