IMPACT OF BIOMASS EXTRACTION METHOD ON DAMAGE TO REMAINING TREES IN MECHANIZED THINNING OF DECIDUOUS STANDS

Uldis Prindulis[1,2], Andis Lazdiņš[3], Santa Kalēja[3]
[1]Latvia University of Agriculture
[2]Latvian State Forest Research Institute 'Silava'
[3]Forest Sector Competence Center Ltd.
uldis.prindulis@silava.lv; andis.lazdins@silava.lv

Abstract
Thinning of young forest stands is a contribution to the future of the stand development. Our study focuses on damage of the remaining trees and soil. Now it is common to see thinning of young stands with heavy forest machines, but most of these operations take place in commercial thinning. This study is focused on precommercial thinning to evaluate different mechanized thinning methods in relation to the damage done to the remaining trees and soil in deciduous tree stands. Data were collected in four stands where the average diameter of trees at breast height was 6.2 cm, the height of average trees - 9.5 m, but number of trees per hectare was more than 2900. The stands regenerate naturally. Damage was evaluated separately after harvester and forwarder operations. The study proves that forwarding makes much less damage to the remaining trees than harvesting. According to the study data, the traditional method results in the largest number of damaged trees, because operators need to cut all trees closer than 1.5 m from the target tree. Both schematic thinning methods result in significantly less damage. A statistically significant difference ($p<0.001$) was found in a proportion of damaged remaining trees between all of the applied working methods. The smallest amount of damage is associated with complex symmetrical thinning method. The most damage appears during harvesting. The aim of this study was to compare three working methods of biofuel production in pre-commercial thinning using harvester John Deere 1070D with accumulating felling head Bracke C16.b in grey alder (*Alnus incana*) pure stand.
Key words: tree damage, pre-commercial thinning, biomass production, grey alder.

Introduction

Grey alder (*Alnus incana* (L.) Moench) is one of pioneer-tree species in Latvia and it belongs to fast growing trees species. Recently it has obtained a higher popularity in the private forest sector. In Latvia grey alder is economically important tree species. Grey alder is used, for example, as firewood and in furniture industry (Rytter et al., 2000). Grey alder is particularly interesting for private forest owners, because it does not have a determined cutting age like spruce, pine or birch, and it regenerates naturally as coppice crop.

The total area covered by grey alder has increased a lot from year to year because it is a pioneer species, and it starts to grow on agricultural lands, if not managed for some years. According to literature, in 1925 grey alder stands in Latvia took up 3962 ha (0.3% of total forest area), but after 35 years, in 1960, the total area of grey alder stands had increased for more than 15 times and reached 80895 ha (4.5% of the total forest area. Latvijas meži, 1987). The area of grey alder stands continued to grow and in 2003 it reached 188992 ha (6.4% of the total forest area), but according to the latest data, in 2010 it reached 210677 ha (7.3% of the forest area. Gadskārta, 2014).

Growing potential for this species is really significant and it mostly depends on soil chemical composition and water regime. The best soil types for grey alder are fertile loam and clay soils or sandy loam soils where grey alder is able to achieve considerable dimensions (Rokjānis, 1957). In naturally regenerated unmanaged alder stands are typically winding, branched and low quality stems, but it does not reflect the productivity and real growth potential of this species (Liepiņš and Liepiņš, 2010). Growing of good quality, valuable grey alder stand requires implementation of the full cycle of forest management. Besides, if a tree has open growing space around it during the whole growing cycle, the quality improvements will be visible after 25…30 years. In the studies of some Latvian researchers it is mentioned that, if we are growing grey alder on agricultural land like a plantation for sawlog production and a stand is managed applying the best available practices, in 30 years we can get approximately 300 m^3 ha^{-1} (up to 400 m^3 ha^{-1}), and output of valuable sawlogs is about 70% (Daugaviete and Daugavietis, 2008).

Pre-commercial thinning with forest machines became so popular because of productivity, if compared with motor-manual operations and ability to get the first income earlier by production of biofuel from small trees. Popularity of biofuel production in pre-commercial thinning is on the increase due to the European Union (EU) targets in renewable energy production and the climate policy. According to recently proposed policies, the EU has to reduce greenhouse gas (GHG) emissions in 2030 by 40% in comparison to 1990. Biomass from forest plays the most significant role in reaching this target, therefore, it is necessary to be prepared for an increased demand and willingness to produce biofuel from early forest management operations, which traditionally do not

Table 1

The main indicators of stand inventory

No of stand	Diameter ($H_{1,3}$), cm	Height, m	Basal area, m^2 ha^{-1}	Volume, m^3 ha^{-1}	Biomass, kg ha^{-1}	Trees, per ha^{-1}	Volume of average tree, m^3
1	7.2	10.9	28.4	166.9	57 763.4	6 400	0.026
2	5.7	8.3	18.1	83.7	28 919.4	6 800	0.012
3	5.7	7.3	20.8	85.3	33 898.5	7 600	0.011
4	6.4	11.6	24.8	155.4	44 148.0	7 333	0.021

$H_{1,3}$ – Diameter at breast height

produce any wood product. In the period between 2020 and 2030, Latvia has to reduce GHG emissions by 8% (Green book…, 2013). To achieve this goal the main task is to reduce the use of fossil fuels replacing them with renewable biofuel like wood chips from pre-commercial thinning.

This study is about the working methods in pre-commercial thinning of deciduous, naturally regenerated stands, to understand how to get the greatest possible benefit (biofuel) from thinning, while increasing the growth potential of the remaining stand. The information available in literature on this topic is very limited due to the relatively small distribution of grey alder stands in Nordic countries, where pre-commercial thinning for biofuel production has already become a significant source of biomass. Similar studies have elaborated on coniferous tree stands, also in Latvia, but the situation with deciduous stands is much different due to the structure of stands, regeneration history, and visibility in stand.

Materials and Methods

Description of research object

The research objects are located in Birzgales parish, Ķegums municipality (56°32.98639’ N, 024°41.23923’ E) in 2 blocks and 4 forest compartments with the total area of 8 ha. Grey alder dominated forest stands with high initial density (at least 6000 trees per ha) were selected for the study (Table 1). All of the stands are naturally regenerated after clear cut and the age of the stands is less than 10 years. In all of the selected stands, the forest site type is *Oxalidosa*.

Data collecting

Circular sample plots (further in text – SP) with radius of 2.82 m (area 25 m^2) were established in all stands before thinning for characterization of stand properties. Number of SP were chosen according to the requirements in regulations of Cabinet of Ministers (Noteikumi par…, 2013) terms of tree felling in the forest. At least a 100 trees were measured in each stand. All trees in SP were measured if the diameter of a tree at breast height exceeded 4 cm. Undergrowth trees and shrubs were also counted and measured in all SP; the average height and total number of stems of undergrowth trees and bushes were noted in each SP. The tree diameter and height were measured in each stand and SP separately. Characteristics of stand after thinning and counting of damaged trees after harvesting and forwarding were done in rectangular SP covering strip-road and thinned stand area, similarly to D. Bergstrom et al. (2010).

SP were established in every strip-road and no closer than 10 m from both ends of strip-roads. The distance between SP may vary, because of different length of the strip-road. If the strip-road is shorter than 160 m, the distance between SP is 20 m, but if the strip-road is longer than 160 m, the distance between SP is 40 m. SP is 20 m long rectangle with 20 m long sides; the area of SP is 400 m^2. Plots are located on parallel with strip roads so that their mid-axis are on one line with strip road mid-axis, but SP side lines are osculating but not overlapping.

All trees with the diameter at breast height above 4 cm were measured in SP. The tree diameter, distance between the tree and strip road centre were measured and tree species were identified. Measurements of height of representative number of trees (10-20 trees of each species) were done before thinning and the same height curve was applied to the measurement data before and after thinning. Damage of remaining trees, divided in 4 groups, was assessed in all sample plots. Data of tree damage were analysed as the proportion of damaged trees was expressed as a difference between damaged trees and all of remaining trees. Mostly data were analysed grouped by working methods.

Trees were marked as damaged if they matched one of the criteria in Table 2. These criteria are used also in joint stock company ‘Latvian State Forests’. Soil damage on strip-roads (length of ruts) was also evaluated after forwarding. The threshold value for ruts is more than 10 cm from topsoil. Ruts were measured on both sides of strip-road.

Damage of trees was classified in four groups:

1. Damage above 0.5 m;
2. Damage below 0.5 m;
3. Damage of roots;
4. Damage caused by chain.

Table 2

Indicators of mechanically damaged trees in thinning*

Location of damage	Type of damage	Description of damage
Crown	Broken top	Broken off top
	Broken branches	More than 60% from crown
Stem	Stem part without bark	The area without bark is more than 25% from stem girth at the damage location.
Roots	Broken root	Root that is thicker than 2 cm broken up to 70 cm from stem.

Norādījumi koku bojājumu novēršanai. 2012.

Description of working methods

Three mechanized thinning methods were compared in the study using John Deere 1070 harvester equipped with felling head Bracke C16.b:

1. Traditional method: the operator evaluates each tree individually, leaves only the best trees with straight stems and qualitative crown and cuts down all potentially competing trees around it. At the first step of thinning, the operator makes a strip-road and cuts 1-1.5 m wide (width of Bracke C16.b harvester head) 'pockets' on both sides of the strip-road, usually in 90° direction from the strip-road, where to put down all extracted trees. The distance between 'pockets' depends on the density of stand. Then the operator does thinning on both sides of the strip-road. The average distance between pockets in the study was 5 m.
2. Simple symmetric method: trees are not evaluated individually and target trees are not identified during thinning. Like in the first method, the operation starts with cutting the strip-road, then perpendicularly to harvester the operator cuts 1-1.5 m wide and 10 m long 'pockets' where to put the extracted tree. This cycle is repeated every 2-3 m to the entire length of the strip-road; no thinning is done if trees are less than 4 cm in diameter at breast height; angle of 'pockets' can be adopted to improve the thinning quality
3. Complex symmetric method: the difference from the second method is the cutting of 1-2 additional stripes near each 'pocket' so that these stripes are branching from the 'pocket' at 30-45° angle. Material is stored in the main 'pockets' as well as in additional stripes, depending on the amount of material. Harvester repeats this operation every 5-6 m.

Visualization sample of the 2nd and 3rd method is given in Figure 1.

Normality of variables was checked by the Kolmogorov-Smirnov test. The data did not follow a normal distribution, or occurred inhomogeneity of group variance the nonparametric Mann-Whitney Test

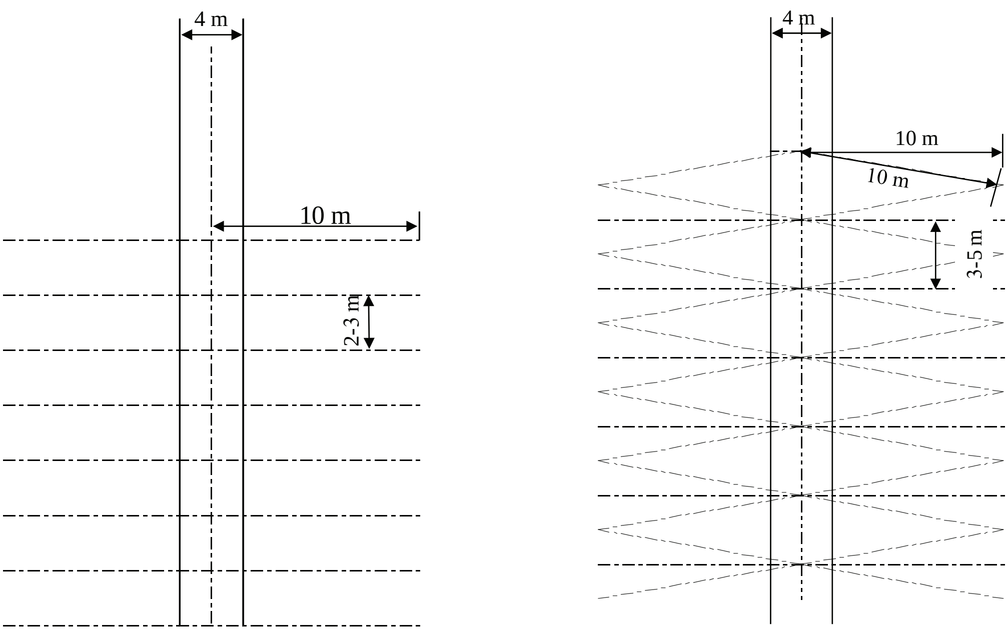

Figure 1. Technological scheme for Simple symmetric (left) and Complex symmetric (right) working methods.

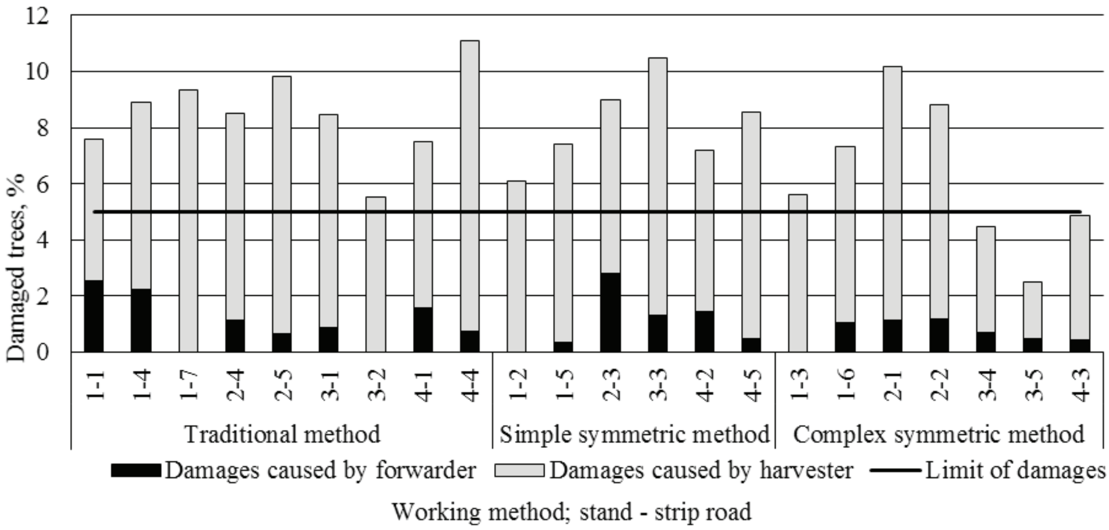

Figure 2. Proportion of damaged trees depending on working method and on each strip road, %.

analysis of variance was used. In all cases the level of significance α = 0.05 was accepted. Difference between working methods was calculated using Dwass-Steel-Critchlow-Fligner procedure and for data analyses the software SPSS Statistics 17.0 was used.

Results and Discussion

The proportion of damaged trees, depending on the working method and in each strip road, is shown in Figure 2. Uninterrupted line represents the maximum permissible proportion of damaged trees (5%) according to the quality requirements of the JSC 'Latvian State Forests' in the forest thinning operations (Norādījumi koku…, 2012). According to the study results, only 3 strip roads from 22 fulfilled the quality requirements for permissible level of damaged trees. The strip-roads with the smallest proportion of damaged trees were thinned with the complex symmetrical method, while the largest proportion of damaged trees were mostly found when the thinning method called traditional working method was used. Most of damage was caused by the harvester; amount of damage caused by forwarder is relatively small on all strip-roads. Damage caused by forwarder does not depend on the applied working method.

The total average proportion of damaged trees by the traditional method was 8.7%, by the simple symmetric working method – 7.9% and by complex symmetric method – 5.9%.

The proportion of damaged trees was calculated separately for used machinery for each of the working methods: for harvester at the first method – 7.7, at second method – 6.9 and at third method 5.2%, but for forwarder 0.9, 1.0 and 0.7% respectively. Scientists in other countries are also mentioning 5% threshold as maximum allowable percentage of damaged trees regardless of trees species (Bäcke, 1997). It was found in the study that all of the applied working methods result in a higher proportion of damaged trees; however, symmetrical thinning methods are more favourable from the perspective of proportion of damaged trees.

The level of difference in the proportion of damaged trees between working methods is significant in all of variants. Results show statistically significant differences between all of the working methods ($p<0.001$).

The proportion and frequency of different types of damage are also analysed depending on the applied working method. It is found that most damage is on stems and they are caused by harvester head or other processed trees. When the 1st working method is used, more than half of damage is detected in the group 'damage below 0.5 m' (56.3%). If symmetrical thinning methods are applied, about half of damage belongs to the group 'damage above 0.5 m' respectively 53 and 52% (Figure 3). The smallest amount of damage is detected for the groups 'damage caused by chain' and 'damage of roots' (not more than 4% in all working methods). Other authors in their studies have mentioned that summarizing the volume of both groups of damage results in stem damage between 90 and 98%. In this study it is also proved that the stem damage is within the range mentioned by other scientists (Sirén, 1982; Fröding, 1992; Jaghagen and Lageson, 1996).

The number of trees in stands after thinning against limiting values determined in regulations and the location of trees in a stand is shown in Figure 4 and Figure 5. Actually it shows the quality of thinning - if the distance between the strip-road centre and tree is growing, then also the number of trees of remaining stand is growing (Figure 4).

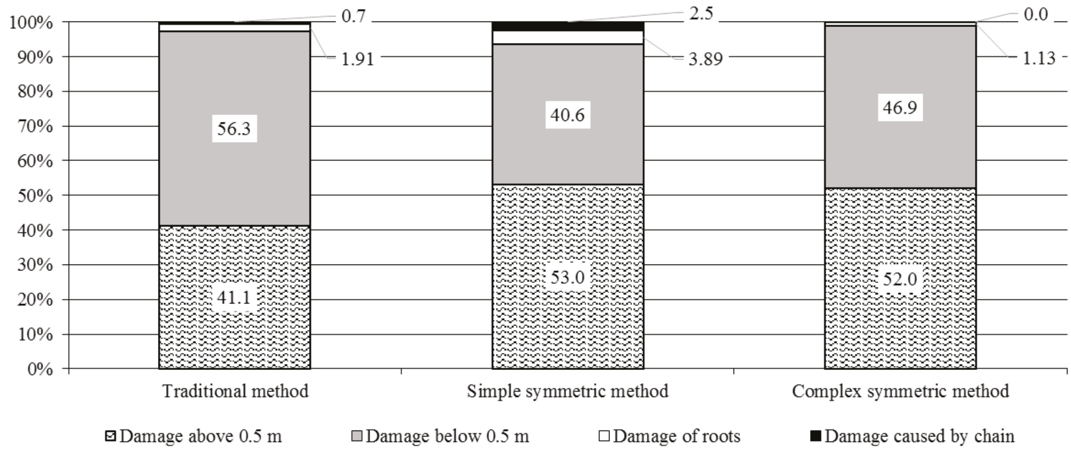

Figure 3. Proportion of different types of damage according to working methods.

According to the charts, the experimental stands are not thinned evenly in any of the used working methods and there are denser areas between strip roads which are not thinned correctly. Intensity of thinning could be increased, because the number of remaining trees is twice higher than the legal thresholds, and it was possible to extract much more biomass from the experimental stands making thinning more feasible (Figure 5).

Soil damage (length of ruts deeper than 10 cm) was measured in each strip road. Forwarding of biomass was done in unfavourable weather conditions (in early

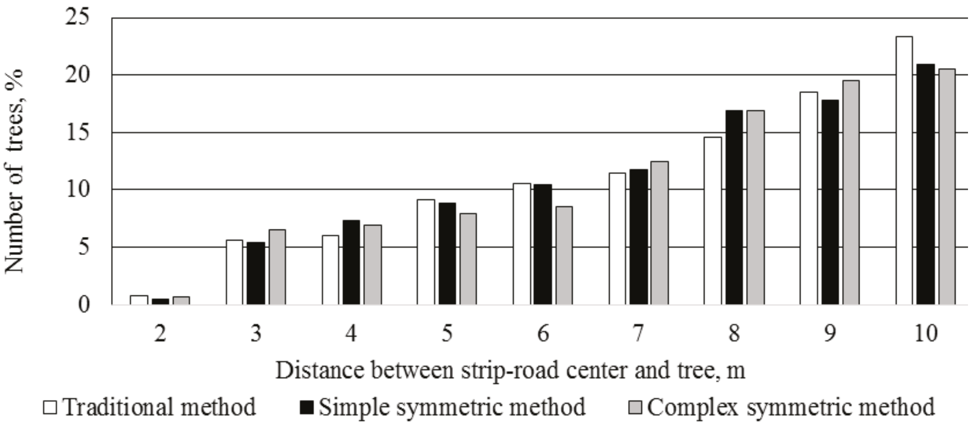

Figure 4. Proportion of trees in distribution by groups of average distance between trees and strip road centre depending on the used working method.

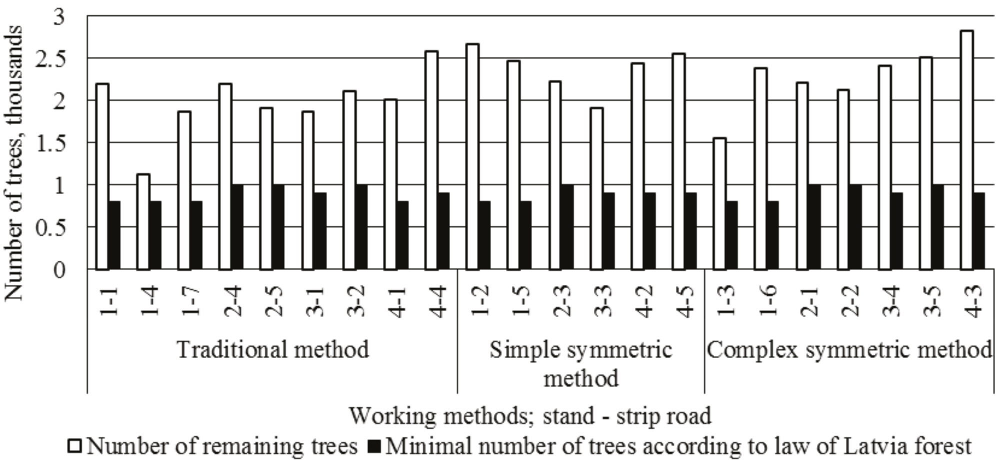

Figure 5. Minimal number of trees (in thousands) according to requirements of regulations (Noteikumi par…, 2013) in comparison with number of remaining trees after thinning.

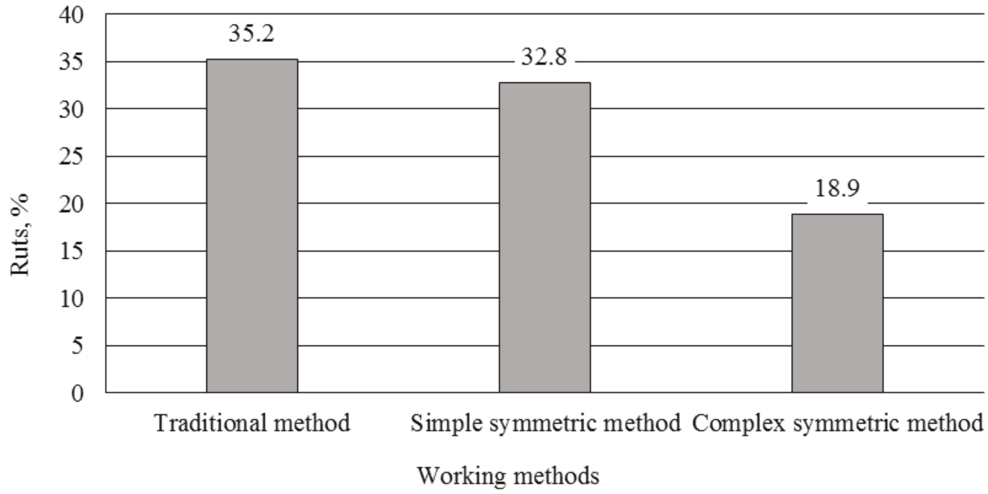

Figure 6. Proportion of ruts from total length of strip-roads depending on the working method.

spring during thaw), when soil became soft; therefore, a lot of soil damage was found. Notably, the formation of ruts mainly relates to forwarding; harvesting did not result in significant soil damage. The proportion of length of ruts was also analysed according to the working methods, assuming that different initial impacts of harvester and location of biomass, besides the strip-roads, might affect the formation of ruts during forwarding.

The smallest proportion of ruts was found on strip-roads where complex symmetric working method was applied (18.9% of the total length of strip roads). The proportion of ruts was more than 30% when the traditional and simple symmetric working method was applied, respectively 35.2% and 32.8% of the total length of strip-roads (Figure 6). The average length of ruts in percentage of the total length of strip-roads grouped by stands and initial number of trees is shown in Figure 7.

The most intensive soil damage was found in the stand with 6800 trees per ha, where ruts covered more than 50% of the total length of strip-roads, while the smallest proportion of ruts was found in the stand with 7600 trees per ha, where ruts covered only 8% of the total length of strip-roads. Differences in soil damage between objects show that soil structure and bearing capacity differ between stands and stand type; also the number of trees per ha is not always a sufficient parameter to predict soil bearing capacity. L. Eliasson (2005) in his research mentioned that rut depth increased significantly ($p<0.001$) with the number of machine passages, but in my research this impact was not observed. Also he mentioned that longer corridors are always subject to heavier damage, but in Figure 8 it is shown that there are not any logical relations. It is possible that this is due to the weather conditions during the forwarding operations. In real life conditions, forwarding had to be stopped and

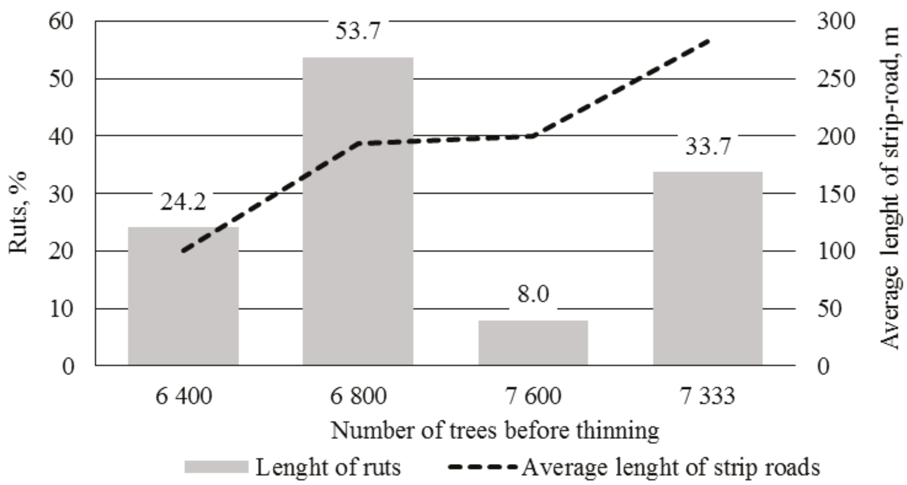

Figure 7. Average length of ruts in percentage of total length of strip-roads grouped by stands and initial number of trees.

continued during more favourable weather conditions. A great benefit of the Bracke C16.b felling head, which is also sometimes called the biggest drawback of this type of felling heads, is the ability to produce only biofuel assortment, that is, it lacks delimbing and cut-to-length function. The benefit is in fact that biofuel can be stored in forest for several months, in contrast to roundwood assortments, and its quality is increasing during storage – small branches become brittle and separate from the main stem, moisture content is reducing and potassium, as well as other easily soluble elements, are partially washed out from biomass. However, utilization of this benefit requires more flexible organization or forest operations.

Conclusions

1. Statistically significant difference ($p<0.001$) was found in the proportion of damaged remaining trees between all of the applied working methods. The smallest amount of damage is associated with the complex symmetrical thinning (3rd method). The most damage appears during harvesting.
2. Regardless of the applied working method, the proportion of damaged trees is above the maximal threshold value of 5%. Respectively, working methods, technical conditions of harvester or operator's skills need to be considerably improved to fulfil the quality requirements.
3. Intensive formation of ruts on strip-roads was determined by unfavourable weather conditions; however, it was found that forwarding of material extracted on strip-roads, where the 3rd method was applied, results in a smaller proportion of ruts.
4. The result of the study proves that it is necessary to improve the working methods, skills of operators and also technical condition of machines, because none of the methods resulted in sufficient thinning quality.

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