Productivity of Energywood Harvesting Chain in Different Stand Conditions of Early Thinnings

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Abstract

The objective of this study was to investigate the effects of stand conditions on the productivity of a harvesting machine chain in early thinning stands. The studied harvesting chain consisted of Pro Silva Ässä 810 harvester equipped with an accumulating Naarva-Grip 1600-40 felling head and Timberjack 810 forwarder. The study was implemented on two separate stands, which were divided into nine blocks; each with unique stand conditions. The stand densities of the studied blocks varied from 2,000 to 7,750 stems per hectare and average tree length on the blocks were between 5.3–9.9 meters. In these conditions the productivity in cutting varied between 4.7–8.5 m^3/h. Average productivity in cutting was 5.8 m^3/h. Forwarding productivity was 7.9 m^3/h in average varying between 6.0–9.2 m^3/h. The increase in stand density and decrease in average stem size reduced less cutting productivity than forwarding productivity compared to separate machine studies.

Key words: energy wood, multiple tree handling, accumulating felling head, whole tree harvesting, productivity

Introduction

In Finland, there are targets to increase the annual use of forest chips for energy production by 10 TWh (5 mill. m^3) per year by 2010, and by 16 TWh (8 mill. m^3) per year by 2015 (Anon. 2003, Kokkonen and Hytönen 2006). These targets presuppose that the harvesting of small-diameter ($d_{1.3}$<10 cm) trees is doubled, or even tripled, over the current harvesting volume. In order to increase the harvesting volumes of energy wood in young stands, the harvesting costs have to be reduced significantly. In thinning, a small stem size, low removal per hectare, a high number of remaining trees and dense undergrowth mean low harvesting productivity. Several research papers have suggested the rationalization of harvesting method for solving the problems of harvesting small-diameter wood using early thinnings (*e.g.* Lilleberg 1994, Bergkvist 2003, Gingras 2004, Kärhä 2006):

- Multiple-tree processing
- Careful selection of harvested trees and stands
- Fewer timber assortments
- Integration of pulpwood and energy wood harvesting

The careful selection of harvested trees and stands is important in early thinnings. As there is a significant relationship between the size of the felled trees and the cutting costs, it is very important not to cut too small trees. When harvesting energy wood from early thinnings, most of the whole-tree stems felled have a breast height diameter of 3–8 cm and typically whole-tree removal is 40–60 solid m^3/ha. There are also correlations between the average stem size removed from the stand, removal density, and whole-tree removal. In other words the smaller the felled stems, the bigger the removal density, and therefore the smaller the whole-tree removal. Based on the results concerning the separate machine studies (Lilleberg 1994, Bergkvist 2003, Gingras 2004, Kärhä 2006), it has been suggested that whole-tree harvesting could be cost-effective, if the trees with a breast height diameter of 1–2 cm would not be harvested at all as whole-trees (Kärhä 2006). The guidelines for whole-tree harvesting were the following:

- no individual trees with a breast height diameter of below 5 cm should be cut, whereas
- trees of 3–4 cm breast height diameter growing in sprouts can be cut.

Processing more than one stem per harvester work cycle, also known as multiple-tree processing or accumulating, can improve the productivity of harvesting small-diameter trees. It is assumed the smaller the trees to be harvested the better the possibilities to apply multi-tree handling are and, subsequently, the greater the potentials for cost savings in energy wood and pulpwood harvesting. In the context of energy wood harvesting, however, this assumption has not been thoroughly studied. In this respect, the guidelines for whole-tree harvesting of small-diameter trees have not been studied using scientific methods. When energy wood is harvested using early thinnings, almost all energy wood harvester heads have been equipped with accumulation properties, and multiple-tree processing is very common. In whole-tree cutting, the wood bunch typically consists of 2–4 trees (*e.g.* Kärhä 2006). However, the number of trees in felling head can be even 15 trees at a time. The influence of felling head load size on time consumption of cutting-gathering-felling work phase is not accurately known. Therefore, the influence of felling head load size on time consumption of cutting-gathering-felling work phase of single tree should be studied. Furthermore, it is not known, even at a stand level, the influence of felling head load size on time consumption of forwarder for synchronizing the machine chain. The objective of this study was to investigate thoroughly the effects of stand conditions on the productivity of a machine chain and to test the presented guidelines for whole-tree harvesting.

Materials and methods

Study stands

Two separate study stands (1 and 2) were selected near the town of Kannus in central Finland. Due to internal variation of tree characteristics, the stands were divided into nine different blocks: the first stand included four and the second stand five blocks. The blocks were measured in order to find out the stand (tree) variables before the harvesting operations. Stand variables were measured from sample plots which were systematically dispersed over the blocks. On the basis of the measurements the number of trees per hectare, the average height, the average diameter and total volume were calculated (Table 1).

Table 1. Study stand characteristics

	Trees/ha	Average height, m	Average diameter, cm	Volume, m^3/ha	Area, ha
Stand 1					
Block 1	5800	8.9	7.0	76	0.59
Block 2	7000	8.5	8.0	195	0.42
Block 3	2600	9.9	9.6	73	0.39
Block 4	2000	9.4	9.9	77	1.44
Stand 2					
Block 1	6100	5.3	4.7	58	0.68
Block 2	5340	6.0	5.3	39	0.51
Block 3	7750	5.8	5.6	67	1.53
Block 4	4600	6.8	6.1	62	1.65
Block 5	3430	5.6	5.7	42	0.44

Time study

To find out the productivity of harvesting operations, a time study was conducted using continuous time study method. In the continuous time study method, a clock is running continuously and the changing moment of a work phase is recorded. In this study the focus was on effective work time (E_0), which does not include breaks. In the time study the work was separated into detailed work phases for both cutting and forwarding. The following work activities were observed:

Cutting:

1. *Cutting-gathering-felling*: Steering of felling head to the base of a tree. Work phase started when the previous work phase had ended, typically, after crosscutting on the ground or releasing of previous load from the harvester head, and ended when the load was released from the felling head. Accumulating felling head enabled gathering of several trees into the felling head at the same time, which for the number of felling cuts was observed.
2. *Crosscutting on the ground*: A work phase where harvester operator crosscuts a bunch of trees on the ground.
3. *Moving*: Began when the harvester started to move and ended when the harvester stopped to perform some other activity. Included also boom-in work phase where the felling head was swung in front of the machine before moving.
4. *Delays*: Included all short breaks that are not related to effective work, e.g. repairing and maintenance, phone calls, *etc*.

Forwarder:

1. *Driving empty*: Began when the forwarder left the landing area and ended when the forwarder stopped at the first loading place to start loading.
2. *Loading*: Began when the operator started to move the loader from the bunk and ended when the grapple loader was resting on the bunk and the forwarder started moving phase. Work phase could end also for a break or another interruption.
3. *Driving while loading*: Started when the forwarder started to move from the previous loading stop and ended when the forwarder stopped at a new loading stop.

4. *Sorting the load*: If the operator needed to sort the trees in the bunk, this time was separated from the loading time.

5. *Driving loaded*: This time started after the last grapple load of the last loading stop and ended when the operator started to unload at the landing.

6. *Unloading*: Started when the operator started to move the loader and ended when the bunk was empty and driving empty started.

7. *Break*: Included all breaks.

The study harvester was Pro Silva Ässä 810 equipped with Naarva 1600-40 accumulating felling head. An accumulating felling head enables gathering of several trees into the felling head before placing the bunch of trees on the ground. Felling cut is performed with a guillotine blade. The forwarder used in the study was a Timberjack 810 with a carrying capacity of 9,000 kg. The grapple of the forwarder was equipped with a load scale, which enabled measuring the load weight. One person operated the harvester and another the forwarder in both stands studied. The operators were experienced and were asked to work the same way as they normally do. Strip roads were not pre-marked, which for the operators planned them during the work. General directives were followed when determining the appropriate thinning density. The harvester operator made the tree selection in cutting.

The proportions of work phase times of the harvester were calculated by dividing the work phase time by total effective time. The number of felling cuts was calculated, which enabled the calculation of average felling head load size (= trees in felling head). In addition, a model describing time consumption of single tree as a function of felling head load was formed. The proportions work phases and productivity of the forwarder were calculated the same way as the values of the harvester. The productivity for each block was calculated by dividing production by effective time. The productivities presented in mass were converted into cubic meters by using multiplier 850 kg/m^3. The multiplier was an estimation of the average green tree density. Total observed effective time in cutting was 61.2 hours and in forwarding 43.9 hours.

Results

Cutting

In stand 1 cutting-gathering-felling work phase times varied between the blocks from 13.3 to 14.7 seconds and in stand 2 from 13.5 to 14.7 seconds. In both stands the average time for cutting-gathering-felling was the same, 14 seconds. In stand 1, the moving work phase took, on average, 10.5 seconds and 10.3 seconds in stand 2. The average time consumption of crosscutting on the ground work phase was 16.5 seconds in stand 1 and 16.2 seconds in stand 2. The structure of total time consumption consisted almost exclusively of cutting-gathering-felling work (Table 2). Productivities of each block varied rather little with the exception of productivity value 8.5 m^3/h in block 4 being the highest productivity in the study. The lowest productivity, 4.3 m^3/h, was in block 5.

Table 2. Proportions of effective time in cutting work phases and productivities of each block

	Cutting-gathering-felling, %	Moving, %	Crosscutting on the ground, %	Productivity, m^3/h
Stand 1				
Block 1	93	6	1	5.3
Block 2	85	6	10	5.7
Block 3	88	11	1	6.4
Block 4	88	9	3	8.5
Average	88	8	4	6.4
Stand 2				
Block 5	93	6	1	4.3
Block 6	91	8	1	5.4
Block 7	94	5	1	4.7
Block 8	88	8	4	6.0
Block 9	90	9	1	5.2
Average	91	7	2	5.1

It was assumed that a decreasing stem size increases the number of trees in the felling head. However, the results showed that in stand 2, where the trees were generally smaller than in stand 1, the average number of trees in the felling head was smaller. In stand 1 the mode value of stems in the felling head was three when in stand 2 the mode value was one or two. In stand 1, 90 % of the felling head loads included more than one stem when in stand 2 the number was 78 %.

The influence of felling head load size on time consumption of cutting-gathering-felling work phase of single tree was studied. For each block each felling head load size an average time consumption was calculated for the cutting-gathering-felling time. In Figure 1 the time consumption of single tree as a function of number of trees in felling head is presented. It is noticeable that after nine trees the time consumption starts to increase.

Forwarding

The average forwarding load volume was 1,500 kg higher in stand 1 than in stand 2 (Table 3). Load weights varied from 3,600 to 6,600kg which is much lower than the maximum carrying capacity of 9,000 kg. In stand 2, productions were rather identical on blocks

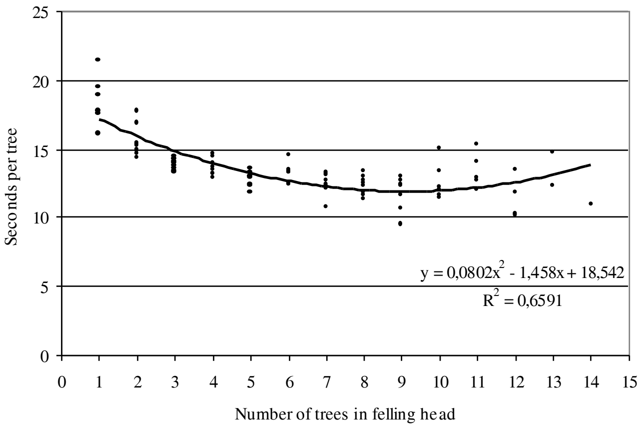

Figure 1. Time consumption of single tree as a function of number of trees in felling head in cutting-gathering-felling work phase

Table 3. Number of loads, average load sizes, productions, average driving distances and productivities for each block

	Number of loads	Average load size, kg	Production, m^3/ha	Driving distance, m	Productivity, m^3/h
Stand 1					
Block 1	5	6600	60.0	420	8.2
Block 2	6	5350	84.1	370	8.4
Block 3	2	5700	34.6	390	8.0
Block 4	8	6400	40.3	450	9.2
Average		6000	54.7	408	8.6
Stand 2					
Block 5	6	4410	42.4	290	8.0
Block 6	3	3600	20.9	300	6.6
Block 7	13	4950	47,9	430	7.4
Block 8	14	4800	46.6	450	7.0
Block 9	2	4550	24.2	500	6.0
Average		4500	36.4	394	7.2

5, 7 and 8. However, driving distance varied between the blocks; with the lowest being block 5 resulting in the highest productivity. The same kind of situation was also in blocks 6 and 9. In stand 1, the highest productivity was reached in block 4.

The proportion of effective time in the forwarding work phases indicated that most of the effective work time, about 35 %, was used in the loading work phase. Both driving empty and loaded took about 20 % of the total time. Unloading took about 15 % of the effective time and driving while loading about 10 %. The proportion of sorting time was minimal; 1 %. The largest differences between the stands were in loading and driving while loading phases.

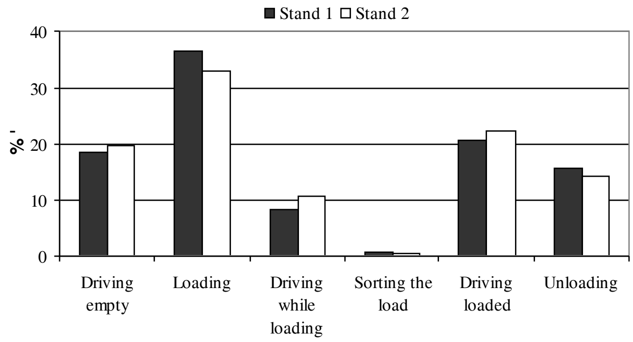

Figure 2. Proportions of effective time in forwarding work phases in both study stands

Discussion and conclusions

In cutting work, contrary to assumptions, stand characteristics had low influence on the proportions of work phase times. For example, in cutting-gathering-felling work phase times varied only 6 %-units between the blocks. On the other hand, for blocks 3, 4, 6, 8 and 9 the moving phase times were a little higher than the average, which can be explained by the lower tree density: in a sparse stand the number of trees felled in one working location is higher and therefore the machine need to be moved more frequently. On block 3 the number of crosscuttings on the ground was considerably higher compared to the other blocks. A rational determination variable for this would be the height of trees, but in this study it did not explain the time consumption since the average height on that block was approximately the same as in other blocks.

In stand 2, where the trees were generally smaller than in stand 1, the average number of trees held by the felling head was smaller. This can be explained by two ways. First, in stand 2 the number of spruce (*Picea abies* (L.) Karst.) under growth was higher than in stand 1. Spruce has a large number of branches, therefore, the felling head fills up fast and the braches limit the visibility of the operator. Second, in stand 2 the number of sprout trees was higher than in stand 1 so it was possible to get several trees into the felling head in one felling cut. The work observer counted only the number of felling cuts, not the number of trees, as counting the trees would not have been possible to perform safely during the work.

The hypothesis was that accumulating harvester head reduces the handling time for a single tree, which is a consequence of the fact that the positioning of the felling head and felling times of single trees decreases. This hypothesis was confirmed in this study with a condition that the average number of trees is less than 10. The results also slightly show that when the felling head has 10 trees the handling time of a single tree starts to increase. That is a rational result, but additional studies are needed to confirm it. An average cutting-gathering-felling time has been stated to be dependent on the felling head load size, time consumption of gathering and the speed of crosscutting and felling movements (Laitila *et al.* 2004). The felling head load size is dependent on the size and the spatial distribution of trees. Instead, the speed of felling head movements is dependent on the characteristics of the felling head, hydraulics and the operator's skills.

The results show that the number of trees per hectare and tree size influenced cutting productivity more than the production of an area since the highest productivity was reached on a block where the number of trees per hectare was smallest but the tree size was the highest. Corresponding productivity values and variations between different kinds of stands as in this study has also been obtained in other studies (Kärhä *et al*. 2002, Mäkelä *et al.* 2003). In forwarding work the proportions of work phase times followed the results of previous studies (Laitila *et al.* 2004). Cutting and forwarding productivities were a little higher in his study. Only the forwarder's sorting the load time was considerably small in this study. When calculating productivities the harvested mass was converted into cubic meters by using multiplier 850 kg/m^3. However, the green mass varies between the tree species to some amount and, for this reason, loads including various tree species should have been divided into tree specie specific masses on the basis of sample plot measurements. This might cause some error in the productivities.

The objective of this study was to investigate the effects of stand conditions on the productivity of harvesting machine chain in small-diameter stands. The study blocks were cut by same person and the bunches of trees were forwarded by another person. For this reason, the worker efficiency does not influence the results, which is the problem in a case of many operators and stands. Therefore, the influence of stand characteristics on the performance of harvester and forwarder is reliably clarified. However, the productivity values cannot be generalized to a larger population since the number of operators, stands and machines was minimal. Similar studies would be useful to repeat for various stand conditions.

In this study stand characteristics were measured from sample plots which were systematically dispersed over the blocks. In each block the sample plots covered about 10 % of the block's area, which for the sample size was sufficient to describe the stand characteristics. In addition, the sizes of stands were large enough for sufficient harvesting data. In sample tree selection the intention was to choose trees visually representing average characteristics of the block. This might have influenced the results since the selection system based on measurements would have been more reliable, but too expensive to execute in practice. However, measurers were experienced for reliable work.

To conclude, the presented guidelines for whole-tree harvesting were supported, because the productivity of harvesting of small-diameter trees decreased for individual trees. The results also confirmed previous assumptions of the suitability of the accumulating felling head for whole-tree harvesting in early thinnings. In total, whole-tree harvesting with accumulating felling head seemed to be a suitable method to cut energy wood, where the use of other harvesting methods is challenging.

References

Anon. 2003. Uusiutuvan energian edistämisohjelma 2003–2006. Työryhmän ehdotus. [A programme to promote renewable energy 2003–2006. Proposal of working group]. Ministry of Trade and Industry, Working group and committee papers 5/2003, (in Finnish)

Bergkvist, I. 2003. Multitree-handling increases both productivity and profitability in small wood thinnings. Skogforsk, Resultat 5/2003.

Gingras, J-F. 2004. Early Studies of Multi-Tree Handling in Eastern Canada. International *Journal of Forest Engineering,* 15(2): 18-22.

Kokkonen, M. and Hytönen, L. (Eds.). 2006. Metsäsektorin tulevaisuuskatsaus. Metsäneuvoston linjaukset metsäsektorin painopisteiksi ja tavoitteiksi. [Future review of the forest sector. Guidelines of Forest Council for the emphases and targets of the forest sector]. Ministry of Agriculture and Forestry, Publications 11/2006, (in Finnish)

Kärhä, K., Jouhiaho, A., Mutikainen, A. and Mattila, S. 2002. Joukkokäsittelevä Naarva-koura energiapuun hakkuussa. [A multi-tree Naarva felling head in energy wood harvesting] Työtehoseuran metsätiedote 655, 12/2002, (in Finnish)

Kärhä, K. 2006. Whole-tree harvesting in young stands in Finland. *Forestry Studies,* 45: 118-134.

Laitila, J., Asikainen, A., Sikanen, L., Korhonen, K. and Nuutinen, Y. 2004. Pienpuuhakkeen tuotannon kustannustekijät ja toimituslogistiikka. [Cost factors of small size tree chips and supply logistics], Metlan työraportteja 3, (in Finnish)

Lilleberg, R. 1994. A multi-tree harvester FMG 990/756 H in first thinning of pine. Metsäteho, Review 8/1994.

Mäkelä, M. Poikela, A. and Liikanen, R. 2003. Energiapuun korjuu harvennusmetsistä. [Energy wood harvesting from thinning forests], Metsätehon raportti 161, (in Finnish)

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ПРОИЗВОДИТЕЛЬНОСТЬ СОВРЕМЕННОЙ МАШИННОЙ ЗАГОТОВКИ ЭНЕРГЕТИЧЕСКОГО ДРЕВЕСНОГО СЫРЬЯ В НАСАЖДЕНИЯХ С РАЗЛИЧНЫМИ УСЛОВИЯМИ ПРИ РУБКАХ УХОДА

Х. Оваскайнен, Т. Паландер, М. Яухиайнен, Я. Лехтимяеки, Л. Тикканен и Ю. Нурми

Целью этого исследования было изучить производительность машинной заготовки энергетического древесного сырья в насаждениях с различными условиями при рубках ухода. Изученная валочная цепочка состояла из харвестера Pro Silva Ässä 810, оснащенного выдвигающейся валочной головкой Naarva-Grip 1600-40 и форвардером Timberjack 810. Исследование проводилось в двух насаждениях, каждое из которых было разделено на 9 блоков, в соответствии с определенными характеристиками древостоя. Густота насаждения в изучаемых блоках варьировалась от 2000 до 7500 пней на гектар и средней высотой дерева 5.3-9.9 метров. В таких условиях призводительность рубки была в интервале 4.7-8.5 м^3/час. Средняя продуктивность рубки была 5.8 м^3/час. Средняя продуктивность работы форвардера была 7.9 м^3/час и варьировалась в интервале 6.0–9.2 м^3/час. Увеличение густоты насаждения и уменьшение среднего размера ствола привело к меньшему снижению производительности при рубке харвестером, чем при транспортировке форвардером, при их раздельном изучении.

Ключевые слова: энергетическое древесное сырье, многоцелевое использование дерева, выдвигающаяся валочная головка, хлыстовая заготовка