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Trade-offs between fuel chip quality and harvesting efficiency in energy plantations

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Single-pass cut-and-chipping with modified foragers currently represents the most efficient technique for harvesting fuel chips from short rotation forestry (SRF). Modified foragers are designed to produce small chips, in the 25–30-mm length range. However, chip length settings can be adjusted for obtaining different commercial products. In that regard, it is important to determine the trade-offs of chip length manipulation, which may affect machine performance. This study tested the same modified forager designed for producing 30-mm chips, under variable chip length settings. In particular, chip length setting was adjusted both downwards to a minimum length of 5 mm (microchips), and upwards to a maximum length of 90 mm (billets). As expected, any setting adjustments that deviated from optimum values resulted in performance decline. Downward alterations of chip length setting resulted in a steady performance decline, which peaked at the shortest length setting (5 mm). Under that setting, productivity was 56% lower and diesel fuel consumption was 183% higher than under the optimum 30-mm setting. In contrast, upward alterations of chip length setting resulted in an immediate and moderate decay of machine performance at the very first increment, followed by the absence of further significant decline as additional increments were introduced. Reducing target chip length below 30 mm doubled or even quadrupled the proportion of fine particles (<3 mm) in the total chip mass, which detracted from chip quality.

1. Introduction

Large amounts of biomass fuel can be sourced from dedicated crops, which could account for three quarters of the total supply of biomass in the near future [1]. Compared with other biomass fuel sources, dedicated crops offer the benefits of intensive management, and may secure the highest yields within the shortest delays [2]. Compared to conventional agricultural crops, fuel crops accrue significant environmental and social benefits, and for this reason they are often supported with public subsidies [3]. Among fuel crops, short rotation coppice (SRC) requires the lowest external inputs [4] and seems particularly suited to farmers, who are used to short waiting times and show little interest towards conventional tree plantations [5]. However, the biomass fuel obtained from SRC plantations is less valuable than conventional farm products, which requires a proportional reduction of management cost in order to maintain financial viability. High efficiency must be achieved in all steps of the production process, and especially during harvesting, which often accounts for over 50% of total production cost [6]. At the same time, the selected harvesting technique may have a strong impact on product quality, and thus on the capacity of maximizing revenues [7].

Previous studies have shown that harvesting cost is lowest when using modified foragers for single-pass cut-and-chip harvesting [8]. However, cut-and-chip harvesting has the limit of producing fresh chips, characterized by a low energy content [9] and prone to rapid decay [10,11]. Furthermore, cut-and-chip operations imply that chip size must be managed at harvest time through the forager, and not at later time through a dedicated chipper. While moisture content issues can be solved by targeting users that tolerate high moisture or by blending [12], the solution to any chip size issues stays with the forager, where the chips originate. The increasing diversification of the biomass fuel market poses additional challenges for what concerns chip size distribution [13], and favours flexible solutions that may adapt to changing user requirements [14]. Different customers may issue different chip size specifications, and the ideal machine should rapidly adapt to customer requirements in order to target the highest-paying fuel markets.

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Fortunately, modern energy wood harvesters offer the possibility of adjusting target chip length, in order to match varying particle size specifications. One of the most recent models can produce particles with a target length between 5 mm and 90 mm [15]. While this machine is designed for optimum operation at a chip length target of 30 mm, chip length can be reduced directly from the cab through the simultaneous increase of feeding speed and chopper rotary speed, and by adjusting the spacing between the blades and the anvil. This way, chip length is decreased from 30 to 5 mm in 1-mm steps. The lower chip length the smaller the boiler that can use it, which implies targeting small-scale residential plants [16]. In fact, the smallest size class configures as micro-chip, which can be supplied to the pellet manufacturing sector. On the other hand, chip length can be increased from the optimum 30-mm length by removing part of the knives from the chopper, although that is a bit more laborious than just adjusting feeding and chopper speed. In that case, the machine can produce so-called "billets", up to a maximum length of 90 mm. Billets are only suitable for large plants, but they offer the distinctive advantage of higher pile permeability, with all its benefits in terms of drying [17], cooling [18] and ignition-risk prevention [19].

Of course, manipulation of target chip length has an impact on other parameters than target particle size, such as productivity, diesel fuel consumption and bulk density. Better knowledge of the trade-offs between chip quality and machine performance is required for making informed choices. Therefore, the goal of this study was to determine the relationship between target chip length, productivity, fuel consumption, bulk density and particle size distribution for a modified forager used in SRC plantations. In particular, the study explored the effect of deviations from optimum chip length, both downwards and upwards.

2. Materials and methods

The machine used for the test was the 441 kW New Holland FR9060 model, fitted with the new 130FB header, which is specifically designed for harvesting large-size SRC (Fig. 1). The header is equipped with a pair of large diameter circular saws placed at the bottom of the vertical crop collector rollers. The saws cut the stems and the crop collectors move them towards the horizontal feed rollers, which convey cut stems to the chopper unit, butt first. The chopper itself is part of the original forager unit and is located inside the carrier. It consists of the same drum device used for chopping maize, which is normally equipped with 16 knives divided in two sections. Once detached from the stem, wood chips are engaged by the blower, and launched through the outlet pipe.

Fig. 1. A view of the energy plantation, the modified forager and the chips.

While the manufacturer recommends production of 30-mm chips, chip length can be set to any values between 5 and 30 mm, directly from the operator's seat by changing the speed of the feed rollers and the chopper, and by adjusting the distance between the blades and the anvil. Chip length can be further increased from the 30-mm recommended setting, by removing part of the knives from the chopper, in order to reduce the number of cuts produced during each revolution. The maximum chip length achieved with this method is 90 mm.

The tests were conducted in Brazil, on two of the new energy wood plantations, established with selected eucalypt clones. The two plantations belonged to different owners, who required different product types. Therefore, the settings from 5 to 30 mm (treatments) were tested at site A, and the settings from 45 to 90 mm were tested at site B. Within each site, the sequence of chip length settings was changed randomly, in order to spread the effect of knife wear equally on all treatments.

The two sites exemplified two main cases. Case 1 consisted in decreasing target chip length from the optimum 30-mm setting, with the purpose of producing small chips and micro-chips. In that instance, the machine was tested with the standard 16-knives configuration for the following length settings: 30, 25, 20, 15, 10 and 5. In contrast, case 2 gauged the effects of increasing target chip length above the optimum 30-mm value, with the purpose of producing billets. In such instance, the machine was tested after removing 10 knives from the chopper, for the following length settings: 45, 60, 70, 80 and 90 mm. In this case, the optimum 30-mm configuration could not be tested because the smallest length one could produce with a 6-knives configuration was 45 mm. Therefore, the results for the 30-mm setting were acquired from the previous test and included into the second dataset, in order to provide a theoretical term of comparison. That allowed gauging the general effect of deviation from the optimum. Of course, the chip length figures reported above represented target lengths, i.e. the expected lengths of the largest chips (or billets) produced by the machine for each setting. They did not represent cut length proper, although cut length and chip length were closely related.

The plantations sampled at the two sites differed for spacing and age, but they were similar for what concerned field stocking and moisture content (Table 1). Even if the machine used for the test was the same and there was no significant difference between the two sites in terms of tree species, moisture content and field stocking, the data from the two different sites were kept separate because age and planting density were different, which could have

Table 1
Characteristics of the test sites.

Site		A	B
Case		1	2
Thesis	From chips...	...to microchips	...to billets
Longitude		20°58′S	15°46′S
Latitude		48°25′W	42°07′W
Location		Botucatu	Taiboeiras
State		SP	MG
Elevation	m als	840	750
Climate		Meso-thermal	Semi-arid
Annual rainfall	mm	1600	855
Mean temperature	C°	20	21
Species		EG × EU	EG × EU
Age	years	2.5	3
Rows		Single	Single
Spacing	m	3 × 1.5	4 × 0.5
Plant density	trees ha^{-1}	2222	5000
Stocking	t ha^{-1}	130.8	136.1
Moisture content	%	53.4	54.5
Yield (dry matter)	t^{-1} ha^{-1} yr^{-1}	24.4	20.6

Notes: SP = Sao Paulo; MG = Minas Gerais; EG = Eucalyptus grandis. EU = Eucalyptus urophylla.