Original scietific paper – *Izvorni znanstveni rad*

Truck Transportation and Chipping Productivity of Whole Trees and Delimbed Energy Wood in Finland

Juha Laitila, Kari Väätäinen

Abstract – Nacrtak

The present study aims to evaluate the competitiveness of various supply systems of small-diameter wood harvested from young stands for fuel. Trees were harvested for the cost comparison either as (i) multi-stem delimbed shortwood or (ii) as whole trees or (iii) the harvesting was based on bundle-harvesting using the Fixteri II bundle harvester. The cutting of whole trees and multi-stem delimbed shortwood was carried out using a conventional harvester head equipped with multi-tree-handling accessories. Forwarding was carried out using a standard medium-sized forwarder. The comparison of procurement costs was done at stand level as a function of breast height diameter (5–13 cm) and on-road transportation distance (5–160 km). The harvested wood was chipped either at a roadside landing or at a terminal using a trailer-mounted drum chipper. The comparison of the supply systems was done using recently published productivity parameters and data obtained from complementary field studies reported herein.

According to the cost assessment, whole-tree harvesting and chipping at the roadside landing was almost invariably the most cost-efficient supply system. The cost of whole-tree and multi-stem delimbed shortwood chips was at the same level when the breast height diameter of the harvested trees was 11 cm (pine) or more. The cutting of whole trees is cheaper, but the cost difference diminished as a function of tree size. The productivity of forwarding, transportation and chipping of multi-stem delimbed shortwood was significantly higher compared to that of whole trees. When applying roadside chipping in Finnish conditions with small and sparsely located forest holdings, acquiring large enough concentrations of wood for profitable production is a great challenge. Machine relocations can be reduced by transporting raw material to terminals or the end-use facility to be chipped. However, the low bulk density of the initial material restricts the operation radius unless the wood biomass is pre-processed. According to the results of our study, harvesting of multi-stem delimbed shortwood is a promising way to simplify operations and to reduce transportation and chipping costs. In the case of whole-tree bundling, savings in transportation and chipping costs did not offset the high felling and compaction costs, and the bundling system was the least competitive alternative.

Keywords: whole trees, multi-stem delimbed shortwood, chipping, transportation, small tree harvesting, young stands, terminals

1. Introduction – *Uvod*

The number of heating and power plants using forest chips has increased from 250 units close to 1000 units during the last ten-year period in Finland (Asikainen and Anttila 2009). Furthermore several new biomass plants are planned or under construction (Laitila et al. 2010a). In 2007 the Council of Europe accepted the proposal of the European Commission that the EU member countries should produce 20% of their energy using renewable sources by the year 2020. Each member country has its own target. The EU obligates

Finland to increase the share of renewable energy sources in energy consumption from 28.5% to 38% by the year 2020.

The Finnish long-term climate and energy strategy assigns wood-based energy an important role in achieving this goal. Currently, processing residues from the forest industry are the most important source of wood-based fuels, but these by-products can be considered to be currently fully utilised (Ylitalo 2011). In addition, the availability of processing residues has decreased during the last few years as a consequence of several closures of pulp and paper mills and the decreased production capacity of sawmills and plywood mills (Kallio et al. 2011; Ylitalo 2011). Thus, the most important means of increasing the consumption of wood for energy in the future is the utilisation of forest chip resources.

Accordingly, the Ministerial Working Group of the Finnish Government for climate and energy policy has targeted the use of forest chips for energy, i.e. logging residues and stumps from final fellings and small trees from early thinnings, to 13.5 million solid cubic metres in 2020. In the year 2010, Finnish heating and power plants consumed 16.0 million m^3 of solid wood fuels, of which 6.2 million m^3 comprised forest chips (Ylitalo 2011). This amount included 2.5 million m^3 of whole trees and delimbed trees originating from early thinnings, while logging residues and stumps from clear-cutting areas were the raw material for more than half of the forest chips consumed by heating and power plants in 2010 (Ylitalo 2011).

The technical harvesting potential of forest chips in Finland has been estimated to be 14–20 million m^3 per year (Laitila et al. 2008; Kärhä et al. 2008). About 45% of this amount could be obtained from small-dimension wood from early thinnings (Laitila et al. 2008). According to the most recent estimates (Salminen et al. 2012), some 75% of the sustainable cutting potential of industrial wood is being made use of, and this is assumed to mean an increasing proportion of the energy wood accrued will be composed of stemwood of industrial wood dimensions or dimensions very close to industrial wood. The harvesting of industrial roundwood and energy wood from early thinnings is costly, owing to the small stem size and low removals. Furthermore, dense undergrowth often weakens the profitability of early thinnings (Oikari et al. 2010).

In Finland the procurement of thinning wood chips is mainly based on chipping at the roadside storage (73%) or at the terminal (24%) (Kärhä 2011). Chipping at the end-use facility is not so common in thinning wood harvesting compared to logging residue or stump wood chip production. Chipping at the landing is a suitable and quite cost-competitive procurement system for power and heating plants of all size categories. A terminal operates as a buffer storage, which enables a more secure supply of fuel chips, and also serves as a process management tool for the whole supply chain. The terminal is also a compromise between chipping at the landing and at the plant. The raw material is transported in an unprocessed form to the terminal and delivered to the plant as chips. However, the low bulk density of the initial material restricts the operation radius unless the wood biomass is pre-processed.

The whole-tree bundler (Fixteri) was developed in order to rationalise the integrated harvesting of small-diameter energy wood and pulpwood and to reduce transportation costs through load compaction (Jylhä and Laitila 2007; Nuutinen et al. 2011; Jylhä 2011). The transportation can be arranged using standard forwarding equipment and long-distance transportation equipment (Laitila et al. 2009). The bundles are, on average, 2.7 m in length, 0.65 m in diameter, and 0.5 m^3 (solid) in volume.

Conventional single-grip harvester heads equipped with multi-tree handling equipment are also suitable for cutting whole trees and multi-stem delimbed shortwood (Laitila et al. 2010b; Belbo 2011). The working technique of whole-tree cutting and multi-stem delimbed shortwood cutting is basically the same apart from the delimbing of the tops of tree bunches (e.g. Laitila et al. 2010b). In energy wood cutting with single-grip harvesters, the trees are cut and accumulated to the chamber of the multi-tree handling harvester head. Subsequently the tree bunch is moved to an upright position alongside the strip road for the processing of the trees to forwarding length and piling. In whole-tree harvesting the tree bunch is fed through the feed rollers and delimbing knives of the harvester head up to the crosscutting point of forwarding length (5–7 metres). After cross-cutting, the harvester crane moves the undelimbed top bunch onto the base bunch alongside the strip road. In multi-stem delimbed shortwood harvesting, both the base and top bunch of the trees are fed through the feed rollers and delimbing knives of the harvester head and piled at the side of the strip road. The top bunch is topped at the top diameter of 3–5 cm and the target length of the bolts is usually about 5 metres. After multi-tree delimbing only short bits of branches are left in the tree bunches.

1.1 Aim of the study – *Cilj rada*

This study aims to evaluate the competitiveness of various supply systems of small-diameter wood har-

Fig. 1 A conventional harvester head equipped with multi-tree-handling accessories (up) and Fixteri II bundle harvester. Chipping of energy wood at a roadside landing or at a terminal using a trailer-mounted drum chipper (down)

Slika 1. *Harvesterska glava (gore lijevo) i bandler harvester Fixeri II – stroj za izradu svežnjeva (gore desno). Iveranje energijskoga drva na pomoćnom stovarištu ili u energani pomoću priključenoga bubnjastoga iverača (dolje)*

vested from young stands for fuel. Trees were harvested for the cost comparison either as (i) multi-stem delimbed shortwood or (ii) as whole trees or (iii) the harvesting was based on bundle-harvesting using the newly-developed Fixteri II bundle harvester (Fig. 1). The cutting of whole trees and multi-stem delimbed shortwood was carried out using a conventional harvester head equipped with multi-tree-handling (MTH) accessories. Forwarding was carried out using a standard medium-sized forwarder. The comparison of procurement costs was done at stand level as a function of breast height diameter (5–13 cm) and on-road transportation distance (5–160 km).

The harvested wood was chipped either at a roadside landing or at a terminal using a trailer-mounted drum chipper (Fig. 1). Multi-stem delimbed shortwood and whole-tree bundles were transported to the terminal using a conventional timber truck and whole trees were transported using a biomass truck equipped with solid side panels and bottom (Fig. 2). The chips from the roadside landing and from the terminal were transported using a standard chip truck (Fig. 2). The comparison of the supply systems was done using recently published productivity parameters and data obtained from complementary chipping and transportation studies reported herein. The strategic goal of the study was to improve the cost-efficiency of production of forest chips from wood harvested from young stands, especially by testing technologies for chipping and on-road transporting of small-diameter thinning wood. Updated data on costs and productivity are useful when selecting the appropriate supply systems for wood harvested from various young stands.

Fig. 2 A biomass truck equipped with solid side panels and bottom (left up), a standard chip truck (right up), and a standard timber truck (down)
Slika 2. *Kamion za prijevoz biomase s obloženim tovarnim prostorom (gore lijevo), uobičajeni kamion za prijevoz iverja (gore desno) te kamion za prijevoz drva (dolje)*

2. Material and Methods – *Materijal i metode*

2.1 The time studies of truck transportation *Studije vremena kamionskoga prijevoza*

In the truck transportation study, the payload and the loading and unloading times of whole trees were compared to those of multi-stem delimbed shortwood when wood material was transported from a roadside landing to be chipped at the terminal. Both loading and unloading were done using the crane of the timber truck. The studies were carried out during daylight hours in May 2010. The empirical data comprised fourteen truckloads, of which five were multi-stem delimbed shortwood (146 tonnes/184 m^3) and nine whole trees (165 tonnes/269 m^3). The volumes and payloads of the timber lots were based on measurements at the terminal. The dry green densities of multi-stem delimbed shortwood and whole trees were defined according to the SCAN-CM 43:95 standard and their moisture contents according to CEN/TS 1477-2. Sampling of wood was integrated into the terminal chipping experiment, which was carried out immediately after the transporting experiment. The average dry green density of the multi-stem delimbed shortwood was 398 kg/m^3 and moisture 49.6%. The corresponding values for the whole trees were 357 kg/m^3 and 41.8%. Whole trees consisted of birch (*Betula pendula* and *Betula pubescens*), pine (*Pinus sylvestris*), spruce (*Picea abies*) and aspen (*Populus tremula*). Multi-stem delimbed shortwood consisted of pine and birch. The average length of the whole trees was 8.7 m and the length of the multi-stem delimbed shortwood was either 3 m or 5 m. The breast height diameters ($d_{1.3}$) of the whole trees and multi-stem delimbed shortwood were 7–9 cm and 10–12 cm, respectively.

The timber was transported by a Volvo FH 460 timber truck comprised of a three-axle tractor and a four-axle trailer equipped with solid side panels and bottom and inside moving carriage (Fig. 2). The truck was equipped with a Kesla 2011ZT hydraulic timber crane. The idea was to load the back end of the carriage first and move it backwards to load the front part last. Thanks to the inside moving carriage, even the rearmost part of the load space could be loaded by using the crane of the timber truck without disconnecting the trailer. One bunch of the whole trees and multi-stem delimbed shortwood was loaded on the tractor and two or three bunches on the trailer. The total length of the truck-trailer combination was 25.25 m and the bulk volume was 150 m^3 (45 m^3 + 105 m^3). The tare weight of the truck-trailer combination was 29 760 kg, which is about 8 000–10 000 kg heavier compared to a conventional timber truck (Peltola 2004).

The time study was carried out manually using the Rufco-900 field computer (Nuutinen et al. 2008). The working time was recorded by applying a continuous timing method, where a clock runs continuously and the times for different elements are separated from each other by numeric codes (e.g. Harstela 1991). The accuracy of the Rufco-900 field computer was 0.6 s (Nuutinen et al. 2008). The harvester's working time was divided into effective working time (E_0h) and delay time (Harstela 1991), which is a common method employed in Nordic work studies. Auxiliary times (e.g. planning of work and preparations) were included in the work phases in which they were observed. The skilful truck driver had extensive working experience. He had fifteen years of working experience in transporting roundwood and two years of working experience in transporting biomass.

2.2 The time studies of chipping – *Studije vremena iverača*

The aim of the time study was to compare the chipping productivity of whole trees and multi-stem delimbed shortwood in terminal conditions. The studies were carried out during daylight hours in May 2010. The mobile industrial chipper used for the experiment was a trailer-mounted Rudnick&Enners MTH 900 X 1000/13 drum chipper. The weight of the tandem axle trailer chipper was 19 000 kg and it was 9 650 mm long, 2 550 mm wide and 4 000 mm high. The height of the feeding tube was 900 mm and its width was 1 000 mm. The chain feed ran longitudinally and the discharge of the chipped material was realised by a pivotable blower with throw control (Rudnick&Enners Maschinen und Anlagenbau GmbH 2003). The drum carried four blades and the blades were sharpened at the beginning of the shift. The chipper year model was 2004 and it had been renovated due to a fire in 2007. The chipper was driven independently and it was powered by a 368 kW Scania V8 diesel engine. The towing vehicle was a three-axle Scania 144 G 530 and the tractor was equipped with a heavy-duty Kesla 2010T timber loader used for bringing the wood to the hydraulic in-feed system. The skilful chipper operator had three years of working experience in chipping.

The time study was carried out manually using the continuous timing method and field computer (Nuutinen et al. 2008). The dry green density of the chipped material was defined according to the SCAN-CM 43:95 standard, moisture content according to CEN/TS 1477-2 and particle size distribution according to the CEN/TS 15149-1 standard. The chipped timber was free of impurities (stones, mineral soil, etc.), which enabled uninterrupted chipping work at the asphalt field of the terminal. In the chipping experiment the chips were blown to the ground.

2.3 The cost comparison of the supply systems *Usporedba troškova s obzirom na duljinu daljinskoga transporta*

The logging cost calculations were made for an artificial stand, where the cutting removal was 1500 pine (*Pinus sylvestris*) stems per hectare and the breast height diameter ($d_{1.3}$) of the removed trees varied between 5–13 cm (Laitila et al. 2010b). The volume of the multi-stem delimbed shortwood as a function of 5–13 cm breast height diameter was 4–73 dm^3 and the volume of whole trees was 8–99 dm^3, respectively. The harvesting intensity amounted to 12–149 m^3/ha when trees were harvested with branches and 7–110 m^3/ha when trees were delimbed. The total length of the strip road network at the stand was assumed to be 600 m/ha, based on an average strip road spacing of 20 m (Niemistö 1992). The forwarding distance was 300 m and the on-road transportation distance varied between 5–160 km. The distance between the terminal and end-use-facility was constant, 15 km, except when the terminal was located at the end-use-facility.

The productivity of cutting whole trees and delimbed stemwood using the multi-tree processing technique was based on the study of Heikkilä et al. (2005) and the productivity model was published in the Excel-based »Cost calculator for delimbed energy wood"« cost calculation program (Laitila 2006). In the case of bundle harvesting, the productivity model of Nuutinen et al. (2011) was used. The forwarding productivity of multi-stem delimbed shortwood was calculated using the model of Kuitto et al. (1994). When forwarding loose and bundled whole trees, the functions of Laitila et al. (2007 and 2009) were applied. The payload of the medium-sized forwarder was set at 9 m^3 for multi-stem delimbed shortwood, 6 m^3 for whole trees, and 24 pieces for bundles (Laitila 2008; Laitila et al. 2009; Laitila et al. 2010). The effective time (E_0) productivities of cutting, bundling and forwarding were converted into gross effective time (E_{15}) productivities with the coefficients applied in the study of Jylhä et al. (2010). The hourly costs were as follows: medium-sized thinning harvester equipped with multi-tree-handling accessories, 81 €/h (VAT 0%), forwarder, 61€/h (VAT 0%), and Fixteri II bundle-harvester, 107 €/h (VAT 0%) (Laitila and Väätäinen 2011).

Multi-stem delimbed shortwood and whole-tree bundles were transported using a conventional timber truck with a trailer, assuming a payload of 48 m^3 for multi-stem delimbed shortwood (Laitila and Väätäinen 2011). In the case of bundle trucking, a maximum payload of 100 pieces was used (Laitila and Väätäinen 2011). The payload of loose whole trees was set at 30 m^3 on the basis of the study reported herein. The payload of the chip truck was 44 m^3 (Laitila 2012). The road transportation times were composed of driving with an empty load, driving loaded and terminal times (incl. loading, unloading, waiting and auxiliary time). Time consumption of driving, with full load and empty load, was calculated as a function of transportation distance according to the speed functions of Nurminen and Heinonen (2007).

One bunch of the delimbed 5 m longwood was loaded on the tractor and two bunches on the trailer. The bundle load consisted of two bunches on the tractor and three bunches on the trailer. According to the time study, the loading time of a truck with 5 m multi-tree delimbed shortwood was 19.0 minutes and the unloading time was 14.2 minutes. For whole-tree bundles, the loading time was 25.1 minutes and unloading time 17.1 minutes (Laitila et al. 2009). In the case of loose whole trees, a loading time of 30.0 minutes and an unloading time of 11.6 minutes were recorded. The preparation time of the crane was 2.6 minutes at the roadside landing and 2.3 minutes at the delivery point for all timber assortments. Cleaning of residues from the roadside landing and delivery point took 4.2 minutes per loose whole-tree or bundle truckload (Laitila et al. 2009). Handling of the inside moving carriage took 1.2 minutes per load when transporting loose whole trees. With multi-stem delimbed shortwood and bundles, the handling times of the bunks and trailer were 1.4 and 2.2 minutes, respectively (Laitila et al. 2009). Binding and opening the load of multi-stem delimbed shortwood took 9.9 minutes, while it took 12.5 minutes with bundles (Laitila et al. 2009). 25 minutes were added to the terminal times, corresponding to the time the trucks spent on items other than actual loading or unloading, e.g. driving at storage point, turning, waiting, weighing, arrangements at the delivery point and sampling.

The loading time of the chip truck-trailer unit at the roadside landing was equal to the direct and indirect chipping times. The chipper productivity at the roadside storage was estimated to be 34 $m^3/E_{15}h$ for whole trees and at the terminal the chipping productivity was 44 $m^3/E_{15}h$ (Laitila 2008). According to the comparative time study reported herein, the chipping productivity of multi-stem delimbed shortwood was 1.22 higher compared to whole trees. This denotes that the chipper productivity at the roadside storage was estimated to be 41 $m^3/E_{15}h$ for multi-stem delimbed shortwood and 54 $m^3/E_{15}h$ at the terminal. The chipping productivity of whole-tree bundles was estimated to be equal to that of multi-stem delimbed shortwood. 35 minutes were added to the direct and indirect chipping times, corresponding to the time the chip trucks spent on items other than actual loading, e.g. driving at storage point, turning, detaching the trailer, waiting, weighing, unloading and sampling (Laitila 2012).

At the terminal, the loading time of chips was estimated to be 15 minutes and the work was done using a wheel loader. The unit cost of chip loading was 1 €/m^3 (Laitila 2008). Chips were transported from the terminal to the end use facility with truck-trailer units that are similar to the ones used when transporting chips from the roadside storages. The unloading time of the chips at the end use facility was estimated to be 25 minutes. The hourly cost of the mobile drum chipper was 154.2 €/$E_{15}h$ in the roadside chipping operations and 145.1 €/$E_{15}h$ when operating at the terminal (Laitila and Väätäinen 2011). The timber truck hourly cost was 86.4 €/$E_{15}h$ for driving and 60.7 €/$E_{15}h$ for terminal time (Laitila and Väätäinen 2011). The corresponding values for the chip truck-trailer unit and biomass truck were 88.2 €/$E_{15}h$ & 63.3 €/$E_{15}h$ and 89.0 €/$E_{15}h$ & 63.2 €/$E_{15}h$, respectively (Laitila and Väätäinen 2011).

3. Results – *Rezultati*

3.1 The time studies – *Studije vremena*

The average payload of loose whole trees was 30 m^3 in the transportation study. The loading productivity of whole trees was 1.0 m^3 per minute, and unloading productivity was 2.58 m^3 per minute. The loading and

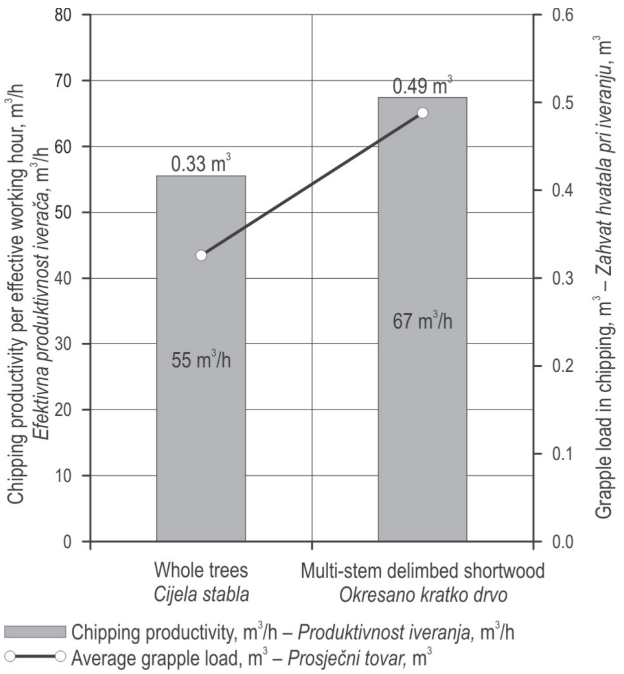

Fig. 3 Chipping productivity of whole trees & multi-stem delimbed shortwood at the terminal (m^3/E_0h) and average grapple load in chipper feeding

Slika 3. *Proizvodnost iveranja cijelih stabala i debala kratkoga drva na glavnom stovarištu (m3/E0h) te prosječan zahvat hvatala prilikom iveranja*

unloading productivity of 5 m and 3 m long multi-stem delimbed shortwood amounted to 2.53 & 3.39 m^3 per minute and 1.7 & 2.56 m^3 per minute, respectively. When loading or unloading 5 m long multi-stem delimbed shortwood, the size of handling unit (grapple load volume) is significantly bigger compared to 3 m long multi-stem delimbed shortwood, which improves productivity.

The average reposition time of the chipper at the terminal – that is, when the chipper is moved within the work site as work proceeds – was 4.5 minutes. Preparing time for chipping, including all preparatory measures from starting the machine to raising the rotation speed of the machine in readiness for chipping, was on average 2.4 minutes at the terminal. The chipping productivity was 55 m^3/E_0h for whole trees and 67 m^3/E_0h for multi-stem delimbed shortwood (Fig. 3). The average grapple load volume in chipper feeding was 0.33 m^3 (211 kg) for whole trees and 0.49 m^3 (317 kg) for multi-stem delimbed shortwood. Feeding of the chipper was effective. The chipper was only running idle during 1.5% of the effective chipping time when chipping whole trees and 0.9% when chipping multi-stem delimbed shortwood. The particle size distribution of whole-tree and multi-stem delimbed shortwood chips was comparable, excluding the proportion of small particles (<8 mm). This is due to the high percentage of branches and needles in the whole-tree material.

3.2 The cost comparison – *Usporedba troškova*

The supply system based on whole-tree harvesting resulted in the lowest logging cost in the cost comparison (Fig. 4). The logging costs of whole-tree and multi-stem delimbed shortwood were at the same level when the breast height diameter of the harvested trees was 11 cm (pine) or more. The cutting of whole trees is cheaper, but the cost difference diminished as a function of tree size. The forwarding costs of multi-stem delimbed shortwood and whole-tree bundles were lower due to higher bulk density and therefore bigger payloads. Also the loading and unloading were more efficient compared to whole trees. In the case of whole-tree bundling. the logging costs exceeded the harvesting of multi-stem delimbed shortwood when the breast height diameter of the removed trees was 8 cm or more (Fig. 4).

The transporting costs of loose whole trees were the highest (Fig. 5) and these costs were also the most sensitive to changes in transporting distance. Trans-

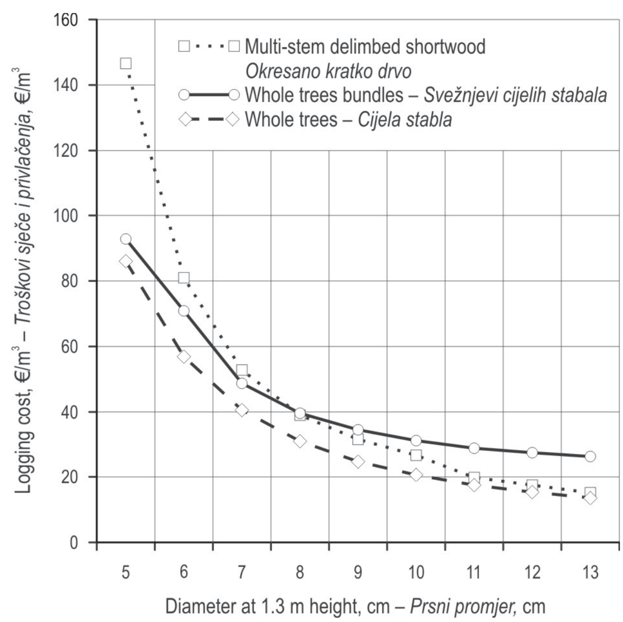

Fig. 4 Logging costs of whole trees, multi-stem delimbed shortwood and whole-tree bundles at the roadside landing. Logging cost, €/m^3 = Cutting + Forwarding

Slika 4. *Troškovi pridobivanja biomase (sječa i privlačenje) iz cijelih stabala, okresanoga kratkoga drva i cijelih stabala u svežnjevima do pomoćnoga stovarišta uz šumsku cestu*

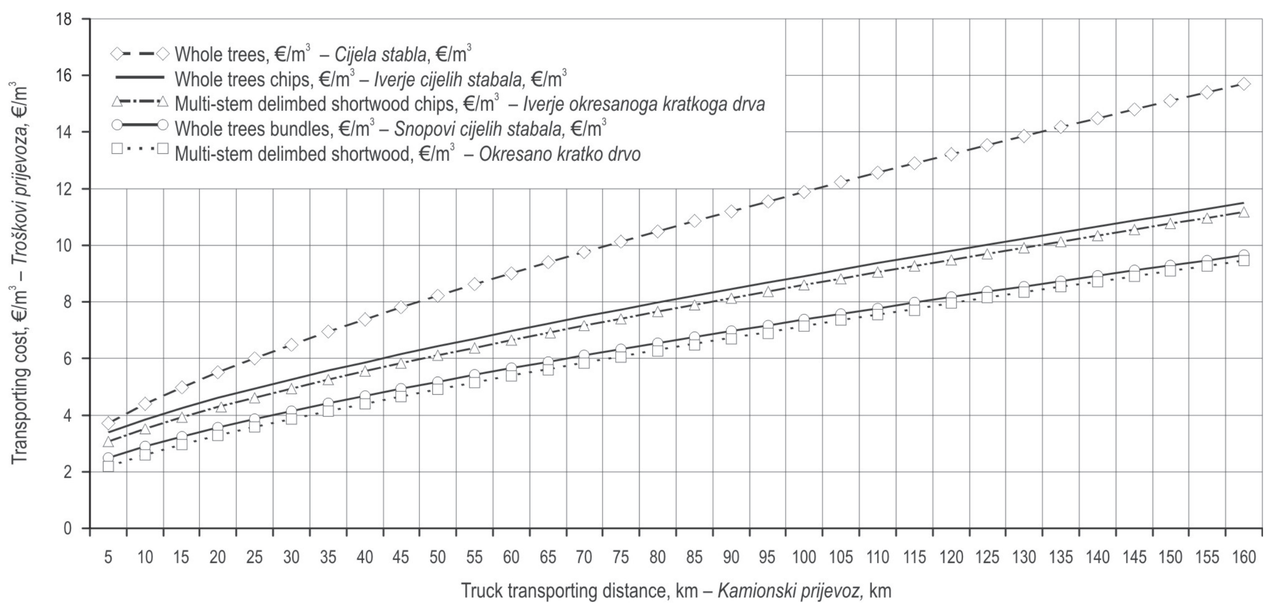

Fig. 5 Transporting costs of chips, loose whole trees, whole-tree bundles and multi-stem delimbed shortwood as a function of transporting distance

Slika 5. *Usporedba troškova prijevoza iverja, cijelih stabala, svežnjeva cijelih stabala i okresanoga kratkoga drva kao funkcija udaljenosti prijevoza*

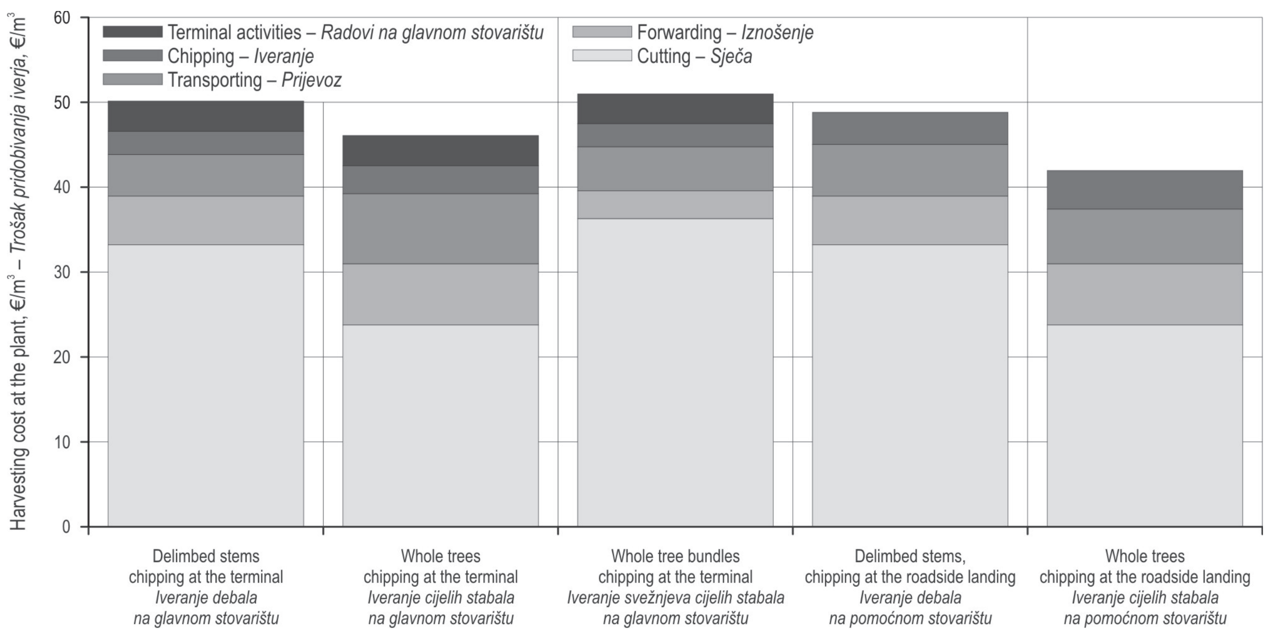

Fig. 6 Cost structure of whole-tree and multi-stem delimbed shortwood chips at the plant, €/m³. Forwarding distance is 300 m and transporting distance to the plant or the terminal is 50 km

Slika 6. *Sustav troškova pri iveranju na glavnom stovarišru (energani), €/m³. Udaljenost je privlačenja 300 m, a udaljenost je prijevoza do energane ili glavnoga stovarišta 50 km*

porting costs of whole-tree bundles and multi-stem delimbed shortwood were about 2 €/m³ lower compared to whole-tree and multi-stem delimbed shortwood chips mainly due to shorter loading and unloading times and somewhat bigger payloads. Also the standard timber truck hourly cost was lower compared to the chip truck-trailer unit.

The harvesting cost of whole-tree and multi-stem delimbed shortwood chips at the plant ranged between 42.0 and 51.0 €/m³ when the breast height diameter of the harvested trees was 8 cm (Fig. 6). Whole-tree harvesting and chipping at the roadside landing was the most cost-efficient supply system in the cost assessment, because the cutting of whole trees was significantly cheaper compared to whole-tree bundling or harvesting trees that have been delimbed. The lower comminution cost at the terminal was not enough to cover the extra handling cost of chips at the terminal or the delivery cost to the plant. Fig. 7 shows the harvesting cost of chips at the plant calculated as a function of breast height diameter when the terminal was located in direct connection to the end-use facility. According to the results, the harvesting system based on terminal chipping and multi-stem delimbed shortwood undercut the harvesting cost of the harvesting system based on whole-tree harvesting and roadside chipping when the breast height diameter of the harvested trees was 11 cm (pine) or more. In the case of whole-tree bundling, savings in transportation and chipping costs did not offset the high felling and compaction costs, and the bundling system was the least competitive alternative (Fig. 7).

4. Discussion – *Rasprava*

Whole-tree harvesting and chipping at the roadside landing was the most cost-efficient supply system in the cost comparison. The cost of whole-tree and multi-stem delimbed shortwood chips was at the same level when the breast height diameter of the harvested trees was 11 cm (pine) or more. The cutting of whole trees is cheaper, but the cost difference diminished as a function of tree size. The productivity of forwarding, transportation and chipping of multi-stem delimbed shortwood was significantly higher compared to that of whole trees. When applying roadside chipping in Finnish conditions with small and sparsely located forest holdings, acquiring large enough concentrations of wood for profitable production is a great challenge. Machine relocations can be reduced by transporting raw material to terminals or the end-use facility to be chipped. However, the low bulk density of the initial material restricts the operation radius unless the wood biomass is pre-processed. According to the results of our study, harvesting of delimbed energy wood is a promising way to simplify operations and to reduce transportation and chipping costs. In the case of whole-tree bundling, savings in transportation and chipping costs did not offset the high felling and compaction costs, and the bundling system was the least competitive alternative.

Eriksson and Björheden (1989) figured out that supply via terminals does not pay off, and our results do not refute this in general. The GIS study of Kanzian et al. (2009) indicate that supply costs will increase by just 10% if half the fuel and 26% if all the fuel goes through terminals in Austria. On the other hand, the additional costs can be designated as expenses necessary to ensure constant supply throughout the year (e.g. Gronalt and Rauch 2007; Kanzian et al. 2009; Laitila et al. 2010a).

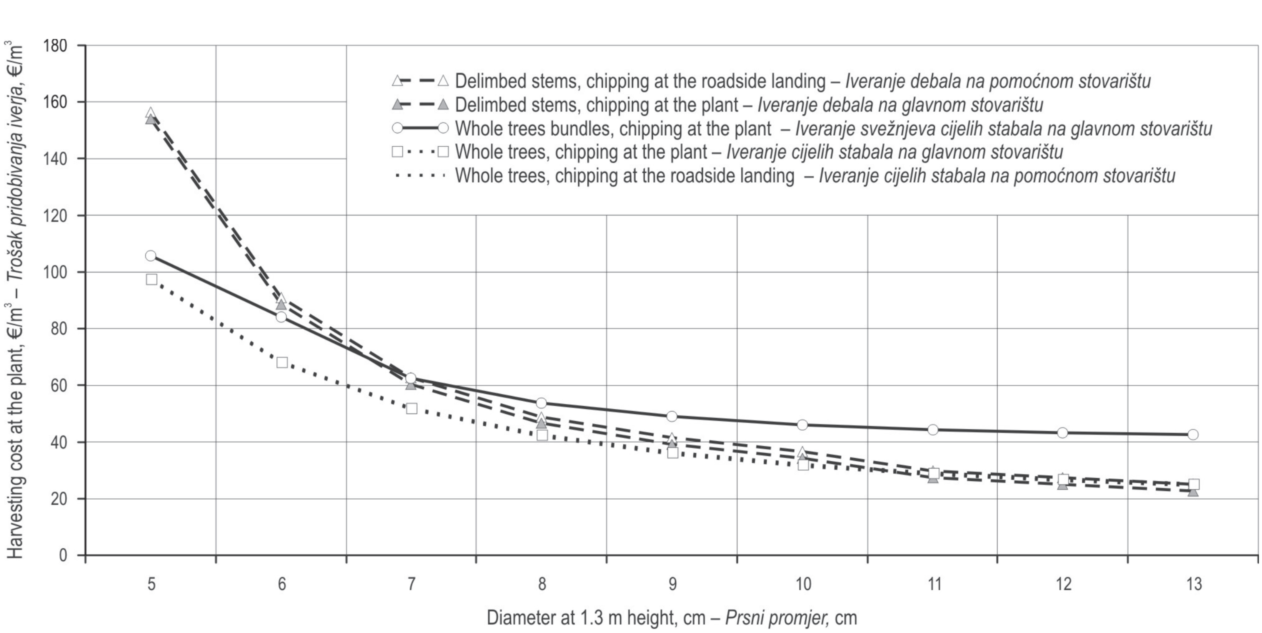

Fig. 7 Harvesting cost of chips at the plant as a function of breast height diameter, €/m^3

Slika 7. *Troškovi pridobivanja drvnoga iverja kao funkcija prsnoga promjera stabla, €/m^3*

Delimbed material produces uniform fuel stock devoid of needles and branches, which may be a benefit especially at some power plants with a restricted capability to handle high levels of chlorine and alkali metals contained in the branch material. Sufficient quantities of alkali metals and chlorine cause agglomeration of bed sand as well as corrosion in fluidised and circulating fluidised bed boilers and heat exchangers (Nurmi and Hillebrand 2007). Since harvesting undelimbed assortments increases nutrient export from the site, which can affect soil productivity, the whole-tree harvesting alternatives included in the present study cannot be recommended on infertile soil stands (Äijälä et al. 2010). However, in Scandinavian studies, no significant growth reductions have been observed due to whole-tree harvesting from Scots pine first-thinning stands within the follow-up periods of at most 20 years (Jylhä 2011). In the simulation by Heikkilä et al. (2007) based on nitrogen removal from the sites, leaving 40% of logging residues on Finnish first-thinning sites, increased thte stem volume by 2.6% over a 10-year post-harvesting period compared to complete whole-tree harvesting.

5. References – *Literatura*

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Sažetak

Kamionski prijevoz i proizvodnost iveranja cijelih stabala i okresanoga kratkoga drva u Finskoj

Ovo je istraživanje usmjereno na ocjenu konkurentnosti nekoliko sustava pridobivanja energijskoga drva iz mladih sastojina. Za usporedbu troškova sustava rada korištena je biomasa iz triju izvora: (i) energijsko drvo iz okresanoga kratkoga drva, (ii) cijelih stabala i (iii) svežnjeva načinjenih pomoću novorazvijenoga stroja bandlera harvestera (stroja za izradu svežnjeva) Fixteri II (slika 1). Sječa stabala provedena je pomoću harvestera, a privlačenje je obavljeno forvarderom. Usporedba troškova pridobivanja biomase učinjena je na razini sastojine kao funkcija prsnoga promjera stabala (5–13 cm) i udaljenosti prijevoza (5–160 km).

Iveranje je biomase obavljeno na pomoćnom stovarištu uz šumsku cestu ili u energani (glavnom stovarištu) pomoću priključenoga bubnjastoga iverača. Okresano kratko drvo i svežnjevi cijelih stabala prevezeni su do energane pomoću kamionskoga skupa, dok su cijela stabla prevezena kamionima s obloženim tovarnim prostorom.

Sustav je rada ocijenjen pomoću nedavno objavljenih podataka o proizvodnosti te usporedbom sličnih istraživanja. Cilj je istraživanja bio poboljšati troškovnu učinkovitost proizvodnje drvnoga iverja dobivenoga iz mladih sastojina, a posebno ispitati tehnologije iveranja tankoga drva iz proreda na pomoćnom stovarištu.

Prema procjeni troškova iveranje cijelih stabala na pomoćnom stovarištu uz šumsku cestu bilo je gotovo uvijek najučinkovitiji sustav pridobivanja biomase. U slučaju izrade svežnjeva uštede u prijevozu i iveranju ipak nisu dostigle troškove nastale pri sječi i izradi svežnjeva, pa je taj sustav najmanje konkurentan. Trošak pridobivanja iverja iz cijelih stabala i iz okresanoga kratkoga drva bio je jednak pri prsnom promjeru stabala od 11 cm (bor) ili više. Privlačenje debala i svežnjeva biomase isplativije je zbog veće iskoristivosti tovarnoga prostora (veća gustoća tovara). Također, utovar i istovar bili su učinkovitiji u odnosu na utovar i istovar cijelih stabala.

Prosječan tovar cijelih stabala pri prijevozu bio je 30 m^3, utovar je bio 1,0 m^3 po minuti, a istovar 2,58 m^3 po minuti. Utovar i istovar debala (duljine od 3 i 5 m) iznosio je 2,53 i 3,39 m^3 po minuti te 1,7 i 2,56 m^3 po minuti. Pri utovaru debala duljine 5 m mnogo je bolja iskoristivost hvatala, pa tako i proizvodnost raste.

Priprema za iveranje, uključujući sve pripremne radove od pokretanja stroja do povećanja brzine iverača, trajala je u prosjeku 2,4 minute. Proizvodnost iveranja bila je 55 m^3/E$_0$h za cijela stabla i 67 m^3/E$_0$h za iverje od okresanoga kratkoga drva. Prosječan zahvat hvatalom iznosio je 0,33 m^3 (211 kg) za cijela stabla i 0,49 m^3 (317 kg) za okresana kratka drva. Raspodjela veličina čestica sječke dobivenih od cijelih stabala i okresanoga kratkoga drva usporediva je, isključujući udio malih čestica (< 8 mm) koje nastaju zbog visokoga postotka grana i iglica u sustavu iveranja cijelih stabala.

Pri primjeni iveranja na pomoćnom stovarištu uz šumsku cestu u finskim uvjetima s malim i prostorno udaljenim šumskim poduzećima velik je izazov jer je potrebna velika količina biomase da bi sustav njezina pridobivanja bio isplativ. Premještanje strojeva može se izbjeći prijevozom sirovine (biomase) do energana i glavnih stovarišta gdje se potom obavlja iveranje. Prema rezultatima ovoga istraživanja pridobivanje iverja iz okresanoga kratkoga drva može smanjiti troškove prijevoza i iveranja biomase.

Deblovna metoda stvara jedinstvenu i homogenu zalihu goriva oslobođenu iglica i grana koje mogu biti prednost pogotovo u onim energanama s ograničenim mogućnostima za obradu visoke razine klora i alkalijskih metala sadržanih u granama stabala. Uporaba cijelih stabala prilikom pridobivanja biomase smanjuje proizvodnost tla jer se nutrijenti iznose iz šume, stoga se takvi sustavi pridobivanja ni ne preporučuju.

Ključne riječi: iveranje cijelih stabala, iveranje okresanoga kratkoga drva, prijevoz, glavno stovarište

Authors' address – *Adresa autorâ*:

Juha Laitila, PhD.
e-mail: juha.laitila@metla.fi
Kari Väätäinen, MSc.
e-mail: kari.vaatainen@metla.fi
Finnish Forest Research Institute
Joensuu Research Unit
P.O. Box 68,
FI-80101 Joensuu
FINLAND

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