INFRES – Innovative and effective technology and logistics for forest residual biomass supply in the EU (311881)

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Demo Report 15: Studies and demonstration on the use of a bundle-harvester system in early fuel wood thinnings

Dissemination Level

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SEVENTH FRAMEWORK PROGRAMME

1. Introduction

In order to reach high cost efficiency in forest fuel supplies high payloads in terrain and road transportations are crucial. Therefore the biomass could be compressed into ca 2.5-3.5 m long bundles with densities of 270-780 kg/m^3 already in the stand or at roadside before being further handled and transported (Nordfjell & Liss 2000). Such systems has been analyzed in the past and it was concluded that if the bundles can be made in such way that they can be transported on conventional roundwood trucks, the logistical advantages are severe throughout the supply chain (Johansson et al. 2006). The bundles are easy to handle when being re-loaded, dry out during storage, and the comminution can effectively be done using large scale systems. However, the technologies studied for bundling are costly and new technologies with higher cost efficiency are required. Bergström and Di Fulvio (2014) show that if bundle-harvester systems for young dense thinnings are developed further, their cost efficiencies when including transportations to the end users will be significantly lower than for conventional tree-parts systems.

A first prototype of whole tree bundler for small trees was tested in Finland in 2007 (Jylhä & Laitila 2007), the early study shown that the bundling productivity was limited by the fact that simultaneous harvesting and bundling phases were only 8–18% of effective working time in the study. Therefore, it was concluded that the studied concept was not competitive with the conventional harvesting systems, however having a great potential for future development. A second prototype was studied in 2009 (Kärhä et al. 2009, Nuutinen et al. 2011), the productivity increased by 38-77% compared to the first prototype, and the improvement was due to a higher cutting-accumulation capacity and the improved bundling hydraulics, which increased the possibility to perform simultaneous harvesting and bundling.

A third version of the “Fixteri” bundling system was launched in 2013 and its efficiency (time/bundle) when implemented in a bundle-harvester concept has been further increased by 90-160% in comparison to previous versions (Björheden & Nuutinen 2014). The systems productivity has however not been extensively studied in stands with an average tree size harvested below 30 dm^3. In these stands, the share of disturbing under-growth trees can be significantly and might decrease cutting productivities (cf. Kärhä 2006).

Objectives

The objective was to study the effect of harvested tree size and density of undergrowth on the operational efficiency of a whole tree bundle-harvester in early fuel wood thinnings in the North of Sweden.

2. Materials and Methods

A stand containing patches dominated by broad leaves and conifers of various characteristics was selected. The study area was located in Holmsund (N 63°43’, E 20°25’) in the costal area of north of Sweden. The forest was 30-35 years old and contained mostly of Scots pine, Norway spruce and birch. The ground had in generally a good bearing capacity, the surface had no obstacles and the slope was slight. In total 26 units were marked out for harvesting with an average surface of 1215 m^2, and a total surface of 3.2 ha (Table 1). In 10 of the 26 units a pre-cleaning was carried out, meaning that trees with a DBH ≤2.5 cm (i.e. undergrowth trees) were cut with a cleaning saw and left on the ground prior to the thinning with the bundler-harvester.

Table 1. Characteristics of the 26 harvesting units after pre-clearance (in 10 of the units) and before thinning.

	DBH[1]	**DBH basal**[2]	**Stem volume**	**Density**[3]	**Height**	**Stem volume**	**Biomass**	**Undergrowth density**
Stats	***(cm)***	***(cm)***	***(dm^3)***	***(trees/ha)***	***(cm)***	***(m^3/ha)***	***(OD t/ha)***	***(n/ha)***
Mean	7.1	8.0	26.5	5406	8.2	133.9	92.3	4523
Min	5.5	6.3	15.0	2765	7.0	91.0	54.0	134
Max	8.5	9.9	43.0	9302	9.7	206.0	148.0	11951
Median	7.0	8.0	24.5	5200	8.1	131.0	91.0	3648
SD	0.9	1.0	8.1	1583	0.7	28.9	24.9	3509

[1]Arithmetic DBH for tree-sizes ≥ 2.5 cm DBH; [2]DBH weighed by basal area; [3]Including all tree sizes.

The machine system studied was a harwarder equipped with a bundling unit able to cut the trees and bundle them into 2.6-m long cylinders with a diameter of ca 60-70 cm (**Figure 1**). The base machine was a 8-wheeled Logman 811FC (Logman, Oy) with engine power of 125 kW, a mass of 15 t, a width of 2.8 m and ground clearance of 65 cm. It was equipped with a 10 m reach Logfit FT100 crane (Logfit AB) integrated on a rotating cabin with endless turning. The crane was equipped with a Nisula 280E+ (Nisula Forest Oy) accumulating felling head with a mass of 0.33 t and a maximum cutting diameter of 28 cm.

Figure 1. The Fixteri FX15 bundle-harvester system

The bundling unit was a Fixteri FX15 with a mass of about 6.5 t, a width of 240 cm, a length of 410 cm, and height 280 cm. The systems total mass was 23.5 t. The bundling unit it featured with two feed rollers, a cut-to length guillotine and a compression and bundling compartment. The bundling chamber has a fixed length of 260 cm and is featured with three sets of chains used for compression and a vertically sliding frame. On the right side of the compression chamber are two plastic net rolls mounted, each roll containing 4000 m of wrapping net. On the opposite side of the chamber are two mobile arms mounted for integrating scaling and dropping-off of bundles. The bundling unit is powered by the base machine´s electrical and hydraulic system (Fixteri Ltd 2014).

Whole trees were cut, accumulated and fed to the bundling unit for processing (Figure 2). The guillotine installed at the chamber gate bucks the stems in the feeding chamber into 260 cm lengths. Once the compartment contained sufficient material for producing one bundle (i.e. 450-500 kg of fresh mass), the bunch of trees was lifted up to a compaction chamber where the bundle was compressed by revolving chains and tied up by means of a plastic net, at the same time the lower compartment could be fed with other trees. Once the bundle reached a sufficient density it was automatically unloaded from the compaction chamber to two side arms, the bundle was automatically scaled and information on time of production and mass were recorded on the base machine computer. Then the bundle was dropped on the ground from the arms and a new bundling cycle started. The bundling process is completely automated and the operator can use the crane for cutting and feeding trees to the bundling unit while the bundle compaction is continuously performed. No residual biomass excesses the bundling process, i.e. the whole trees feed to it are bundled.

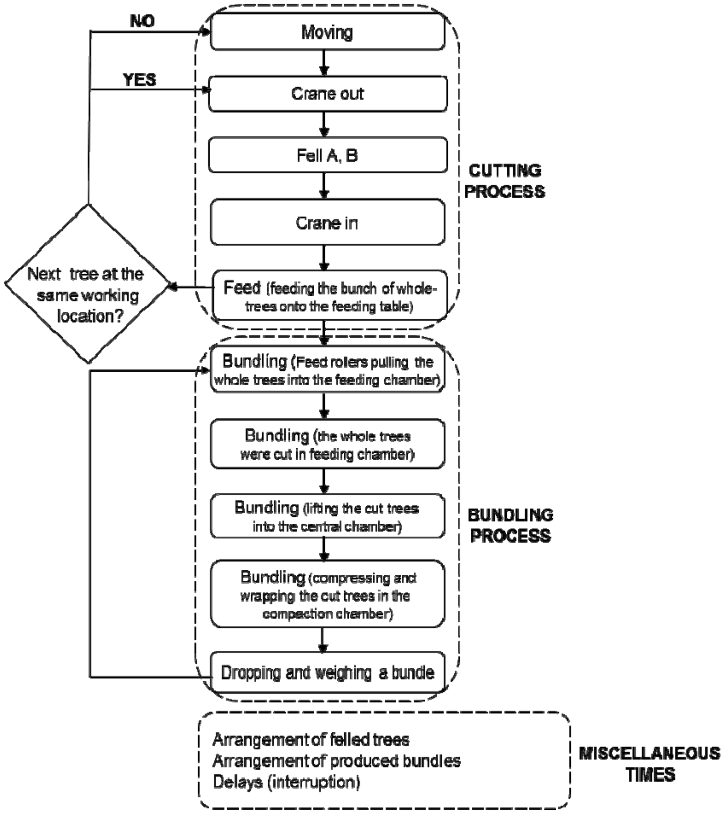

Figure 2. Flow chart of the work processes for the studied bundle-harvester. Notations A and B indicates that the several trees can be cut in one crane-cycle before delivered to the bundling unit.

The thinning was carried out selectively from below on a strip road pattern with a 20 m spacing between the roads. Removing priority was given to broadleaved species and the target was to leave at least 1200-1500 future crop trees/ha (i.e. trees with DBH > 6-7 cm).

The time study was conducted between 5th and 14th of May 2014, and the total duration of the study was 29.4 hours. The productive work time (PMH_0) consumption was continuously recorded and delays were recorded apart. The highest priority in the recording of time elements was given to the crane work, i.e. if the crane work and bundling were performed at the same time, the crane was prioritized and recorded. During the harvesting the number of felled trees per crane cycle (DBH > 2.5 cm) was also recorded (the threshold was visually estimated). At the same time, the machine computer created a dataset for each harvesting unit which contained the time (hour: minute: second) when each bundle was expelled from the bundler and its fresh mass (kg), as acquired from the integrated scale.

After the time study, the remaining stand's characteristics were inventoried again by using permanent transects used for the inventory of the stand characteristics prior to the thinning.

The oven-dry (OD) biomass content of stems, branches and needles was calculated using Marklund's (1987) functions. For conversion to solid volume, Hakkila's (1978) basic density values for crown biomass were used. The bundle mass was acquired directly from the machine database as a fresh mass and was converted to oven dry (OD) mass by using the moisture content (MC) recorded in each harvesting unit. Immediately after harvesting, in each of the harvesting units, one bundle was randomly sampled from which a 10 cm thick slide was cut off (in the middle of its length) by using a chainsaw for MC determination. The average MC for the pine, spruce and birch dominated harvesting units were 53.4 (SD =2.5), 58.7 (SD =1.3) and 52.6% (SD =3.0), respectively.

3. Study result

There were no differences between treatments (pre-clearance vs. no pre-clearance of undergrowth) on the remaining stands' properties (i.e. stand density, damage, strip road spacing). The remaining stands had in average 1852 trees/ha and consisting of of 39% pine, 20% spruce and 41% birch, by number. The strip-road width was in average 4.5 m and the distance between strip-roads 19.8 m. The bundles had in average a fresh weight of 439 kg (SD 24.1 kg) with a minimum and maximum value of 391 and 493 kg, respectively. The corresponding dry mass was 203.4 OD kg (SD 17.3).

The number of undergrowth trees had no significant effect on the harvester and bundling work time consumption. The felling crane was standing idle 7.4% of the effective work time, mostly due to feeding large trees and moving droppedbundles . In average 4.1 trees/crane cycle were harvested and there were no statistically significant differences between treatments. In average each crane cycle took 44.6 seconds and in average 5.5 crane cycles were required to produce a bundle. Hence, in average 4.1 min of work time were required per bundle.

The productivity reached in average 3.1 OD t/PMH_0 (SD 0.6 t/PMH_0) (6.6 fresh t/PMH_0 (SD 1.2 t/PMH_0)) .The independent variable, harvested tree size (stem volume), explained most of the variability in the productivity (67%) and was used as single variable for modeling the harvester-bundler productivity (OD t/PMH_0), since all other combinations of independent variables gave lower prediction values and/or were biased with multicollinearity (Figure 3).

In average 15.1 bundles/PMH_0 (SD 2.7) were produced with a minimum and maximum production rate of 10.8 and 20.3, respectively. The productivity in terms of bundles/PMH0 was also mostly explained by the harvested stem volume, and in this case it explained a slightly higher degree of variability compared the productivity in term of mass (74% vs. 67%).

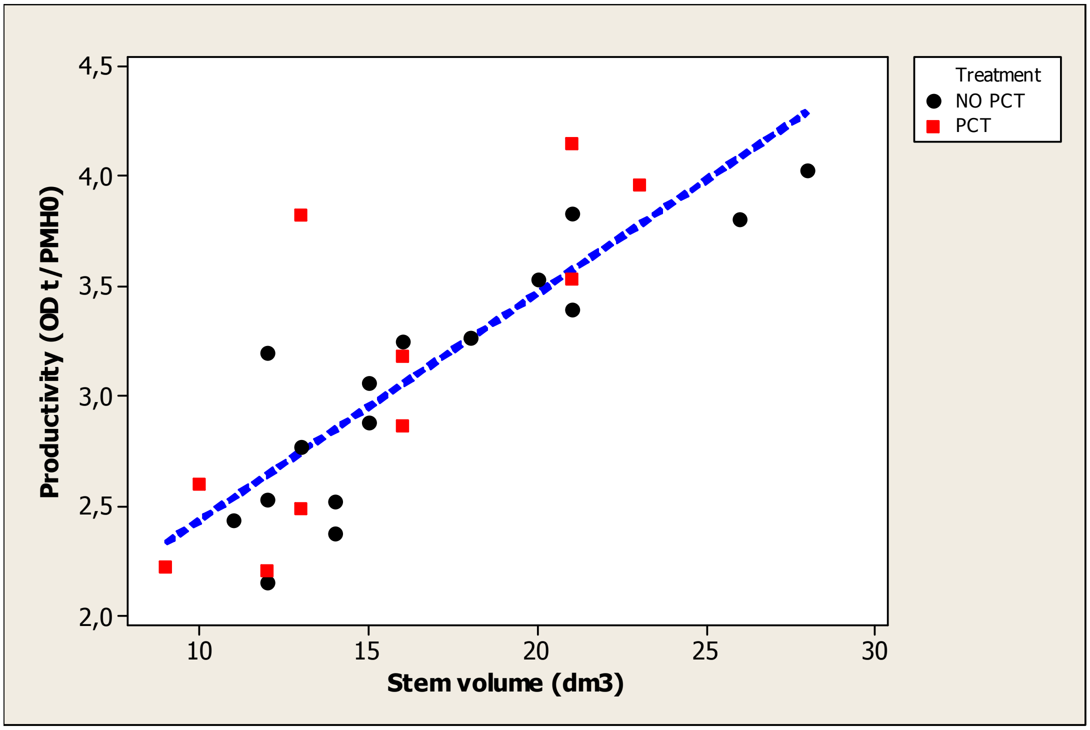

Figure 3. Productivity of the bundle-harvester system as a function of average harvested stem volume and treatments, PCT=pre-cleaned, NO PCT=not pre cleaned.

4. Chain level comparison with conventional supply chains

The cutting efficiency of the system is in line with previous studies (Björheden & Nuutinen 2014) and in line with conventional loose tree-parts harvesters. In average 4.1 trees/crane cycle were cut. Iwarsson Wide (2010) stated that the number of handled trees per crane cycle is a critical parameter for multi-tree handling in small diameter stands. Belbo (2011) showed through a simulation that the optimal number of accumulated trees in multi-tree cutting is from 4 to 5 trees per crane cycle. Thus, it seems that the cutting capacity was highly utilized in present study. As bundles achieve higher payloads than loads of loose tree parts the overall productivity of bundle supply systems are therefore higher. However, the operational cost of the bundle harvester is higher than for conventional harvesters, therefore the systems suitability is dependent on tree size harvested and transportation distances. Bergström and Di Fulvio (2014) show that bundle-harvester systems, similar to the studied one, are competitive compared to conventional tree pert systems in early fuel wood thinnings where the average stem volume harvested is greater than ca 30 dm^3. One obvious drawback with the bundle-harvester system is its high mass, which limits the machines usability on weak grounds.

5. General evaluation

The following conclusions can be drawn from the field study:

- The system efficiently produces high density bundles with high durability from whole trees.
- The efficiency of the system is limited by the cutting work speed, i.e. the efficiency of the bundler exceeds the efficiency of which trees can be feed to the bundler.
- The machine is relative heavy and its center of gravity is relatively high from the ground which gives high ground pressure and limits its maneuverability in side slopes.

In order to optimize the efficiency and potential of the bundle-harvester system, the following technical improvements/changes and future studies are suggested:

- The system can reach higher efficiency if featured with an accumulating head able to achieve higher cutting efficiency.
- A reduction of the bundler-harvester mass would render higher utilization (more type of stands could be harvested).

6. Demo results

In May 16th 2015, 80 persons gathered in Holmsund (10 km from Umeå) in north of Sweden for a field demonstration. The participants were researchers, machine manufacturers, machine developers, representatives from refining industries, forest companies and forest owners associations. The in-field demonstration included the entire supply system for small tree bundles (**Figures 4-9**): 4 & 5) cutting and production of bundles; 6) forwarding of bundles; 7) building of a storage pile; 8) truck transportation of bundles; 8) chipping of bundles. The main event was the demonstration of the “Fixteri FX15” bundling system which was attached to a Logman811FC equipped with a Nisula Forest 285 head (Figure 4). This system has previously been studied in Finland by the Metla (i.e. currently “Luke”), the Swedish Forest Research Institute (Skogforsk), Metsäteho and Pöyry Management Consulting. The Finnish study results show that the system is effective and competitive in comparison to conventional systems, and therefore it was interesting to study and demonstrate also in the Swedish conditions. The system was demonstrated while thinning a young dense stand. During the demonstrations, the audience had the possibility to ask questions both to the machine operators and machine owners/manufacturers.

Figure 4. The Bundle harvester system demonstrated.

Figure 5. Strip road with produced bundles.

Figure 6. Forwarding of bundles with a Komatsu Forest 865 forwarder equipped with a slash grapple (E36) and a crane-scale system (Intelweigh XW 50PS).

Figure 7. Building of a storage pile. Bundles are laid in cross sections for higher wind penetration.

Figure 8. Bundles are loaded on a conventional timber truck.

Figure 9. Chipping of bundles with a Doppstadt DH-910 drum chipper.

7. Acknowledgements

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