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The effect of chipper cut length on wood fuel processing performance

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ABSTRACT

The authors tested the same chipper under two alternative cut length settings (7 mm and 20 mm), with and without a piece breaker. The study included 10 repetitions per treatment, over 2 different feedstock types: chestnut logs and locust logs. The total number of repetitions was 80, each consisting of about 30 kg of logs. Cut length setting and piece breaker option are the main drivers of chip size, and they are manipulated with the main purpose of managing particle size distribution. Our study showed that the proportion of small chips increased dramatically with the shortest cut length setting (7 mm). Installing a piece breaker allowed maximizing the incidence of small chips, which reached 70% of the total mass when the piece breaker was used in combination with the shortest cut length setting. All else being equal, reducing cut length determined a substantial decrease of productivity (ca. 30%), and an even higher increase of specific fuel consumption (ca. 50%). All strategies to reduce chip size also resulted in increasing the incidence of fines. These results were obtained with new sharp blades. Blade wear may enhance or weaken the effect of cut length and piece breaker option.

1. Introduction

Wood fuels may offer a significant contribution to climate change mitigation, social welfare and local development [1]. For these reasons, many countries support the increased use of wood fuels through subsidies, tax-exemptions and other incentives [2]. The success of these measures depends on the capacity of wood fuels to compete with other energy sources, in terms of cost and convenience. Efficient processing is crucial to the production of competitive wood fuel: comminuted wood (chips) can be fed to automatic boilers, offering user-friendly operation, just like conventional boilers [3]. However, comminuted wood is still relatively wet and heterogeneous, which justifies the higher complexity of the new automated chip-fed boilers. As a result, these plants have a much higher investment cost than their conventional counterparts, which prevents widespread adoption by small-scale users [4]. Hence the overwhelming success of wood pellets, which are drier and more homogeneous than chips, and therefore much easier to handle [5,6]. For this reason, pellets can be fed to simpler and cheaper boilers, allowing widespread adoption by small users, for heating few rooms or single flats [7]. In contrast, pellet manufacturing is more complex and expensive than chip production [8] and is outside the reach of local small-scale operators, which reduces the beneficial impact of energy biomass on rural development [9]. The ideal solution would be to produce top-quality chips that can be fed to very simple boilers, or by the same boilers designed for firing pellets. Moisture and ash content could be reduced within acceptable limits by prolonged storage and careful raw material selection, respectively. Yet, achieving the right particle-size distribution might prove the hardest challenge [10]. Recently, a completely new chipper has been developed for producing pellet-grade chips, but this machine is still at the prototype stage, and is not widely available [11]. As an alternative, one may resort to a conventional chipper, properly set for producing so called “mini-chips”. Current experience shows that regular, small-size chips can be produced with conventional chippers by manipulating cut length. Similarly, the presence of oversize particles can be minimized by equipping the machines with screens or piece-breakers. However, chipper performance is significantly affected by cut length setting [12,13] and screen size [14]. These effects are likely to be strongest for extreme settings, as required for the production of mini-chips. Therefore, it is important to determine the trade-offs of mini-chip production, in terms of chipper productivity and fuel consumption. The goal of this study was to determine the effect of cut length and piece-breaker use on the productivity, fuel consumption and product quality obtained with a commercial disk chipper model.

2. Materials

The mobile chipper used for this experiment was a Farmi 260 HFC (www.farmiforest.fi). This model is very popular among small-scale operators, who are especially interested in catering to small-scale residential users. The Farmi 260 is a conventional disk chipper, and is run by the tractor power-takeoff (PTO). Its disk has a diameter of 1050 mm, and weighs 240 kg. The specimen used for the test was a three-knife

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version, with the new optional chain infeed. The test was conducted in February 2013, at a fuel wood terminal in the Chianti area, on the Florentine hills. The chipper was powered by a SAME Silver farm tractor, with maximum rated power of 77 kW at 2350 rpm, and a maximum engine torque of 265 Nm at 1400 rpm. The PTO was set on the 1000 rpm economy range.

3. Methods

The study was conducted on 2 to 4-m-long logs, of two different hardwood species, namely: black locust (*Robinia pseudoacacia* L.) and sweet chestnut (*Castanea sativa* L.). In Italy, hardwoods represent about 70% of the annual harvest and are especially appreciated as fuel wood, due to their higher density and lower moisture content compared to softwoods. Locust and chestnut are very common all across Central Italy, but they are much less valued than oak or beech when it comes to firewood production. Therefore, locust and chestnut have become the main target for fuel chip producers.

For the purpose of the study, chipper cut length was set alternatively to 7 and 20 mm, corresponding to mini-chips and standard chips. The machine was used with a piece breaker and without a piece breaker. The experiment consisted of ten replications per each combination of raw material, cut length and piece breaker option (i.e. 10 x 2 x 2 x 2 = 80 replications). Work was divided into four batches, each corresponding to one combination of cut length and piece breaker option, as previously described. For each batch, the machine was fed alternately with the two material types, starting with chestnut logs. New knives were installed before starting the experiment, and blade sharpness was visually assessed after each batch in order to contain the effect of blade wear. Each replication consisted of one to three logs, for a total weight of about 30 kg. This weight was considered representative of the average load fed to the chipper with manual loading, as commonly occurs in small-scale operations [15]. Processing small loads also allowed minimizing the effect of blade wear. During the whole experiment the chipper processed about 2.5 t of wood, which were hardly enough to determine significant blade wear [16]. All logs were weighed with a portable load cell before chipping, in order to assemble loads with similar weight.

Diesel fuel consumption was determined by installing a volumetric flow meter on the fuel supply line of the engine. The flow meter had a frequency output of 2000 pulses per dm^3. Fuel consumption was recorded at 0.2 second intervals. A torque and rotational speed transducer was placed between the cardan shaft and the tractor power take-off (PTO), making it possible to calculate rpm and delivered power at the PTO. All measurement devices were checked and calibrated before starting the test. Sensors fitted on the tractor were connected to a data acquisition system integrated with a personal computer, making it possible to record torque and speed at the PTO, as well as diesel fuel consumption. All parameters were recorded at the 500 Hz frequency. Before starting the test, the engine was run for about 30 min in order to reach a steady temperature. Each replicate lasted between 5 and 34 s, with an average of 15 s.

Effective time consumption was determined on the fuel consumption graphs, rather than by timing the actual work [17]. When the machine is processing small batches, it is very difficult for an external observer to accurately determine when the machine is working and when it is running idle. In fact, the machine evacuation system will keep spitting small amounts of chips for many seconds after the disk has finished its job. During this time the engine work load is dropping again. Under real work conditions, a new load would be engaging the chipper at this stage, and the engine work load would not be decreasing so sharply and for so long. To determine the beginning and the end of process time, all graphs were analyzed in order to estimate a basal fuel consumption figure, taken as a reference for the running machine before its disk actually engaged the wood. This reference figure was found to be 6.4 kW, which was adopted as the threshold for defining actual chipping time. Every test time when power request was above this level was counted as chipping time and used for calculating net chipping productivity. Average fuel consumption when chipping was calculated on the records above the 6.4 kW threshold.

A single 500 g sample was collected from each repetition for determining moisture content and particle size distribution. The former was obtained with the gravimetric method, according to European standard CEN/TS 14774-2; the latter with the oscillating screen method, using four sieves to separate the following five chip length classes: >63 mm (oversize particles), 63–46 mm (large chips), 45–9 mm (medium chips), 8–3 mm (small chips) and < 3 mm (fines). Each fraction was then weighed with a precision scale.

Data were analyzed with the Statview advanced statistics software, in order to check the statistical significance of the eventual differences between treatments. After checking the data for normality, the software was used for performing typical analyses of variance (Anova), especially suited to the factorial experiment just described. Anova tables were drawn, in order to see how the sum of squares was divided between main effects, interactions and residuals (crf. η^2). Logarithm and arcsine transformations were used to normalize data distributions that did not fulfill the normality assumption.

4. Results

The average moisture content (wet base) was 42 and 36% for chestnut and locust logs, respectively. That difference was statistically significant at the 5% level (Mann–Whitney *U*-test, p-value <0.0001). In contrast, mean load size was almost identical (32.1 and 31.9 kg for chestnut and locust, respectively). However, equally-sized loads were assembled using differently-sized logs. Locust logs were about 50% bigger than chestnut logs, and therefore a chestnut load contained a significantly larger number of logs, compared to a locust load.

Table 1 shows that the average power requirement varied between 32 and 43 kW, with the peak requirement reaching between 64 and 94 kW. When cut length was increased from 7 mm to 20 mm, average power requirement increased by 5 to 10%. Peak power requirement increased even further, and between 15 and 45%. These differences were statistically significant, especially for peak power requirement, whose variability was explained by cut length for over 50% (Table 2). Average power requirement increased between 5 and 15% when using a piece breaker, regardless of cut length. In contrast, use of a piece breaker caused a 6% increase of peak power requirement for the 20 mm cut length, and a 6% decrease of peak power requirement for the 7 mm cut length. All these effects were statistically significant. On the average, chipping locust required between 7 and 14% more power than chipping chestnut. Differences were smaller for peak power. The effect of tree species was significant, but it was generally small and it explained only a limited proportion of the overall variability in the data set.

Table 1
Data for power requirements.

	Species	Cut length	Piecebreaker	Mean	SD	Min	Max
Average power requirement (kW)	Chestnut	Max	No	36.2	5.7	26.1	44.4
			Yes	38.1	3.5	32.9	42.9
		Min	No	32.6	6.5	19.9	40.2
			Yes	37.3	3.5	34.0	43.7
	Locust	Max	No	42.2	4.2	35.0	47.2
			Yes	43.3	2.4	39.1	46.7
		Min	No	37.9	8.2	27.1	50.2
			Yes	40.1	6.4	29.1	49.1
Peak power requirement (kW)	Chestnut	Max	No	79.2	11.9	63.0	98.1
			Yes	84.6	10.5	65.9	96.6
		Min	No	69.3	9.7	55.0	85.9
			Yes	64.9	8.3	52.6	84.4
	Locust	Max	No	88.5	7.7	70.4	95.6
			Yes	94.6	4.2	87.3	98.3
		Min	No	68.4	10.6	57.6	88.4
			Yes	64.7	9.5	53.5	81.7

Note: SD = standard deviation.