8th International Scientific Conference
RURAL DEVELOPMENT 2017
Bioeconomy challenges
23–24 November, 2017, Aleksandras Stulginskis University

Proceedings of the 8th International Scientific Conference Rural Development 2017

Edited by prof. Asta Raupelienė

ISSN 1822-3230 / eISSN 2345-0916
eISBN 978-609-449-128-3

Article DOI: http://doi.org/10.15544/RD.2017.176

EFFICIENCY OF VIMEK 610.2 FORWARDER AND ITS IMPACT ON SOIL IN FOREST THINNING

Guna PETAJA, Latvian State Forest Research Institute "Silava", Rigas street 111, LV-2169 Salaspils, Latvia; guna.petaja@silava.lv (*corresponding author)*
Edgars Muižnieks, Latvian State Forest Research Institute "Silava", Rigas street 111, LV-2169 Salaspils, Latvia; edgars.muiznieks@silava.lv
Santa Kalēja, Latvian State State Forest Research Institute "Silava", Rigas street 111, LV-2169 Salaspils, Latvia; santa.kaleja@silava.lv

Effective haulage is one of the main requirements for cost-efficient logging services. The aim of the study is to estimate productivity of Vimek 610.2 forwarder in thinning and to determine soil compaction during haulage. Trials were conducted in Latvia, in 2 forest stands located in northern part of the country, in Engure municipality. The Vimek 610.2 Biocombi harwarder with additional bunk was used as a forwarder in the trials. It was equipped with Mowi P25 crane, tracks on rear axle and net chains on front axle to enhance performance on soils with low bearing capacity. Detailed time study was implemented for 56 forwarder loads. Working time was evaluated according to working cycle of forwarder crane (13 operations in total). Productivity of Vimek 610.2 forwarder and the prime cost of roundwood forwarding under optimal and extreme conditions is determined based on the time study results. According to the results productivity of forwarder Vimek 610.2 in trials with average hauling distance of 181 m, recalculated to productive time consumption spent to forward 1m^3 of roundwood under optimal conditions is 6.03 min and under extreme conditions – 6.23 min. In soils with low bearing capacity Vimek 610.2 did not compacted soil, however formation of ruts were observed, and in areas with optimal soil bearing capacity soil compaction was detected at surface layers (down to 10 cm depth). Prime costs of forwarding with Vimek 610.2 under optimal conditions to 180 m distance is 2.46 € m^{-3}, but under extreme conditions – 3.36 € m^{-3}.

Keywords: forwarder, Vimek 610.2, soil compaction, productivity

INTRODUCTION

Forwarding or offroad transport is an important stage of logging and there are several factors influencing costs and environmental impact of forwarding, as well as further development of a forest stand. Productivity of forwarding is influenced by terrain, soil bearing capacity, meteorological, technological and mechanical conditions. The number of felling sites in Latvia, located on soils with low bearing capacity, is increasing along with the area of timely unthinned young stands in private forests. With increasing awareness of the possible impact of forest machines on soil (compaction, changes in water regime, increased risk of root rot spreading), requirements of soil protection are getting more strict.

According to results of the international Horizon2020 innovation project "Innovative solutions for the future of wood supply" forwarding conditions in thinning and final felling sites in Latvia during the last 5 years was extreme in 4 % of areas and bad – in 35% of areas. If all growing forests are compared, extreme conditions are possible in at least 10% of forests and bad conditions – in 33% of forests. These results indicate that in future the need for machines that can work productively in extreme and bad conditions will increase.

Wheels of forest machines, used in mechanized logging, cause changes in soil structure. The most visible change is soil compaction resulting in deterioration of aeration of soil and water regime and negative effect on physiological processes in roots (Sarmulis, Saveljevs, 2015). Soil compaction during forwarding is influenced by pressure of wheels, number of passes, amount and arrangement of residues on strip-roads and soil bearing capacity. The ability of tree roots to grow through soil layers is one of the most important indicators characterizing impact of forest machines on soil. The threshold value of soil resistance for optimal development of roots is 1 MPa. Penetrologger cannot detect cracks and irregularity of soil structure, therefore in practice roots usually continue to grow if the penetration resistance exceeds 1 MPa. According to a study conducted in the Netherlands, root growth continues when soil resistance is 1.5 MPa. Major growth limitations appear if soil penetration resistance reaches 3 MPa, resulting in decrease in water and nutrient uptake and reduction of increment (Smith, Mullins, 2000). Trials conducted in Sweden suggested that after intensive hauling in areas where forwarder has driven through strip roads more than 40 times, increased rate of soil compaction remains even after 10 years (Hakansson, 1985). Impact of forest machines on soil compaction and its changes over 5 years was also studied in the USA, where it was found that forest machines increases density of topsoil by 19% on strip roads and by

10% in 1 m distance from strip roads, but the greatest impact was observed in depth of 20-30 cm. Cycles of freezing and thawing during 5 years had no impact on soil compaction (Labelle, Jaeger, 2011). In trials conducted in Latvia similar results were obtained, when analyzing soil compaction on strip roads 20-40 years after the final felling (Liepiņa et al., 2014). In several studies on soil compaction in Latvia in final felling a significant soil compaction was observed and mainly topsoil layers were compacted (Lazdiņš et al., 2008). According to a Swedish study, wheel slippage enhances destruction of tree root coating layer. Rut depth is proportional to the weight of the machine (Hallonborg, 1979). In Latvia soil penetration resistance has been studied in depth of 0-80 cm. It was concluded that soils with thick organic layer and low initial penetration resistance (low soil bearing capacity), are not subjected to the risk of soil compaction, however probability of formation of deep ruts during haulage increase with reduction of the soil penetration resistance (Prindulis, Lazdiņš, 2016). In other studies conducted in Latvia it was found that significant soil compaction on strip roads in soil layers below 40 cm remained for several decades that slightly affected forest regeneration results, expressing as predominance of deciduous trees and decrease number of self-seeded trees on strip roads (Liepiņa et al., 2014).

Vimek 610.2 and Vimek 610.2 Biocombi belong to the group of small-size forwarders with 5-8 tonnes of own weight. Vimek 610.2 and similar forwarders are widely used in thinnings and selective logging in central Europe, however it is not common in Latvia. Vimek 610.2 Biocombi is built, based on Vimek 610.2 forwarder, and it can be used as a harwarder, e. i., it can act as small harvester and forwarder simultaneously. The machine is equipped with a felling-bunching head, which allows to produce biofuel from relatively large trees. Delimbing function is not considered, partially due to small size of the machine and limited capacity of hydraulic system. Vimek 610.2 Biocombi is used as a forwarder by equipping it with the standard forwarder grapple. During forwarding of logs, which are shorter than 3 m, harwarder can be equipped with additional pair of bunks. The main drawbacks of small machines are small load capacity, which significantly influences hauling costs in long distances, and relatively low level of comfort, which results in shorter shifts (Lazdiņš, 2016). However, studies on this kind of machines, particularly, on their effective life-time, productivity, costs and ergonomic are insufficient.

In trials in Sweden the average loading productivity of Vimek 610.2 forwarder was 17.9 m^3 per productive hour, but unloading productivity – 56 m^3 per productive working hour. There were no technical delays during trials, therefore the proportion of productive time exceeded 90%. The average driving speed was 23 m min^{-1} (Lazdins, 2015). When measuring soil compaction in strip roads, Italian researchers found that Vimek 610 Biocombi caused a significantly lower impact on soil in comparison with middle-class machines. When working with Vimek 610 Biocombi, soil porosity decreased from 40 % to 30 %, but by using 2 times heavier harwarder, porosity decreased down to 20% (Spinelli et al., 2014).

During forwarding with small machines (e.g. Vimek 610.2 forwarder) the risk of soil compaction can be significantly reduced, whereas wheeled middle class forwarders in similar conditions cause significant soil compaction, which can be observed down to of 80 cm depth in good and average forwarding conditions (Prindulis, Lazdiņš, 2016). It is more feasible to use small forest machines in small felling sites in private forests. These machines can be transported with small trailers or even in a motorcar trailer, thus decreasing transportation costs. Ability to maneuver is another advantage of small machines, which allows forwarding without hauling roads, which are necessary for middle-class machines (Lazdiņš, 2015).

Forest operations on soils with poor bearing capacity characterizes with increased time and fuel consumption and decreased efficiency of forwarding operations, resulting in considerable additional costs in forest management. The aim of this study is to estimate productivity of Vimek 610.2 forwarder, as well as to determine its impact on soil compaction in thinnings.

MATERIALS AND METHODS

Experimental sites were 2 forest stands, managed by Joint Stock company "Latvia State Forests" and located in northern part of Latvia nearby Engure (Table 1). Optimal forwarding conditions mean that soil bearing capacity is good, wet lowlands should not be crossed and it is not necessary to equip forwarder with tracks. Extreme forwarding conditions mean that soil bearing capacity is low, swamped, overflown areas should be crossed, and it is possible to haul logs without additional tracks only during prolonged periods of frost. Codes in species composition are: Ba – black alder, B – birch, A – aspen, P – Scots pine, S – Norway spruce; number before species code is percentage of growing stock, number after species code is age of trees. Distance between strip roads in both stands was 20 m.

Table 1. Inventory data on study sites

Compartment key	Conditions	Coordinates LKS92		Area, ha	Peat depth, m	Species composition	Growing stock, m^3 ha^{-1}	Tree height, m	Tree diameter, cm	Age in years
		X	Y							
82-02-07-712-308 29-0	Extreme	436040	348807	3.0	0.5	7Ba2B1S35 +B73 A35 some P35	175	20	22	35
82-02-07-712-308 26-0	Optimal	436005	348587	6.2	0.2	5B43 4S58 1Ba43 some P58	163	20	17	43

The average daily temperature during forwarding trials was between -1.1 and +9.9 °C. In some days there was rainfall from 0.1 mm to 10.4 mm. Amount of precipitation was evaluated according to the information available on Latvian Environment, Geology and Meteorology Agency official website from nearby observation station. Precipitation considerably deteriorated forwarding conditions. Soil was not frozen during the experiments.

The Vimek 610.2 Biocombi harwarder was used as a forwarder in trials. It was equipped with Mowi P25 crane, tracks on the rear axle and net chains on front wheels to enhance passability on soils with low bearing capacity. Additional pair of bunks was installed to forward short logs. Parameters of Vimek 610.2 Biocombi harwarder are shown in table 2.

Table 2. Parameters of Vimek 610.2 Biokombi harwarder

Parameter	Value
Unladen weight	4.9 tonnes
Engine	CAT C2.2T, 44 kW/2700 rpm
Drive	Hydrostatic/mechanical
Hydraulic system	Max flow 60 L/min, 175 bar
Generator	12 V, 60A
Front tire size	500/60-22.5, one pair
Rear tire size	400/60-15.5, two pairs
Dimensions	Length: 6.60 m, cargo length 3.00 m, loading area 1.85 m^2; width: 1.9 m, number of fixed bunks (3 pairs)
Load capacity	5 tonnes
Ground clearance	40 cm
Maximum driving speed	18 km h^{-1}
Crane	Mowi P25 max reach: 5.2 m; lifting capacity at 5.2 m: 400 kg

Time accounting during forwarding trials was carried out with a field PC Allegro CX equipped with time study program SDI. Working time consumed for each work operation was accounted separately for each crane cycle. In total, 15 operations were accounted (Table 3).

Table 3. Work operations during time study

Working time category	Operation	Explanation
Informative fields	Notes	Various notes, e.g., about breaks, drives, corridor change
Productive time	Drive in	Drive into the stand without load
	Reach	Reach logs with crane
	Grip	Grip logs when loading in
	Load in	Load logs into loading area
	Rearrange load	Rearrange logs in loading area, put back fallen logs
	Drive when loading in	Driving in stand during loading
	Strip roads	Putting logging residues into strip roads
	Drive out	Driving out from the stand with load
	Reach when loading out	Reaching logs with crane when loading out
	Grip when loading out	Gripping of logs during loading out in loading area
	Load out	Putting logs into assortment pile
	Rearrange assortments	Rearranging of landing area (lining up of tops, putting fallen logs into pile etc.)
	Drive in landing area	Driving in landing area during loading out
	Other	Other work-related operations (small repairs and service, checking driving conditions etc.)
Unproductive time	Stop	Operations unrelated to work (such as resting, answering phone calls, etc.)

Logging in trial objects was carried out with petrol chainsaws, logging residues and tree tops were loaded into strip roads. Logging residues were used to fasten strip roads in places were wet areas had to be crossed. Additionally before the trials in extreme conditions Vimek 610.2 Biocombi bring logging residues from nearby stands with optimal forwarding conditions and loaded them into strip roads, especially in turning points and at landing area, where forwarding conditions were the most difficult. Two experienced operators participated in logging. Operators were working in 2 shifts, the length of a shift was 8 hours. Most of forwarded logs were 2.4-4.5 m in length. During forwarding operators loaded longer logs at the beginning and placed shorter ones between them. The accounting of the amount of hauled logs was carried out according to notes done by of the operator on filling of loads and hauled assortments.

Soil penetration resistance was measured in areas of felling sites where soil was not affected by forestry machines and on strip roads, using digital penetrologger *Eijkelkamp*. Measurements of penetration resistance were carried out every 7 m. Data were logged in 0-80 cm depth, measurement step was 1 cm.

Data were processed with MS Excel. The average statistical indicators were calculated with data analysis tool Descriptive Statistics. By the means of descriptive statistics average values and variance of the studied characteristics were estimated. Level of significance was evaluated using F-test.

An hourly cost model adopted for calculating of logging costs was used to calculate forwarding costs. The model is created in Latvia and based on the Swedish model FLIS (Lazdiņš et al., 2015, von Hofsten, et al. 2005). It is developed in LibreOffice Calc program and can be used for calculation of prime costs of felling and timber transportation, including system analysis. In calculations it was assumed that hauling is done in 2 shifts, each 8 hours long, by 2 operators. 15% of the working time constitutes unproductive time, when forwarder's engine is stifled. Transfer of the equipment between felling sites was subtracted from the working hours, assuming that it is done 50 times per year and each transfer lasts 2 hours. Operator salaries were calculated for 260 days, including vacation payment, per day costs, compensation for transportation. Training costs and health insurance were also included in the calculation.

RESULTS

In the forwarding trials with Vimek BioCombi 610.2 in total 56 loads were hauled, the average size of a load was 5.5 m^3. The total volume of forwarded logs was 308 m^3, mostly low grade hardwood logs and firewood was forwarded. The average hauling distance in compartment with extreme and optimal conditions was 150 m and 184 m accordingly. The main productivity indicators are shown in Table 4 and Table 5. Productivity values used in cost calculation are provided in Table 6.

Table 4. Distribution of work time consumption (min. per load) except driving

Plot	Reach	Grip	Load in	Rearrange load	Drive when load in	Strip roads	Reach when load out	Grip while load out	Load out	Rearrange assortments	Drive in landing area	Other
Optimal	0.23	0.26	0.60	0.09	0.34	0.14	0.20	0.28	0.43	0.10	0.27	0.31
Extreme	0.18	0.28	0.46	0.06	0.28	0.86	0.12	0.15	0.27	0.04	0.02	1.71

Table 5. Main productivity indicators, min. m^{-3}

Plot	Total time spent	Productive time spent	Total time for loading in operations	Total time for load out operations
Optimal	6.11	6.03	1.73	1.28
Extreme	7.03	6.23	3.66	0.61

Table 6. Productivity values used in cost calculation

Plot	Average load, m^3	Time for Load in per 1 load, min	Time for Load out per 1 load, min	Driving speed, m min^{-1}
Optimal	4.5	110.4	3.8	59
Extreme	5.5	20.4	3.7	37

By assessing and comparing time consumption for hauling operations in optimal and extreme conditions, a significant difference was found for time consumed for operation Strip roads ($p = 0.027 < 0.05$). This is due to differences in hauling conditions – in extreme conditions time consumption to put harvesting residues and low grade logs into strip roads took 6 times more time than in optimal conditions. Comparison of time consumed for operation Other demonstrated significant difference ($p = 0.003 < 0.05$), which is associated with specific operations in extreme conditions like unloading in the stand to pull tractor out of mud. Additional time consumption is associated with evaluation of situation, when machine is stacked, and identification of technical issues, like damages of hydraulic systems (oil spills from pipes), which had to be replaced more often in extreme conditions.

The average productivity was calculated from time study results. In order to forward 1m^3 in trials with average hauling distance 181 m 6.95 min (±0.65) were consumed, from whose 6.24 (±0.16) min were productive working time, which constitutes 89.8 % from the total consumed time in hauling. Unproductive work time includes repairs (replacement of hydraulic pipes etc.). The average time consumption to load 1 m^3 of logs was 3.49 min (±1.36), for unloading – 0.67 min (±0.47), whereas for operations Drive in and Drive out – 1.90 min (±0.49). A significant difference was found during comparison of the total time spent per 1 m^3 in both plots ($p = 0.003 < 0.05$), which can be explained with major differences in hauling conditions. The total time consumed for hauling 1 m^3 of logs in optimal conditions was by 13 % less than in extreme conditions. In cost calculation additional repairs should be considered when comparing operations in optimal and extreme conditions.

Soil compaction data from the forest stand with extreme forwarding conditions was analyzed. In total 8874 soil penetration resistance measurements were obtained. In order to characterize hauling conditions in study site, penetration resistance was calculated for 0-20 cm depth before hauling considering that the most of roots are located in this zone. Haulage conditions were considered extreme, when soil penetration resistance in 0-20 cm depth is below 0.5 MPa.

When assessing the whole soil profile down to 80 cm depth, difference in penetration resistance between strip roads and control sites is not statistically significant ($p=0.32>0.05$), which leads to a conclusion that in soils with low bearing capacity Vimek 610.2 does not cause additional soil compaction; however, there is considerably higher risk of formation of deep ruts, which can have adverse effect on development of forest stands, especially in spruce forests. The maximum penetration resistance of penetration slightly exceeds 2.5 MPa, but it can't be considered an obstacle for the tree root development, because significant disturbances appear only when resistance exceeds 3 MPa and topsoil layers should be compacted. In order to detect a significant compaction in depth of 60-80 cm, additional trials are necessary, because the soil penetration resistance can differ even in relatively close distance and number of measurements in the project might not be sufficient.

In prime cost calculation of Vimek 610.2 BioCombi services purchase of machine, personnel costs and operational costs are considered. Hauling conditions do not significantly impact prime cost, because most of it consists of personnel costs and investment costs. Proportion of operational costs from estimated total costs is 34%.

Prime cost of forest haulage was calculated using data on forwarder productivity in trials. Prime cost was obtained using data from optimal and extreme forwarding plots. In optimal hauling conditions costs of hauling 1 m^3 was 2.46 EUR, but in extreme conditions – 3.36 EUR. As a comparison, the prime cost of a middle class forwarder John Deere 810 D is 3.36 EUR in similar conditions (Lazdiņš, 2014). However increase of forwarding distance reduces difference between small and medium-class forwarder. A summary of forest hauling prime cost calculations is given in Table 7.

Table 7. Prime cost of hauling in optimal and extreme conditions

Indicator	Vimek forwarder in optimal conditions	Vimek forwarder in extreme conditions
Technical costs, Eur per year		
Investment	13590	13 590
Personnel costs	30 232.59	30 233
Operational costs	21490	21490
Total costs	68578	68578
Planned profit margin, Eur per year		
Planned profit	3266	3266
Productivity, m^3 E15 h^{-1}		
Productivity	13.3	9.7
The amount of manufactured timber by a single technical unit m^3 per year		
Processed logs	27895	20438
Logs under bark	25092	22 968.70
hauling costs		
Logs under bark, EUR m^{-3}	2.46	2.75

CONCLUSIONS

- Productivity of forwarder Vimek 610.2 in trials, recalculated in time consumed for hauling 1m^3 timber at the same hauling distance (181 m) in optimal conditions is 6.03 min and in extreme conditions – 6.23 min. Influence of hauling conditions is significant and it mainly consists of time consumed for strip road fastening and other operations necessary due to difficult hauling conditions.
- Evaluation of soil profile down to 80 cm depth demonstrated that the difference between the strip road and remaining stand in experimental site with extreme hauling conditions is not statistically significant ($p=0.32$), respectively on

soils with low bearing capacity Vimek 610.2 forwarder does not cause soil compaction, however there is still risk of formation of deep ruts even if the machine is equipped with tracks. In areas with optimal soil bearing capacity significant compaction was detected nearby soil surface (down to 10 cm depth), however, it doesn't reach critical values hampering growth of roots. Long-term observations in thinned stands are needed in order to conclude, if reduced pressure on soil during hauling has a positive impact on further stand development.

- Prime costs of forest hauling with Vimek 610.2 in optimal conditions in 180 m distance is 2.46 € m^{-3}, but in extreme conditions it is considerably higher – 3.36 € m^{-3}. In practice prime cost will be influenced by machine workload, operator salaries and other factors, respectively obtained data should be used to evaluate relative impact of forwarding conditions and not as absolute values of the service cost.

REFERENCES

1. Hakansson, I., 1985. Soil compaction research in Sweden. *Proceedings of Soil Compaction Conference, Ohio State University*.
2. Hallonborg, U. 1979. *Depth of ruts caused by forwarders*. Logging research foundation. Stockholm.
3. Labelle, E.R., Jaeger, D. 2011. Soil Compaction Caused by Cut-to-Length Forest Operations and Possible Short-Term Natural Rehabilitation of Soil Density. *Soil Science Society of America Journal,* Vol. 6, pp.2314–2329. https://doi.org/10.2136/sssaj2011.0109
4. Lazdiņš A. 2014. *Trials of plastic chain use in timber forwarding in commercial thinning*. Research report, Latvian State Forest Research Institute „Silava".
5. Lazdiņš, A. 2015. *Evaluation of productivity of Vimek Biocombi harwarder during forest thinning in young stands*. Research report, Latvian State Forest Research Institute „Silava".
6. Lazdiņš, A. 2016. *Productivity of Vimek harvester in birch plantations*. Research report, Latvian State Forest Research Institute „Silava".
7. Lazdiņš, A., Liepiņš, J., Zimelis, A. 2008. *Impact of forwarding conditions on costs of forwarders in final felling – results of soil compaction measurements*. Research report, Latvian State Forest Research Institute „Silava".
8. Lazdiņš, A., Zimelis, A., Kalēja, S. 2015. *Production of biofuel in thinning of young stands, in first thinning and slope land cover with Moipu harvester head*. Research report, Latvian State Forest Research Institute "Silava".
9. Liepiņa, A., Lupiķis, A., Sarkanābols, T., Lazdiņš, A. 2014. Impact of forest machines on soil compaction and reforestation. *Proceedings of the scientifically practical conference of the Faculty of Forestry*, pp. 51–54, Latvia University of Agriculture.
10. Prindulis, U., Lazdiņš, A. 2016. Soil compaction in young stands during mechanized logging of biofuel and roundwood assortments, Forestry and wood processing. *Proceedings of the International Scientific Conference: Research for Rural Developmen*t, Vol.2, pp. 69–76.
11. Sarmulis, Z., Saveļjevs, A. 2015 *Forest operations and technologies*. LUA, Faculty of Forestry, Student's union "Šalkone", Jelgava.
12. Smith, K. A., Mullins, C. E. 2000. *Soil and Environmental Analysis: Physical Methods*. 2nd ed., Marcel Dekker Inc., New York.
13. Spinelli, R., Magagnotti, N., Di Fulvio, F., Bergström, D., Danelon, M., Alberti, G. 2014. Comparison of Cost Efficiency of Mechanized Fuel Wood Thinning Systems for Hardwood Plantations on Farmland. *Croatian Journal of Forest Engineering,* Vol. 35, pp.111–123.
14. von Hofsten. H., Lundström, H., Nordén, B., Thor, M. 2005. *Biomass harvesting systems, analyses of seven final felling systems and four thinning systems*. Research report, Skogforsk, Uppsala.