PRODUCTIVITY AND GHG BALANCE OF HARVESTING AND FORWARDING IN THINNING OF ASPEN HYBRID PLANTATIONS

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Abstract. The aim of the study is to evaluate the productivity and potential reduction of greenhouse gas (GHG) emissions due to use of the compact class Malwa harvester 560H and forwarder 560F in thinning of aspen hybrid plantations as well as to indicate the production cost and to analyse the possibility to use forest machines of this class in aspen plantations and to definite the quality of thinning, including the damage to the remaining trees, width of strip-roads, as well as to provide recommendations for the further development of the technology. These parameters have significant effect on productivity, fuel consumption and the vitality of the remaining trees. The productivity and cost are affected by tree dimensions, if the average harvested stem diameter is 12.2 cm, the productivity is 8.63 m^3 per productive hour and the harvesting cost is 12.24 $EUR \cdot m^{-3}$, but in average productivity gives a big impact on the cost – 10.96 m^3 per productive hour and harvesting cost – 10.04 $EUR \cdot m^{-3}$. The average forwarder load in the study is 4.03 m^3, forwarding productivity 5.1 m^3 per productive hour and total harvesting and forwarding cost – 21.04 $EUR \cdot m^{-3}$. Harvesting related GHG emissions in aspen plantations are 4.12 kg $CO_2 \cdot m^{-3}$, including harvester related emissions – 49% and forwarding – 51%. According to the study results the harvesting GHG emissions using the Malwa harvester and forwarder are significantly smaller than of a middle-class forest machines due to smaller fuel consumption and high productivity values; besides, maintenance and investment costs of compact class machines are significantly smaller. The mechanical damage to roots and stems of the remaining trees during logging is inevitable. This is ensured by the use of recommended working methods setting special attention to the felling direction and the distance between the remaining trees in the stand, as well as avoiding unnecessary movements with the manipulator.

Keywords: greenhouse gas emissions, productivity, plantation forests, harvester.

Introduction

Climate change is one of the most debated topics. It is dissected by scientists and politicians. In line with the EU targets set by 2050, committed to climate action it is planned to implement a variety of measures. Climate change is currently capable of measuring temperature changes, with average increases in spring and summer seasons between 1986-2005 by 0.55-0.87 ºC [1], with average temperature change of 1ºC for the first time in 2015 [2; 3].

The carbon cycle and its breakdown are important for the development of different strategies. A total of five carbon storage sites is distributed: fossil resources (85% coal), ocean, pedosphere, atmosphere, and biotic environment [4; 5]. Carbon life cycle calculations are complex, one-way and two-way carbon flows are distributed [6]. One-way calculations are applied to the use of fossil energy resources, while the two-way are between the atmosphere and the biotic environment.

Circulation of carbon in the forest ecosystem can produce three large carbon storage sites: live biomass, stillborn biomass, and subsurface (including the soil) [7]. Carbon sequestration is carried out by living plants, producing biomass for the duration of the process. Biomass-increasing plants are associated with their age, older stands have more biomass compared to younger stands [8]. In forestry the amount of accumulated carbon is determined by the biomass as a function of volume and density. Consequently, it does not necessarily attract more carbon to larger stocks. Research in Latvia mainly looks at the young stands of pine tree, birch and grey alder, in which the associated carbon is grown [9]; [10]. It is possible to calculate the carbon sequestration in the maturity stand for pine, spruce, birch, and aspen [11]. It is important to assess not only the amount of each species in terms of carbon sequestration, but also the lifespan of the fractions.

GHG emissions in logging have been addressed in the most cases by means of medium and high-class machines, using cut to length technology [12; 13]. GHG emissions due to harvesting are determined by productivity, fuel, oil and grease consumption, as well as by proportion of biofuel and biooils and efficiency of the engine (Euro generation determining emissions of N_2O and CH_4). Much attention has been paid recently to the whole forestry cycle in analysing GHG emissions.

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Materials and methods

The study was carried out by small-scale logging machines – Malwa harvester 560H and forwarder 560F, the most important technical parameters are summarized in Table 1.

Table 1

Technical specification Malwa

Specification	Malwa 560H	Malwa 560 F
Weight, kg	5700	
Width, m	1.95	
Ground clearance, mm	400	
Engine type	Caterpillar C2.8	
Engine power, kW	55	
Crane reach, m	6.2	6.1
Gross lifting torque, kNm	37	45.6

Forest machine divisions: compact class – wight 8-18 t, engine power till 140W, middle class – wight till 20 t, engine power 150-200 kW, big class – wight till 24 t, engine power 200-240 kW [20].

Working methods and techniques. Logging is planned in 45º angle against the strip-roads' direction. In the process of timber preparation, logging residues are left scattered. Harvesting shall be stated with trees located on a strip-road, but not further away from machine than 50% of the manipulator extend. The trees located in a longer distance from the harvester should be extracted when the harvester changes position. Movement distances should be between 2 and 5 m. To improve productivity, it is recommended to use shorter distances and relocate the machine more frequently. Trees located on the strip-road must be felled in perpendicular to the strip-road direction, thereby ensuring that assortments are landed in compact piles. In plantations, similarly to forest stands, the harvesting should be planned in sectors, ranging from the right or left edge to the felled trees. The overall sector needs to be divided into 2 zones. The first zone shall consist of trees that are located within arrange of 60% of the total manipulator side extend. The trees are felled in parallel to strip-roads. In zone 2 the harvesting approach is different – trees are felled at 45° angle or perpendicular to strip-roads, and the operator decides to pile harvesting residues in zone 2. To minimize root damage, the felling residues from strip-roads and zone 1 are placed on the strip-roads. The location of assortments is determined by the harvesting method. Larger logs should be placed closer to the machine, but smaller logs can be placed further away from the harvester in zone 1, thereby ensuring optimal working conditions for the forwarder. The forwarder is planned from the further oblique corner. To ensure high productivity, every load should contain at least two types of assortments. This leads to higher productivity and reduces potential root damage since each trip meets less mileage compared to the conventional approach when assortments are forwarded one by one.

The roundwood assortments are produced according to the quality requirements in Latvia [14; 15], the assortments are prioritized according to market prices to ensure the highest possible productivity.

Forest machine operators with long experience participated in the study. Duration of shifts was 8 hours per day, both for harvester and forwarder operators. To determine the productivity indicators, the study shall keep time records dividing three categories and identify work elements in each of the categories [16].

Fuel consumption is determined by the flow counting unit in AIC systems AG, Model:AIC904. Lubricants are counted according to information on regular servicing and actual data on the application of the greasing materials, and used for further GHG calculations. Net Calorific Value (NCV) and density can be calculated from thermodynamical values, Table 1 [17]. Emission factors according to IPCC 2006 guidelines are provided in Table 3.

Tree trunk volume for scarred aspen using the formula 1.1 [18].

$$v = 0.5020 \cdot 10^{-4} \cdot H^{0.92625} \cdot d^{0.02221\lg(H)+1.95538} \tag{1}$$

where v – tree volume, m^3;
H – height of tree, m;
D – tree DBH, cm.

Harvesting costs are calculated according to a model verified in Latvia [19]. The harvester price of EUR 220000, but the forwarder price of EUR 180000, the period of technical depreciation of 5 years.

Mechanical damage to the remaining trees and roots has been measured in accordance with the requirements adopted in Latvia [21].

The Wilcoxon rank mark test was used to describe the performance characteristics using inferential statistics to describe the differences between the traits or sample groups studied. For productivity calculations parametrical methods ($p = 0.42$) are used. The Spearman rank correlation test was used to determine correlations.

Table 2

Net calorific value and density of fuel, engine oil and lubricants

Parameter	**NCV**			**Density**	
	MJ·L^{-1}	MJ·m^{-3}	MJ·kg^{-1}	kg·L^{-1}	kg·m^{-3}
Diesel in off-road transport	36.0	-	42.6	0.846	-
Lubricants	-	-	41.9	-	-
Engine oil	39.2	-	39.5	0.991	-

Table 3

Emission factors for fuel, engine oil and lubricants

Parameter	**CO_2, t·t^{-1}**	**CO_2 t·TJ^{-1}**	**CH_4 kg·TJ^{-1}**	**N_2O kg·TJ^{-1}**
Diesel in off-road transport	-	74.7	5.5	28.0
Diesel in road transport	-	74.8	2.8	2.8
Lubricants	0.6	-	-	-
Engine oil	0.6	-	-	-

Results and discussion

The volume of logs produced during the study is 252 m^3 over bark. The volume of average felled tree is 0.11 m^3, the diameter of average felled tree is 12.2 cm. On average, 88 trees were processed during the productive working hour, the proportion of the productive working time is 96% of total working time. The average productivity is 8.63 m^3 h^{-1} per productive hour, the relationship between the productivity and the volume of an average trunk is described by the polynomic equation (Fig.1), the correlation coefficient of the developed equations is 0.95.The average productivity figures obtained within the scope of the study are compared with those estimated in other studies and no significant differences are found [22-24]. The average productivity of the forwarder is 5.1 m^3 h$^{-1$} per productive hour, the proportion of productive time is 94%. Average fuel consumption for both machines during the study was 7 L·h^{-1}.

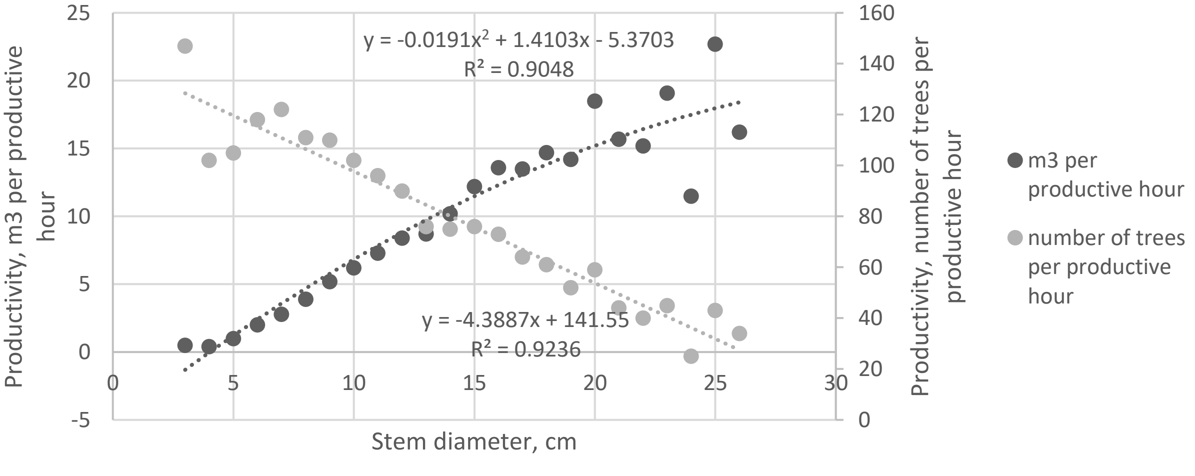

Fig. 1. **Characteristics of the productivity depending on the diameter of an average felled tree**

The remaining tree damage after logging was less than 1%. The largest advantage of the compact class harvester in comparison to the middle-class harvester is shorter manipulator's extend, what means that compact-class machines are working at almost twice shorter distance between the tree to be processed and the operator's eyes, which significantly improves the visibility and thus reduces mechanical damages to the remaining trees. The average harvesting cost is 12.24 EUR·m^{-3} and together with the forwarder 21.04 EUR·m^{-3} over bark.

Cut-to-length technology is used in the study to evaluate the productivity, cost and GHG emissions. During the logging process fossil fuel is the largest source of emissions. It represents up to 93% of the total GHG emissions, while lubricants contribute to 1.3% of the emissions [25]. The emission factors are applied following to default parameters in the IPCC 2006 guidelines (Table 3). Based on the results of the study (average productivity and fuel consumption), the harvester fuel consumption is 0.8 L·m^{-3} and the forwarder fuel consumption is 0.7 L·m^{-3}, while for middle-class machines working in first and later thinning the fuel consumption is 1.97-2.75 L·m^{-3} [13]. GHG emissions due to thinning of aspen hybrid plantation equals to 4.12 kg CO_2 eq·m^{-3}, of which 49% are harvester emissions and 51% are forwarder emissions. There calculation is done according to average consumption of materials and parameters provided in Table 2 and 3. The reduction of GHG emissions is limited by the forwarder load capacity. Average GHG emissions due to use of middle-class harvesting machines are 8.1 kg CO_2 eq. m^{-3}; therefore, use of compact class machines in similar conditions can lead to twice smaller GHG fluxes [13].

According to the obtained data of the fuel consumption and the productivity achieved, GHG emissions may vary depending on the dimensions of an average felled tree. The emissions due to use of hand tools in other authors' studies are less than 0.11-0.26 kg CO_2 eq·m^{-3} [12]. It is reasonable to start mechanized thinning if it is possible to produce industrial roundwood. The CO_2 consumption per cubic meter depending on dimensions of trees is modelled using the productivity achieved in the study. Mechanized harvesting of trees with an average diameter of 5 cm results in emissions of 17.46 kg CO_2 eq·m^{-3}, with a rapid reduction trend, if the average extracted tree reaches 10 cm diameter (2.5 kg CO_2 eq·m^{-3}). Logging is not the only source of CO_2 emissions, it is necessary to assess the whole forestry cycle to identify, where the mitigation possibilities are located, but given the specific nature of the study we can prove that compact class machines provide a possibility to reduce GHG emissions due to harvesting and forwarding nearly twice.

Conclusions

1. It is the necessary to draw attention to dimensions of an average extracted tree, which has significant impact on GHG emissions during harvesting. It is recommended to use mechanized logging using compact class machines, if the average extracted tree diameter exceeds up to 10 cm.
2. The productivity figures achieved in the study are similar to those of a middle class harvester compared to the same average tree diameter. In contrast, compact class logging forest machines have lower fuel consumption per cubic meter, resulting in reduced GHG.
3. Compact class machines can be recommended for thinning of aspen hybrid plantations to reduce the costs, GHG emissions and stand damages, while retaining productivity at relatively high level.

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Author contributions

Data acquisition G.S.; methodology G.S. and A.Z.; data processing and analysis A.Z. All authors have read and agreed to the published version of the manuscript.

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