Fuel consumption and productivity for two tractor-mounted chippers in relation to knife wear and raw material

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Abstract: *When producing fuel chips from wood biomass important aspects to consider are the economics of chipping, the quality of wood chips in terms of moisture content and size distribution, and finally the fuel consumption in chipping operations. Thus it is important to evaluate parameters that may have an influence on one or more of those features. Important factors that influence the productivity and the environmental balance of chipping is the knives conditions and the raw material. In order to make an in depth analyze of those variables, test trials of two chippers were carried out in Sweden. The first chipper was a drum model, tested with residues coming from an ordinary logging and tree sections from a thinning. In this case knives were in three different wear conditions: new, good and dull. Hourly net production is significantly influenced by the knives wear and by the type of raw material as well. The effect of new and dull knives on fuel consumption is significant, as well as the effect on the same parameter of good and dull knives. The second chipper studied – a disc one – was tested with residues and pulpwood and the effect of knife condition were not studied. Regarding particle size distribution no effects on blades status or raw material could be found for the drum chipper, while for the disc chipper a statistical significant effect, limited to the accepts particles, was detected between forest residues and pulpwood.*

Keywords: chipping, fuel consumption, productivity, knives wear

1 Introduction

Nordic countries, as Finland and Sweden are innovators in the field of using wood biomass – including forest residues – for energy purposes. In Sweden, the great interest in utilization of forest residues started in the beginning of the 70s, after the first oil crisis and speeded in the late 90s (Mälkki & Virtanen, 2003). In 2009, 20,5 TWh of unprocessed wood fuels and 5.2 TWh of processed wood fuels (pellets and briquettes) were used for heat and electricity production in district heating plants (Svensk Fjärrvärme, 2010). Unprocessed wood fuels consists of sawmill residues, mostly saw dust and bark, and primary forest fuels, such as logging residues and wood from pre-commercial thinning. Logging residues and small diameter wood from thinning are commonly used in Nordic countries to produce wood chips (Ranta, 2005). In addition to the biomass used to produce energy in the district heating plants a substantial amount is used by the forest industry itself (Björheden 2011). A strong connection exists between the energy sector and the forestry and forest products industry, because the direct harvest of fuel wood and other forest fuels implied a certain amount of wood residues generated at different stages in the production chain for different wood products (Hillring, 2006). Since most biomass used in Sweden originates from the forests, forestry and the forest industry represent key sectors for the biofuel market (Ericsson & Nilsson, 2004).

An increasing demand of solid biofuels necessitates an increased efficiency in the supply chain in order to avoid increased fuel costs (Björheden R., 2011). The cost for comminuting the biomass is a major part of the supply chain costs. The closer the comminuting is to the plant the more cost-efficient it is (Kärhä, 2011). Thus in Finland, chipping is expected to move in from roadside landings closer to users locations, either to terminals for a temporary storage or directly to the plants. In Sweden, 80 % of the logging residues were chipped on landing, 15 % were transported in loose form to terminals or end users for chipping and 5 % were bundled on the cut block and transported to terminals or end users for storage and chipping in 2009 (Brunberg 2011). Chip trucks have a higher pay load than trucks for loose residues and thus decreases the transport costs per ton. Thus chipping on the landing leads to lower total costs in the supply chain on medium and long transport distances. Currently roadside chipping are dominant in Sweden as well as in other European countries, e.g. Italy where terrain or roadside chipping are prevalent compared to other systems.

In order to enhance the cost effectiveness of chipping, it is crucial to both improve chipper productivity and reduce the fuel consumptions of the chipper. The aim of this study was to describe the effect of raw material (forest residues, thinning or pulpwood), and blades sharpness (softwood or hardwood) on chipper productivity, fuel consumption and the particle size distribution of chips produced. The experiment included at least three replications per treatment, each replication consisting of a full chip load.

2 Material and Methods

The study tested two different chippers, namely the drum chipper Jenz 561 powered by a 246 kW Claas Xerion 3300 tractor (Fig. 1) and a TS 1200 disc-chipper mounted on a John Deere 810D forwarder equipped with a bin of 13 m3 of capacity. The drum mounted a rotor with 20 knives and a screen 80 x 80 mm wide, while the disc chipper carried two blades and a counter-blade to cut oversized material on the fan. Trials were carried out in four different locations: the drum chipper worked in the South-West of Sweden. Logging residues from a final felling were chipped at Skultorp (N 58 20.268 E 13 51.267), approximately 10 km from Skovde, and tree sections from a thinning were chipped near Tibro (N 58 25.216 E 14 04.980). The disc chipper comminuted logging residues from a final felling located near Mariestad (N 58 35.873 E 13 42.658), and pulpwood at the biomass terminal in Götene (N 58 31.351 E 13 29.071).

Figure 1: Chipping of forest residues at a roadside landing located in Skultorp

A time study was carried out at a cycle level to measure the time consumption in the chipping operations. Both productive and delay time were measured but only effective time were included in the analysis. Time recording was made with Allegro hand-held computers equipped with Skogforsk SDI software. Studied treatments combinations for the Jenz HEM561 chipper were good knives and logging residues, dull knives and logging residues, and new knives and tree sections. Only the effect of chipped material was studied for the TS1200 chipper, studied materials were logging residues and pulpwood.

Figure 2: Measures of fuel consumption concerning a single full load of wood chips

The chippers threw the wood chips directly in containers and each filled container was considered as a replicate. For each container, fuel consumption measurements were measured using a highly accurate pump to fill up the fuel tanks of the machines. The pump was equipped with a fuel reader, with an accuracy of one centiliter (Fig. 2). Produced output of the chippers was measured by taking the filled containers to a certified weighbridge, where both the filled and empty weight of the container was recorded. Every container was labeled, in order to match its weight to the chipping time. A 10 liter sample of the chips was taken from each container for determining moisture content and particle size distribution. Moisture content determination was conducted on subsamples, collected in sealed bags and weighed fresh and after drying at 105 °C until samples did not lose further weight (i.e. according to SS-EN 14774-2). Moreover, wood chip quality was assessed by sieving the wood chips according to the SIS-CEN/TS 15149-1 standard. Five sieves were used to separate the six following chip length classes: > 63 mm (oversize particles), 63–45 mm (large-size chips), 45–16 mm (medium-size chips), 16–8 and 8-3 mm (small-size chips), < 3 mm (fines). Each fraction was then weighed with a precision scale.

To test the effect of blade sharpness on fuel consumption, hourly productivity and particle size distribution, sharp and dull blades were used on the drum chipper only, by varying also the kind of raw material. Different materials were tested on the disc chippers as well but not different knives wearing. Overall almost 190 tons of wood were chipped at a 40% of moisture content.

Data were analyzed with the Statview advanced statistics software, in order to check the statistical significance of the eventual differences between treatments. Data satisfying the normality assumption were analyzed with Scheffe's post-hoc test, which is considered most conservative and robust (SAS 1999). In the few cases were the normality assumption was not verified, the Kruskal-Wallis non-parametric test was used.

3 Results

During the study almost 190 tons of wood were chipped at an average moisture content of 40 per cent. There was a strong correlation between hourly productivity and blades wear for the drum chipper. Passing from a "good" blades status to a "dull" one, there is a 15.7% decrease in productivity (green tons hour^{-1}) for the same kind of raw material, namely forest residues from a final felling. By replacing knives for chipping material from thinning the gross productivity increases to 32 gth^{-1}, equivalent to an increase of 9.5% if compared to the blades in good conditions that were used at the beginning (Fig. 3).

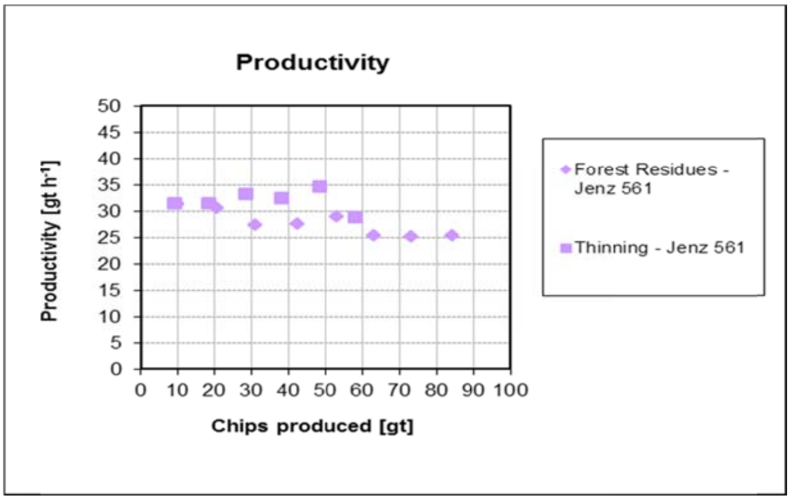

Figure 3: Hourly productivity related to progressive dullness of drum chipper blades

The statistical analysis confirms that both treatments had a significant effect on productivity for the drum chipper (Table1).

Concerning fuel consumption, expressed as liter per oven dry tons, chipping of forest residues required 2.4 l odt^{-1} when blades were in good conditions and 3.1 l odt^{-1} with dull blades. By replacing a new set of blades the fuel consumption was on average 2.3 l odt^{-1} by comminuting thinning material.

Table 1: ANOVA table for productivity (drum chipper)

	Effect	DF	SS	MS	F-value	P-value	Power
odt h^{-1}	Raw Material Residual	1 11	29.339 11.986	29.339 1.090	15.584	0.0019	0.962
odt h^{-1}	Blades Status Residual	2 11	39.945 11.986	19.973 1.090	18.330	0.0003	0.999

The graph in Figure 4 shows a rising trend about fuel consumption when the knives wear increases as a consequence of the chipping progression.

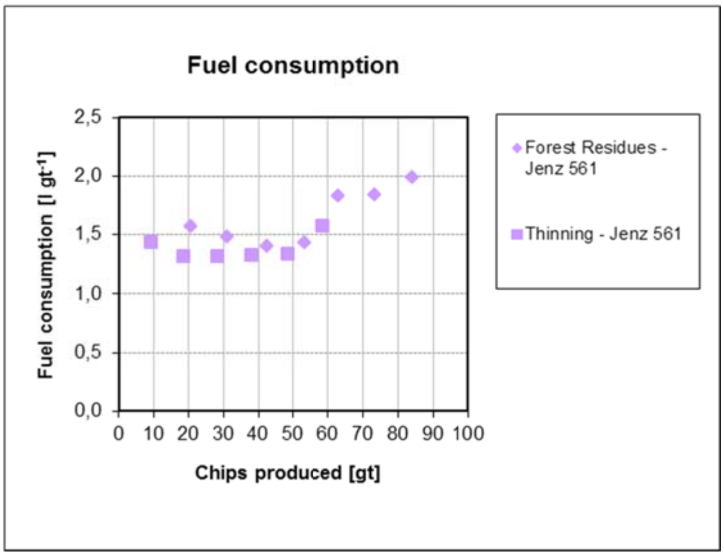

Fig. 4. Fuel consumption in relation to progressive dullness of drum chipper blades

A statistical significant difference emerges between fuel consumption, blade wear and different raw materials (Table 2).

Table 2. ANOVA table for fuel consumption (drum chipper)

	Effect	DF	SS	MS	F-value	P-value	Power
l odt^{-1}	Raw Material	1	0.720	0.720	7.562	0.0189	0.711
	Residual	11	1.047	0.095			
l odt^{-1}	Blades Status	2	1.536	0.788	33.220	<0.0001	1.000
	Residual	10	0.231	0.23			

Coming to particle size distribution no effects on blades status or raw material could be found for the drum chipper, while for the disc chipper a statistical significant effect, limited to the accepts particles, was detected between forest residues and pulpwood.

4 Discussion

Fuel costs accounts for a large share of the overall costs for chipper contractors (Granlund, 2011) and their revenues are dependent on the material to chip, chip quality and the amount of chips produced. Thus, knife wear increases costs at the same time as revenues decreases making it one of the most important factors to control in order for a contractor to remain both profitable and competitive. It is also one of the few factors that the contractor can control by himself, chip qualities are often tightly regulated in contracts and the chipping work are paid differently dependent on material. Furthermore, emissions from chipping operations amount to around the 30% of SO2, TSP and CO of the emissions in the supply-chain for forest chips (Mälkki & Virtanen, 2003).

One factor explaining the productivity differences between materials are the piece size both tree sections and pulpwood logs are bigger and more even in size than the mix of tops and branches that the logging residues consists of. A larger and more even piece size is known to contribute to a higher productivity (Spinelli & Hartsough, 2001). The effect of blade sharpness on productivity and fuel consumption is comparable to the effects found by the same Authors (Nati et al., 2010). However, it is difficult to say if the dull knives were completely worn out since different operators will have different opinions of how dull a knife should be before it is worn out or before it should be changed.

Delays are a major factor limiting chipper productivity (Spinelli & Visser, 2009). In order to get representative data on delays in an operation a long study period is needed due to the random and infrequent occurrence of delays. The performed study was a short study of two chipping operations, thus it was not possible to get representative data on delays, relocation times, etc., affecting the work. Therefore all reported productivities and fuel consumptions relates to effective chipping work excluding all by times and delays.

It wasn't possible to introduce moisture content as a parameter in our analysis as there was not much variation in moisture content as the studied materials were seasoned during the summer. This is a common practice in Nordic countries (Suadicani & Gamborg, 2009).

This study has shown that productivity decreases and fuel consumption increases when the blades of a chipper gets worn. Therefore, there must be an economically optimal interval between blade changes of a chipper, which is defined by the cost to replace the blades with sharp ones and the increased production costs when using dull blades. The present study does not provide enough information to do such an optimization, as the chippers needs to be continuously studied during the entire lifespan of the blades.

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