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Research paper

Influence of chipping system on chipper performance and wood chip particle size obtained from peach prunings

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ABSTRACT

Many obstacles hamper the full exploitation of pruning residues for energy. Among these, harvesting is a crucial point in the development of a sustainable supply, because it greatly affects the quality of the fuel and profitability of production. In normal forestry operations, drum or disk chippers are the tools most frequently used for comminution. A new chipper has been designed which can collect different pruning residues produced under different field conditions and reduce them to a standard chip size (P45) suitable for boilers. Comminution is carried out by a double-auger on which different types of blades can be mounted. This paper compares outcomes in terms of machine performance and particle size distribution as a consequence of the use of a helical (HELK) or hoe-shaped (HSK) blade. The study was conducted on a peach plantation in Spain grown with the "open centre" or "vase" training method. Analysis of the main elements illustrated the difference between the types of blades. The HELK blade performed better in terms of coverage of area (0.52 ha h^{-1}) and material processed (1.06 t h^{-1}). Moreover the main fraction of the particle size (60% of the fraction $3.15 \leq P \leq 45$ mm) reached 79.2% with the HELK compared with the 67.9% with the HSK. However, from a mechanical standpoint, the HSK blade was found to perform better in terms of ease of maintenance, though the helical blade gave better results for the collection of peach pruning residues.

1. Introduction

Despite its huge potential as biomass, pruning residues can be deemed a neglected source, poorly utilized until now for bioenergy purposes [1]. There are many reasons for this, including variability in space, time and typology of pruning; the reluctance of farmers to introduce innovations; the lack of an efficient and cost-effective supply chain. Of course, exploitation will become an effective opportunity only when the biomass can be delivered to the end user at a reasonable price [2,3].

In the framework of a logistics chain, harvesting plays a pivotal role in producing high-grade fuel at an affordable cost. Following this course, a number of machine manufacturers have started to develop dedicated equipment for collecting pruning residue, using either shredding [2,4–7] or baling technology [8–11]. However, some problems remain due to the limited productivity of harvesting–processing machinery [2], and particle size distribution [12] so that use has been restricted mainly to olive and vineyard pruning residues.

The size of wood chips must comply with quality standards and will determine whether the fuel can be used in industrial or residential furnaces, as well as its economic value. As pointed out by several scholars [13,14] particles size distribution of wood chips is one of the most important parameters affecting storage and handling methodologies [15,16,17,18]. Moreover, meeting target particle size standards also means being able to influence machine productivity, diesel fuel consumption and bulk density [17]. Different comminution processes have been studied in considerable depth for wood energy crops [19–22] equipping the commercial machines with disc, drum or cone-screw chipper systems [22–24].

To overcome some of the technical barriers related to harvesting, on-site pre-treatment, quality and transport, the EuroPruning project (www.europruning.eu) studied the development of new improved logistics for pruning residues [25]. One of the most important outcomes of this activity was the design of a chipper to collect and process the largest number of pruning residue types, because harvesting is a key point affecting product quality, the development of a logistics chain and the economic sustainability of the chain [25]. The chipper developed under the aegis of the project could install alternative cutting systems using helical (HELK) or hoe-shaped (HSK) blades). The objective was to achieve a particle size distribution that would comply with the standard

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Fig. 1. Demonstration field test at Fraga (Spain).

requirements requested by stakeholders interviewed during the project (technical experts, boiler constructors, woodchip producers) [26]. In particular, because the chip particle size P45 was the one most requested by the stakeholders, all the tests focused on obtaining that size.

The purpose of this paper is to analyze both the performance of the machine and the compliance of the product with particle size requirements when HELK or the HSK blades were used to harvest and chip peach (*Prunus persica* (L.) Batsch) pruning residues and to determine which type of blade is more appropriate for the purpose.

2. Materials and methods

The tests were conducted in 2015 in an agricultural setting typically devoted to the cultivation of peach orchards. The field, almost flat, was located at Fraga (41° 53′ N, 0° 35′ E, 118 m a.s.l.), in the Aragonese region of Spain (Fig. 1). The shape of the field was irregular, with variable length of the rows.

The plantation was 3 years old with plants of the Paraguayo variety grown in a layout 5 × 3 m (666 plant ha^{-1}). The trees were trained in the open center or vase form, which has become the most popular training system for new orchards for its early bearing, easy mechanization and relatively low labour input and establishment costs. Trees trained in this way tend to remain relatively small, up to 3 m high, with an open centre, trained via repeated mechanical summer pruning in the first two years. Accurate winter pruning begins in the second year to control yield and maximize fruit quality. The pruning stage was managed manually by the farmer and co-workers, who stacked the cut biomass in the middle of the inter-row. In accordance with the vegetative growth of the peach tree, the residue showed a fairly irregular structure.

Before harvesting, five plots of 10 m^2 were randomly selected in the field within the windrows to evaluate the total biomass of the plot. Moreover, for each plot the following data were acquired on twenty observations: windrow height, windrow width, pruning diameter, and pruning length.

The prunings were harvested using a chipper made by ONG snc di Naldoni Domenico & C., mod. PC50 [1,27]. Briefly, the chipper is 1.75 m wide, 3.90 m long, and needs to be towed by a tractor with a minimum power of 45 kW (Fig. 2). The chipper is designed for windrowing, picking up, conveying, chipping and collecting the final product [27]. A gooseneck at 2.5 m height from the ground discharges the product with four alternative options: “big bag”, a breathable plastic bag (volume 1.5 m^3) held by the prototype, a machine tilting box (volume 3 m^3), a trailer towed by the machine; a tractor-trailer unit moving alongside the machine. The choice of the unloading method to use depends on farm logistics and facilities availability, and each unloading system has pros and cons that several authors have already described in other studies [6,43]. During the test, the big bag configuration was used.

Fig. 2. The PC50 chipper with the rear big-bag.

The pickup system of the machine collects the prunings from the ground by means of a roller 1.570 mm wide with 18 teeth. The height of the pickup system is adjustable from the control panel on the tractor. Afterwards, the feeding system conveys the prunings into the chipping device. It consists of an ascending central chain and two toothed counter-rotating rollers (CRR) below the chain. The chain has an array of retractable teeth (220 mm long) and dragging teeth (70 mm long), which direct the pruning residues into the chipping system.

The speed of the counter-rotating feed rollers (∅ = 250 mm L = 350 mm), as well as that of the windrowing and pick-up rollers can be adjusted by the machine's hydraulic system. The higher the speed of the rotating rollers, larger the size (length) of the chips.

During the trial in Fraga, the chipper was powered by a New Holland tractor mod. TF030F with a 56.7 kW engine. The speed of the CRR was set at 1.23 Hz.

The key element of the chipping system is an auger (rotating speed 13.3 Hz) powered by the PTO of the tractor with a ratio 1:2, so that each rotation of the PTO shaft causes two rotations of the auger. Two types of blades can be mounted on the auger, helical (HELK) and hoe-shaped (HSK) (Fig. 3).

The HELK blade set consists of two elements positioned consecutively in the direction of the auger rotation. Once installed, the two elements function like a single blade cutting left to right with a “scissor effect” created by the blade and counter-blade. This cuts the wood cleanly, minimizing the use of the tractor's power. The HSK blade set, instead, includes six separate elements that perform a “guillotine” cut, similar to the drum chipper of a forage harvester. HSK blades have been indicated by the constructor as hoe-shaped blades due to their curved shape. The HSK was designed to produce a cut “one blade at a time” which, considering the cutting angle, would reduce the power necessary to comminute the prunings. This would lead to a theoretical reduction of the power and fuel required.

Prototype performance (Table 1) was evaluated by measuring the working time according to ASABE standard methods [28]. Other references include the Commission Internationale de l’Organisation Scientifique du Travail en Agriculture (C.I.O.S.T.A.) and the Italian Society of Agricultural Engineering (A.I.I.A.) 3A R1. A reference to these methods can be found in Ref. [29].

The big bags with the comminuted product were weighed on the field using a dynamometer made by PCE Italia Srl (CS 1000N model - range of measurement 1000 kg and sensitivity 0.2 kg) connected to a tractor equipped with a fork. No repetitions were carried out during the biomass harvesting. The yield per each experimental field was calculated considering the comminuted product collected (big bag weights) over the experimental field area.

Fuel consumption was measured during the performance test starting with a full tank and refilling the tank at the end of the work. In this way the total fuel consumption (comprehensive of the forward progress, turns, time for maintenance on field with the motor running, and unloading) was assessed.

Furthermore, an additional test was performed to estimate fuel consumption for the actual work (productive work) that is, the work done in the chipping stage. The fuel consumption for the actual work separates it from consumption due to unproductive work (e.g. turns, stops, maintenance on the field). This test was carried out in separate rows. For each row the machine started with a full tank which was

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