PRODUCTIVITY AND CARBON DIOXIDE (CO_2) EMISSIONS OF COMPACT CLASS VIMEK 404 T5 HARVESTER IN THINNING OF YOUNG BIRCH STANDS IN AFFORESTED CROPLAND

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Abstract. The aim of the study is to evaluate the productivity and carbon dioxide (CO_2) emissions of the compact class Vimek 404 T5 harvester in thinning of birch plantations, including the determination of production costs to evaluate the possibility to use compact class forest machines in management of woody shelter belts around drainage systems in farmlands. A total of 69 m^3 of logs were prepared in the experiments, the average diameter of the sawn tree was 10 cm (average stem volume was 0.06 m^3). The average productivity of the harvester is 6.2 m^3 per productive hour. Logging costs, according to the assumptions used in the study, are 21.1 $EUR \cdot m^{-3}$ (under the bark), including 8.1 $EUR \cdot m^{-3}$ of logging costs. The total CO_2 emitted to produce and forward 1 m^3 of timber (about 235 kg of carbon) is 3.6 kg, excluding chipping (1.3 kg m^{-3}). According to the study results the hourly cost and CO_2 emissions of a Vimek 404 T5 harvester is significantly smaller than of a middle-class harvester due to lower fuel consumption, maintenance costs and initial investments.

Keywords: harvester, CO_2, productivity, costs, thinning.

Introduction

The proportion of mechanized thinning grows continuously in the Nordic countries becoming the dominant harvesting technology [1]. The literature describes several technological solutions in logging, at least 14 different technological solutions have been identified [2-4], but nowadays the most common solutions consist of separate machines for harvesting and forwarding [1; 4- 7]. In Latvia, still the most common approach in selection of harvesting solution in thinning is adaptation of machines initially developed for commercial thinning and regenerative felling, instead of using of the compact class harvesters and forwarders designed for pre-commercial thinning [8-11]. Use of compact and middle-class harvesters, designed to single- or multi-tree handling (equipped with additional knifes), in thinning is common practice in the Nordic countries [12] and gradually this practice is being introduced in Latvia [3]. According to previous studies, in areas, where the volume of felled trees does not exceed 0.1 m^3, the use of compact and middle-class harvester is a good solution [12-15]. However, compact class harvesters have also disadvantages, such as a short boom (less than 10 m), which is not suitable for stands where the distance between strip roads is 20 m (typical situation in Latvia), as well as limited possibility to process trees with the stem volume exceeding 0.5 m^3 [12; 16].

Vimek AB is one of the leading manufacturers of compact class forest machines and the use of these machines in harvesting has been studied extensively during recent years [2; 16-18]. In the winter of 2015, a study was carried out in Sweden in coniferous stands to determine the productivity of a compact class harvester Vimek 404 T5, as well as to evaluate the suitability of this type of forest machinery in Latvia. In coniferous stands with average tree height 10.6 m and stand density 3625 $trees \cdot ha^{-1}$ the average productivity achieved in the trial were 5.5 m^3 per productive hour ($E_{15}h$) [2]. In studies comparing the productivity achieved by compact- and medium-class harvesters in similar conditions in thinning in Finland, it was found that the productivity does not differ significantly [12], but the advantages of compact class machines are smaller fuel consumption and relatively lower costs [11; 18].

The climate change mitigation targets may become one of the drivers in forest management. As mechanization of the technological process of harvesting increases, the efficiency grows, but at the same time machines are an increasing source of greenhouse gas (GHG) emissions. The main factors affecting GHG emissions in forest operations are fuel consumption during harvesting, forwarding, relocation of forest machines, chipping and secondary transport of wood logs and biofuel. Combustion of fuel produces CO_2, which is one of the GHG. [19]. According to studies in Latvia compact- and medium-class harvesters with the engine capacity from 44 kW to 136 kW in thinning consumes 5-12 $L \cdot h^{-1}$ of fuel [8; 9; 14; 20; 21]. According to the studies implemented in Finland and Sweden, the average fuel consumption of medium-class harvesters in thinning is 12 $L \cdot h^{-1}$ (average productivity 8.2 $m^3 \cdot E_{15}h^{-1}$) and 11 $L \cdot h^{-1}$ (average productivity 8.2 $m^3 \cdot E_{15}h^{-1}$), accordingly [15; 19].

The aim of the study is to evaluate the productivity and CO_2 emissions of the compact-class Vimek 404 T5 harvester in thinning of birch plantations, including evaluation of thelogging costs to evaluate the possibility to use compact class forest machines in management of woody shelter belts around drainage systems in farmlands.

Materials and methods

Tests were performed on a birch (*Betula pendula*) plantation in the south-western part of Latvia in the autumn of 2018. Before thinning, the average diameter at the breast height (DBH) of trees was 12 cm, planting density – 2000 $trees \cdot ha^{-1}$, accordingly.

Compact class harvester Vimek 404 T5 (weight 3.8 tons, engine power 44.7 kW), equipped with the Keto Forst Silver harvester head (weight 305 kg, max. felling diameter 30 cm, boom reach 4.6 m) was used in the study. Strip-roads later used by forwarder have been created every 20 m, "ghost paths" between the strip-roads.

Time study in thinning was carried out manually using a hand-held data logger and the continuous time recording method. The total work time represents the duration of the shift, but the productive work time is calculated by deducting the time spent on repairs and non-work activities. The average productivity figures, which are represented by the volume of timber prepared per productive working hour stratified by stem volume, are plotted using the polynomial regression function. The standard deviation was calculated for the means. In order to determine the significance level of the data, the T-test was used.

For cost calculation the model developed within the COST project FP0902 [22] supplemented with standard economic methods [17] was used. The production cost calculation uses empirical data obtained from long-term observations (information provided by technical service providers and service companies on regular maintenance costs) and published data on the cost analysis. The cost items include investments, personnel costs, and operational or maintenance costs [22-25]. In the cost calculation it was assumed that the harvester is employed 24 hours a day (each of 2 involved operators worked in two 6-hour shifts). The average work productivity of each unit of the forest machines was used for cost calculation.

Methodology reflected in the "2006 IPCC Guidelines for Natural Greenhouse Gas Inventories" [26] was used to calculate the amount of CO_2 emissions in harvesting and forwarding of timber. Data of the average fuel consumption are used in calculation and these data conform to the data acquired in earlier studies in Latvia. The calculations according to the methodology assume that 74100 kg of CO_2 are emitted when burning TJ of diesel. The calculations also assume that 1 TJ corresponds to 277.8 MWh. According to the methodology, the amount of CO_2 emissions is calculated by multiplying the fuel consumption by the corresponding emission factor. Carbon stock in sawn materials is calculated using the average wood densities [31] and carbon content in wood [32].

The results are compared for two scenarios, the first of which envisages the use of a compact class machine in harvesting and forwarding. The second scenario considers use of middle-class machines in harvesting and forwarding. Literature data on productivity, costs and fuel consumption in similar stands extracted with middle-class forest machines were used in the study [27-29].The calculations also assume that both scenarios are realized under similar conditions, the average volume of sawn tree is 0.08 m^3, the productive work time is 85% of the total work time, the technical availability of machines is assumed to be 80%. It is also assumed that in both scenarios forest machines will operate 2895 productive hours per year, forwarding distance in the forest – 145 m.

Results and discussion

In total 69 m^3 of logs were prepared in the experiment. The average diameter of a tree was 10 ± 0.5 cm, and the average volume of the stem was 0.06 ± 0.001 m^3. In average 98 ± 4 trees were processed in productive hour, using the Vimek 404 T5 harvester resulting in 6.2 ± 0.3 m^3 per productive hour. The average share of the productive work time of the total work time was 93%, including 6% of the productive work time spent for entering and leaving forest stands. The regression function can explain

98% of the changes in the productivity depending on the volume of stems of the extracted trees (Fig. 1). The productivity in the birch plantation does not differ significantly from the data previously obtained in thinning of coniferous stands [2]. The dimensions of the trees in the birch plantation were not large enough to reach the point (diameter of harvested trees) at which productivity of the Vimek harvester starts to decrease and becomes smaller compared to the values acquired by a middle-class harvester according to other studies [8; 9; 13; 14; 21].

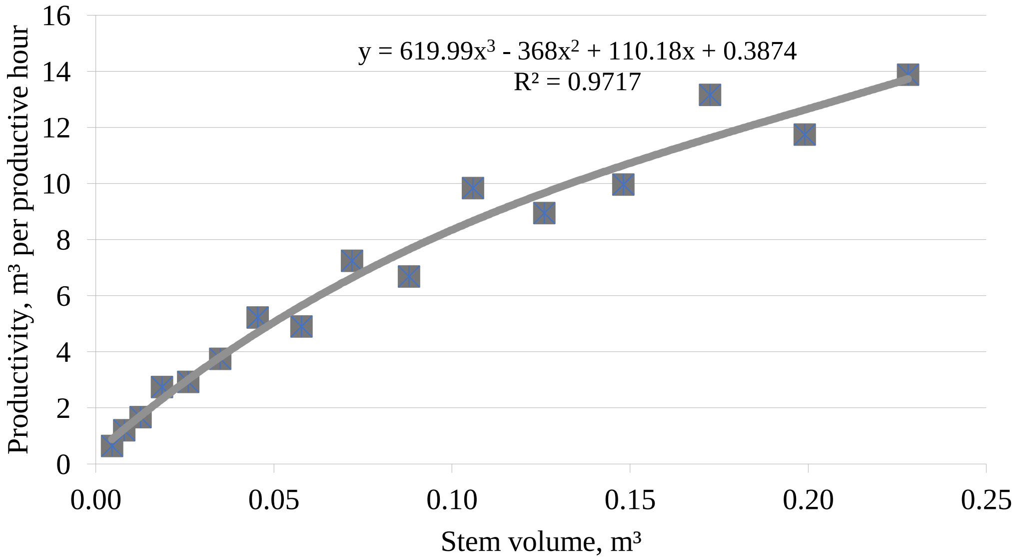

Fig. 1. **Average productivity in thinning by stem volume groups**

The prime cost of an average planned working hour of the Vimek 404 T5 harvester is 34 EUR, and the prime cost of the productive working hour is 42 EUR. The average productivity of the harvester is 6.2 ± 0.3 m^3 per productive hour (average stem volume 0.06 ± 0.001 m^3), assuming that the harvester works 2880 productive hours per year producing annually 14782 m^3 of timber. Average logging cost is 8.1 EUR·m^{-3}. When using a middle-class harvester in similar conditions, the average logging cost is 12.5 EUR·m^{-3} [8; 9; 13]. The hourly cost of the Vimek 404 T5 harvester is significantly smaller than the hourly cost of a middle-class harvester (assuming similar yearly utilization rate of a harvester, the prime cost of the planned work hour is 53 EUR and the prime cost of the productive work hour is 64 EUR). The difference is due to different fuel consumption, maintenance costs and initial investments. At the same time, the Vimek harvester provides at least as good productivity as the middle-class harvester in pre-commercial thinning [8; 9; 13; 21; 30]. Considering similar productivity rate, the cost of harvesting per cubic meter differs significantly [19].

Cost calculation of the production cycle proves that, according to the assumptions used in the study, the cost of timber production and delivery to the consumer is 21.1 EUR·m^{-3} (under bark). One of the possibilities to reduce the prime costs of the harvesting process is selection of a more efficient forwarder. Middle-class or Vimek 610 forwarders are two options evaluated in the study. Compact-class forwarders can transport smaller loads, but they also make less damage to soil and can transfer logs through growing stands without strip-roads thus reducing the forwarding distance [11; 17; 18]. The use of a middle-class forwarder increases the width of the technological corridors, losing one of the most important advantages of compact class logging machines – the possibility to perform thinning without technological corridors or making them much narrower, significantly reducing the number of felled trees on strip-roads, therefore, the use of forwarders that match the dimensions of the Vimek 404 T5 harvester in thinning should be considered in the first order [2]. According to the results of earlier studies, despite of small dimensions, the Kranman Bison 10000 forwarder is not really suitable for pre-commercial thinning due to its relatively small load capacity and insufficient stability on existing forwarding trials. Due to the small capacity forwarding costs are relatively big [13]. Use of a Vimek forwarder in pre-commercial thinning increases the average load size significantly, particularly in areas with low bearing capacity, the average load is not significantly smaller than the average loads of the middle-class forwarders, thus the use of the Vimek forwarder reduces the prime costs of the total harvesting system [17; 18; 25].

Sensitivity analysis proves that changes in the production costs are significantly affected by the machine work load (annual operational hours), as well as the dimensions of the extracted trees (Fig. 2). The harvesting cost using the Vimek 404 T5 harvester is mostly affected by the workload of the machine; if less than 1500 hours are worked per year, the harvesting costs increase rapidly. Taking in account that this harvester is suitable mainly for pre-commercial and the first commercial thinning and removal of woody vegetation from abandoned farmlands, planning of work is crucial to ensure that the machine is employed throughout the whole season.

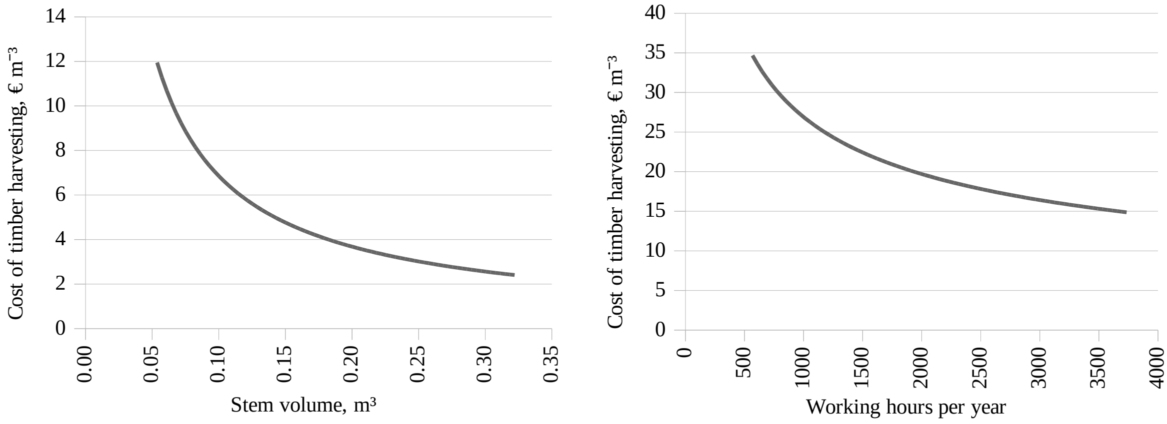

Fig. 2. **Stem volume and harvester utilization rate impact on timber harvesting costs**

The total CO_2 emitted to harvest and forward 1 m^3 of timber (about 235 kg of carbon) using compact class forest machines is 3.6 kg. In the logging process, using middle-class logging machines, 9.3 kg of CO_2 is emitted to harvest and forward 1 m^3 of timber.

Total fuel consumption in case of the compact forest machines in harvesting and forwarding (the first scenario) is 4.7 L per m^3 (10.3 kg CO_2 per m^3). Total fuel consumption during production of roundwood in case of the conventional harvesting system (middle class harvester and forwarder or the second scenario) is 6.5 L per m^3 (in total 15.7 kg CO_2 eq. per m^3). The results show that use of the compact class forest machines reduces CO_2 emissions during harvesting and forwarding by 34%.

Conclusions

1. Vimek 404 T5 harvester is suitable for birch plantations and the research results approve the earlier findings about Vimek’s main advantages over middle-class harvesters because of smaller fuel consumption and maintenance costs, good productivity and compact size (can operate in narrow areas, e.g., shelter belts without losing the productivity).
2. The study proves that due to smaller fuel consumption, maintenance costs and initial investment, the hourly cost and production costs of the Vimek 404 T5 harvester are significantly smaller than of a middle-class harvester.
3. In order to increase the workload of the Vimek harvester, it is necessary to develop an integrated approach, using the harvester to ensure continuous operation during the whole season and thus operations in shelter-belts would significantly improve possibilities to utilize compact-class machines and reduce management costs.
4. CO_2 emissions of the Vimek 404 T5 harvester are significantly smaller than of a middle-class harvester. The use of a compact class harvester and forwarder in roundwood production would reduce the fuel consumption and CO_2 emissions by 27% and 36%, accordingly.

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