IMPACT OF ASSORTIMENTS' STRUCTURE ON HARVESTING PRODUCTIVITY AND COSTS OF PRE-COMMERCIAL THINNING

Santa Kalēja[1], **Andis Lazdiņš**[2], **Agris Zimelis**[1]
[1]Latvian State Forest Research Institute 'Silava'
[2]Forest Sector Competence Centre, Latvia
kalejasanta@inbox.lv

Abstract
The study aims to find productivity of biofuel production in pre-commercial thinning, depending on the structure of assortments and to identify factors that influence the cost of mechanized tending of young stands. Five work methods were compared in the study, starting from standard thinning (production of sawn timber, pulpwood and firewood) with no use of accumulating device and finalizing with the biofuel method – no other assortments except biofuel are produced and the most intense use of accumulating device is considered. Accumulating device is not used for production of standard round-wood assortments. The experiments were implemented in February – March, 2013. The material produced in the study was used by 'Graanul Pellets' company to evaluate possibilities to use timber extracted in pre-commercial thinning of coniferous stands in production of premium class pellets. The average productivity in different stands is statistically different. The study shows that productivity of harvesting is 3.7 … 5.1 m^3 h^{-1}, which can be increased by more intensive use of accumulation. No difference found between work methods in forwarding trials, but productivity grows with increase of share of firewood. Average loading time 26 min, unloading 3.6 min, average load 6.0 m^3. Prime-cost calculation shows that harvesting costs depending on the working method is in the range of 22.4 … 26.5 EUR m^{-3}. Comparison of potential expenses and incomes demonstrates that economically the most efficient is production of traditional assortments (sawn wood, small size sawn wood, pulp wood and firewood) with an active use of accumulating function.
Key words: biofuel, work methods, young stands.

Introduction

Yong stand tending or per-commercial thinning is a measure required in forestry. It is performed mainly with manual cutting without collecting of small diameter wood (Lazdāns, 2006; Meža enciklopēdija, 2003). Studies of efficiency of young stand tending technologies in 2012 showed that the young stand manual cutting still is the most cost-efficient way of young stand tending, followed by young stand tending with harvester equipped with special additional accumulating device for head (Lazdiņš et al., 2012). However, with growing demand for biofuel, the mechanized tending of young stands becomes an urgent issue. It is possible to perform qualitative young stand tending by using harvesters and produce round-wood assortments and biofuel.

Technology of young stand tending can be divided into four groups: harvesting with a harvester, with a harwarder, combined harvesting and chipping equipments, or manual cutting (Lazdiņš, 2013c). Studies on the young stand tending in Scandinavia and Latvia confirm, that mostly medium-sized harvesters with accumulating device are suitable for young stand tending (Lazdāns et al., 2008; Sirén and Aaltio, 2003). A head with an accumulating device allows multiple gripping of trees and cutting (Lazdiņš, 2013c). Such harvesters are maneuverable in young stands and are suitable for cutting and processing of small diameter trees.

Studies of usage of the mid-class harvesters in mechanized tending of young stands are carried out by Joint Stock Company 'Latvia's State Forests' commissioned project 'Industrial research of renewable energy production, processing and logistics'.

The study evaluated the impact of the structure of assortment gained by young stand tending on productivity and costs (Kalēja et al., 2014; Lazdiņš, 2013a; Lazdiņš, 2013b; Lazdiņš, 2013c). In addition to the traditional round timber assortment groups (sawn timber, pulpwood and firewood), an assortment of biofuel can be prepared from treetops and trunks that couldn't be used for traditional assortment (Lazdiņš, 2013c).

Studies in Latvian and Scandinavian countries have shown that the usage of accumulating device for preparation of non-traditional assortment greatly increases productivity and reduces the cost of mechanized tending of young stands (Lazdiņš, 2013a; Lazdiņš, 2013c; Sirena and Aaltio, 2003). Assuming that an average distance of forwarding is constant, the main factors affecting the productivity are average tree size of the stand, removal per hectare and number of timber assortments (Sirena and Aaltio, 2003). The structure of produced assortment, in turn, is determined by the chosen method of working. The studies confirmed the hypothesis that the highest productivity (amount of trees that are harvested in certain amount of time) of each machine could be achieved by reducing modifications of produced assortment (Lazdiņš, 2013c).

Studies of deciduous stands show that the cost of manual tending of young stands in harsh conditions, depending on tree's dimensions and tree stands thickness, ranges from 343 EUR ha^{-1} to 488 EUR ha^{-1}. Actual costs are up to 3 times smaller, as service providers have to tend a variety of stands, including those where the cost of 1 ha is significantly below average (Lazdiņš, 2013b). Costs of mechanic young stand tending, depending on the harvester's type, ranged on average from 800 EUR ha^{-1} to 1 113 EUR ha^{-1} (Lazdiņš, 2013b; Lazdiņš, 2013c). Although mechanized tending of young stands requires a significantly higher cost, realization of produced assortment provides some revenue. Earnings are determined by current market situation as well as the chosen supply chain model (Laina et al., 2013; Lazdiņš, 2013c; Walsh and Strandgard, 2014). The aim of the study was to find productivity of biofuel production in pre-commercial thinning, depending on the structure of assortments and to identify factors that influence the cost of mechanized tending of young stands.

Materials and Methods

The study was implemented in 4 coniferous stands representing fertile *Myrtillosa* and *Hylocomiosa* site types in the central part of Latvia nearby Koknese. The stands were specially selected for proper density (at least 1500 trees per ha^{-1}) and dimensions of trees (height of trees 9 … 12 m). The experiments (harvesting and forwarding operations) were implemented in February – March, 2013. The average temperature during the study was 1.6 degrees lower than the temperature in the given historical period. The strip-roads were marked before thinning at 20 m distance between each other. The main characteristics of stands are provided in Table 1.

For production of different assortments (work methods 1 … 4) stands 503-479-12 and 503-481-6 were selected and biofuel method (work method 5) was implemented in stands 503-455-13 and 503-455-14. Biomass expansion factors elaborated for afforested lands are borrowed for calculations (Lazdiņš, 2011d). Five work methods were compared in the study:

1. Production of traditional assortments (sawn wood 14 X 18 mm, small size sawn wood 10 X 14 mm, pulp wood and firewood), min. diameter of firewood at top 50 mm, residues left in stand, accumulating function is not used.
2. Production of traditional assortments (sawn wood, small size sawn wood, pulp wood and firewood), min. diameter of firewood at top 30 mm, residues left in stand, active use of accumulating function.
3. Production of limited number of assortments (sawn wood, small size sawn wood and firewood), min. diameter of firewood at top 30 mm, residues left in stand, active use of accumulating function.
4. Production of limited number of assortments (sawn wood and firewood), min. diameter of firewood at top 30 mm, residues left in stand, active use of accumulating function.
5. Production of firewood with min. diameter at top 30 mm, residues left in stand, active use of accumulating function.

John Deere 1070 E with H754 head equipped with special additional holders and boom length 10 m was used in the study. Two experienced operators drove the machine; however, none of the operators had previous experience with small dimension biofuel assortments and accumulating felling heads.

Standard Timberjack 810B forwarder was used in the study. All loads were weighed during forwarding, and after each fifth load or after changing position of scales empty loads were weighed.

The material with a truck was delivered to LLC 'Graanul Pellets' storage yard using standard 68 m^3 truck Delivery distance 150 km in one direction.

The material (biofuel assortment as well as sawn timber and pulp-wood produced in trials) was chipped with stationary chipper Jenz HE 700 after debarking in LLC 'Graanul Pellets' storage yard. Proportion of bark according to information provided by LLC 'Graanul Pellets' was 10% by mass (naturally wet). In order to perform recalculation to dry matter tons,

Table 1

Characteristic of stands

Object code	Area, ha	Dominant species	Average diameter of trees, cm	Average height of trees, m	Average basal area, m^3 ha^{-1}
503-455-13	3.6	spruce (*Picea abies*)	9.7	7.7	12.1
503-455-14	4.3	spruce (*Picea abies*)	9.6	9.2	19.3
503-479-12	2.4	pine (*Pinus sylvestris*)	12.0	11.7	29.5
503-481-6	1.2	spruce (*Picea abies*)	8.2	10.0	13.1

a conversion factor (1 ton of naturally wet material (average moisture content 60%) corresponds to 0.4 dry tons) was used.

Prim-cost calculation and potential income and expenses of mechanized young stand tending calculations are done according to calculation models that are used in similar studies carried out previously (Lazdiņš[c], 2013).

To determine the level of significance of data, the t-test is used.

Results and Discussion

Basal area before thinning on average in all stands was 18 m^2 ha^{-1}; the average number of trees 2360 per ha^{-1}; diameter 10 cm; tree height 10 m; growing stock 62 m^3 ha^{-1}. After thinning the average basal area reduced to 13 m^2 h^{-1}; number of trees – to 1154 per ha^{-1}; diameter of trees increased to 12 cm. Proportion of extracted trees is 26 … 61% from initial number of trees. In 3 of 4 objects the number of extracted trees exceeds permitted value by 9 … 21% (if the area of strip-roads is considered). If the area of strip-roads (20%) is not considered, intensity of thinning could be increased.

The distribution of trees after thinning is even (Figure 1).

In total, 10722 trees were extracted in the experiment. Extracted biomass according to weighing of forwarder and analyses of moisture of fresh wood was 133 tons of dry matter (60 MWh ha^{-1} of primary energy); harvested stock with bark – 351 m^3 (31 m^3 ha^{-1} or 152 LV m^3 ha^{-1} of chips). According to round-wood measured data, the amount of delivered wood was 316 m^3 under-bark (about 354 m^3 with bark) or about 147 tons of dry mass. The study approved that harvester measurement data cannot be used to account the amount of biomass produced by simultaneous extraction of multiple trees, because they are considerably underestimating the amount of produced material. The volume of average extracted tree is 0.03 m^3; the diameter of average extracted tree – 10 cm; the average number of trees per cycle – 1.3 pieces (max. 8 … 10 trees per cycle, in firewood method – 1.4 trees per cycle). On average, 30 trees have to be processed to produce 1 m^3 of round-wood assortments.

The average distribution of productive work time in all work methods is shown in Figure 2. Bucking is the most time consuming work element (28%), the second is reaching tree (24%). Both work elements can be considerably reduced, if accumulating function is used more often, respectively.

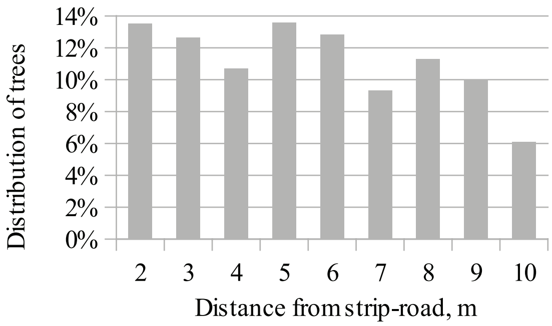

Figure 1. Distance of remaining trees from center of strip-road.

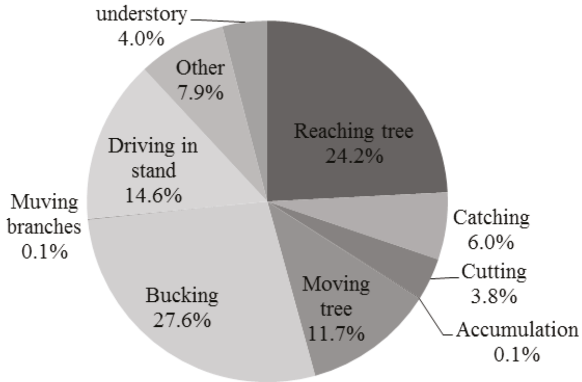

Figure 2. Average distribution of work elements in harvesting.

The production of less assortments reduces bucking time, and this value correlates with the number of crane cycles with more than one tree. In work method 4 the duration of bucking is twice less than in work method 1. This means that broader use of accumulating function may increase productivity considerably. In stands for biofuel (only) production average productivity was:

- 503-455-13 – 4.5 m^3 or 151 trees per productive hour;
- 503-455-14 – 5.0 m^3 or 159 trees per productive hour;

In stands used for comparison of impact of assortments' structure average productivity was:

- 503-479-12 – 5.0 m^3 or 133 trees per productive hour;
- 503-481-6 – 4.4 m^3 or 137 trees per productive hour.

Average productivity in all stands was 4.9 m^3 or 148 trees per productive hour. The provided productive figures exclude driving in and out of the stand.

Comparison of work methods demonstrates an increase of productivity of harvesting with reduction of the number of assortments, except work method 5, where the average diameter of trees was considerably smaller than in other stands. The productivity figures for different methods are:

1. work method – 4.7 m^3 or 114 trees per productive hour;
2. work method – 5.1 m^3 or 126 trees per productive hour;
3. work method – 5.0 m^3 or 141 trees per productive hour;
4. work method – 5.7 m^3 or 156 trees per productive hour;
5. work method – 3.7 m^3 or 136 trees per productive hour.

Production of biofuel assortments from pulp-wood and small dimensions saw logs increase harvesting productivity significantly. The study approves that the potential of accumulating device is not fully utilized.

In total, 58 loads were extracted, the average load of 2.3 tons dry mass or 6.1 m^3. Weight of pure biofuel loads equals to the weight of average load – 2.3 tons of dry mass or 6.0 m^3.

Work elements in forwarding are shown in Figure 3. The forwarding time during trials was considerably increased by snow-fall that took place some days after harvesting. Most of productive time was spent to find assortments below snow and to identify different categories of assortments; therefore, the most time consuming work element in these forwarding studies was unpredicted operations. Considering that such a situation might take place in reality, especially in winter this work element was not excluded from productive work time.

Structure of forwarding work elements depending on work method is shown in Figure 4. The highest productivity figures are characteristic to work methods with a larger share of biofuel. Less productive is work method 1, because of smaller concentration of assortments (more driving from pile to pile).

Productive forwarding time (min. per load) for different work methods is:

1. work method – loading 36 min., unloading 4 min., average load 6.6 $m^{3,}$
2. work method – loading 38 min., unloading 4 min., average load 7.3 m^3,
3. work method – loading 19 min., unloading 3.4 min., average load 5.6 m^3,
4. work method – loading 16 min., unloading 2.9 min., average load 5.0 m^3,
5. work method – loading 23 min., unloading 3.5 min., average load 6.0 m^3.

Average loading time 26 min, unloading 3.6 min, average load 6.0 m^3. Average driving speed 68 m min^{-1}.

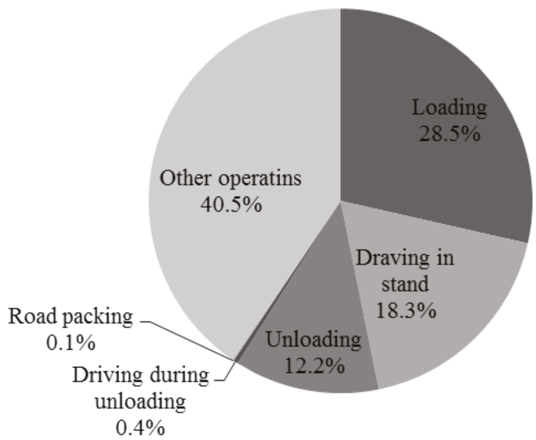

Figure 3. Average distribution of work elements in forwarding.

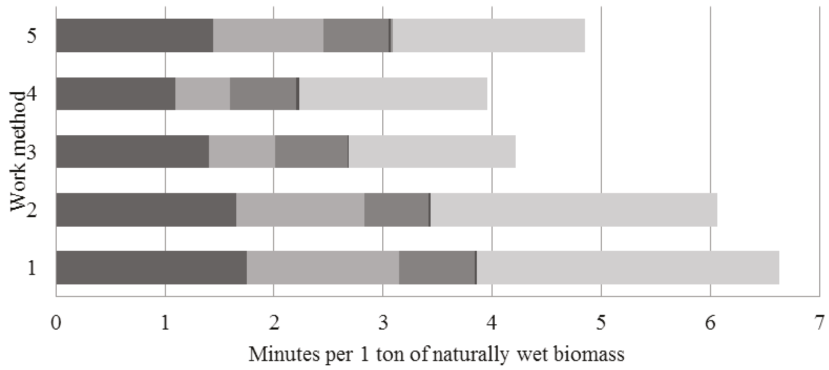

Figure 4. Structure of forwardig work elemets depending from work method.

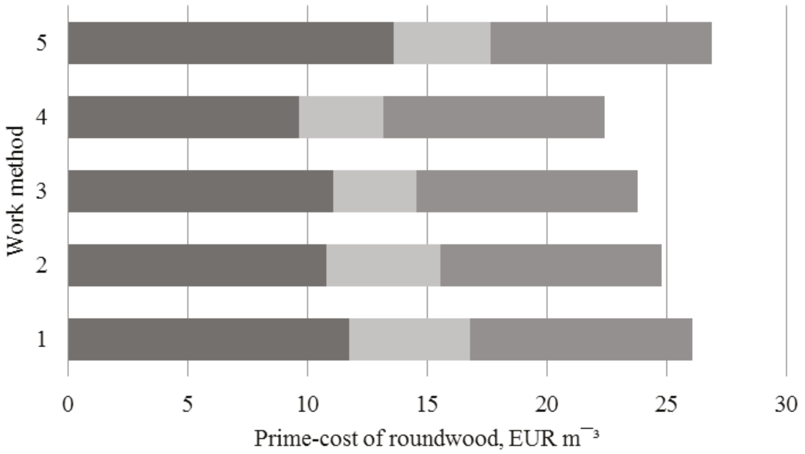

Figure 5. Structure of prime-cost of production and delivery of round-wood matherial.

The structure of prime-costs of production and delivery of round-wood material depending on work method is shown in Figure 5. If work method 5 is not considered (because of smaller dimensions of extracted trees and, respectively, higher production cost), the most efficient is the 4th method. Although the cost of production and delivery of round-wood materials depending on work method ranges from 22 (work method No.1) to 27 (work method No. 2) EUR m^{-3} and differences from the economical point of view are considerable, differences between work methods are not statistically significant ($p<0.05$).

Prime-cost of round-wood considerably drops if a part of cost equal to standard motor-manual thinning is excluded (Figure 6). In spite of that, the production cost is still too high to produce only biofuel assortment in pre-commercial thinning. Market price of firewood utilized in pellet production (respectively, accounted under bark) is 23 EUR m^{-3} on average; therefore, the risk of failure (economic losses) is very high for all methods. There are no statistically significant differences ($p<0.05$) between work methods.

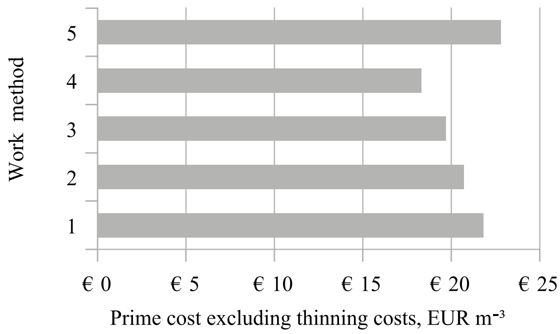

Figure 6. Prime-cost of round-wood excluding thinning cost.

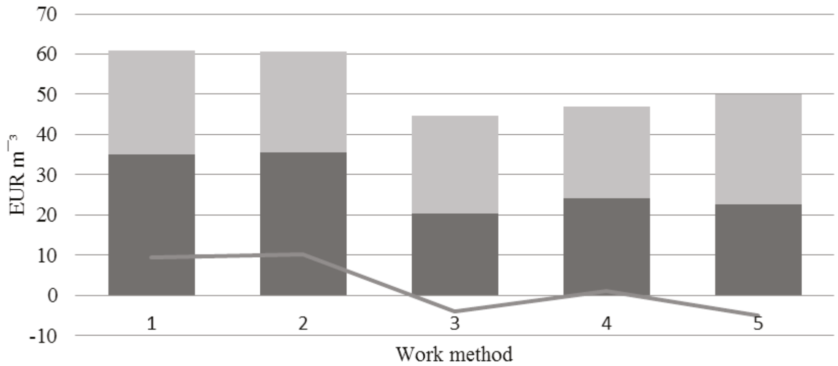

Figure 7. Modelled structure of cost and income in equal working conditions.

Potential income from selling round-wood is considered in a separate calculation of modelled structure of cost and income in equal working conditions. According to Figure 7, working methods 3 … 5 are related to high risk of negative net income; but the most profitable method is No 2 – production of standard assortments and biofuel from undergrowth trees considering reduced min. top diameter of biofuel logs (30 mm).

There are no statistically significant differences ($p<0.05$) between work methods.

Conclusions

1. Average amount of round-wood (under bark) produced in thinning is 28 m^3 ha^{-1}. Share of firewood is 20 – 100%.
2. The average productivity in different stands is statistically different. In stands where only biofuel is prepared, the average productivity was 155 trees per productive hour, but in stands where also other assortments are prepared, the average productivity was 135 trees per productive hour.
3. Comparison of work methods demonstrates an increase in productivity of harvesting with reduction of the number of assortments, except work method 5, where the average diameter of trees was considerably smaller than in other stands. Productivity of harvesting is 3.7 … 5.1 m^3 h^{-1}. Productivity can be increased by more intensive use of accumulation (only 20% working cycles in the study contained more than 1 tree).
4. No difference was found between work methods in forwarding trials, but productivity grows with increase of share of firewood. An average loading time is 26 min, unloading is 3.6 min., but an average load - 6.0 m^3. An average driving speed is 68 m min^{-1}.

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