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Energy performance of a new biomass harvester for recovery of orchard wood wastes as alternative to mulching

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ABSTRACT

Woody crops such as orchards and olive groves require annual pruning operations, which leave abundant residues on the ground. These must be removed both for disease control and for facilitating the following tending activities. The resulting biomass can be managed as a waste or a by-product, in both cases incurring in a cost for farmers. A harvester prototype for collecting and comminuting apple pruning residues was tested and compared to a traditional mulcher. In particular, the study aimed at: 1) quantifying productivity and costs of the two systems, 2) evaluating the possible influence of apple variety, tree age and machine type on the productivity per hectare, and 3) estimating and comparing the energy balance of the two working options.

The mulcher achieved a productivity of 0.41 ha SMH^{-1} against an average 0.27 ha SMH^{-1} of the harvester. Age of trees significantly influenced the productivity of both machines, with operative speed 42% higher in younger plantations. The cost of the operation added up to 137.5 € ha^{-1} and 275.2 € ha^{-1}, respectively for the mulcher and the harvester. But the latter also produced 0.77 t dry matter ha^{-1} of biomass fuel suitable for in-farm use, whose value can cover most or the total of harvest costs.

Accordingly, the energetic inputs amounted to 0.59 GJ ha^{-1} and 1.06 GJ ha^{-1} respectively for the mulcher and the harvester, while the recovered biomass provided an output of 6.30 GJ ha^{-1} for the latter system, resulting in a positive energy ratio (5:1).

1. Introduction

The replacement of fossil energy carriers by means of renewable energy sources (RES) [1] has become one of the key factors to mitigate greenhouse gas (GHG) emissions and to improve energy supply security, both by diversifying and reducing the dependency from imported fossil sources. According to the forecasts of the European Commission up to 2050 [2], biomass is expected to maintain its major role in RES consumption compared to the other sources [3]. The largest increase in bioenergy use is foreseen in industrial sectors such as electricity generation or in co-firing combined heat and power plants (CHP). Biomass availability is a critical issue for the bioenergy production sector. Competition between alternative uses of biomass, e.g. for energy [4] vs industrial purposes such as pulpwood or particle board production [5] is a major concern for bioenergy deployment. This competition has pushed solid biofuel producers to direct their interest towards new sources of biomass, as for example pruning residues from agricultural woody crops such as olive groves, vineyards, almond or apple orchards [6–9] since these feedstocks have been proved to be unsuitable for industrial uses such as particle board production [10,11].

Most woody crops require annual pruning operations, which lead to the production of a relevant amount of woody biomass per hectare [12]. In agriculture, the removal of residues is a preparatory operation to the following tending, and the material produced can be considered as a waste or a by-product [13]. In the first scenario, woody biomass is disposed of by on-site direct combustion or by mulching it in the field [14]. In both cases, the farmer incurs in a cost and in significant drawbacks: open combustion is generally

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forbidden by law, while leaving the comminuted residues on the ground may increase the risk of fungal diseases [15]. A further problem is related to the reduction of the nitrogen available for the crop due to the unfavorable C:N ratio of woody residues [16], requiring an increase in fertilization input in order to avoid fruit yield losses. As an alternative, biomass can be gathered and converted into appropriate form for being used as solid biofuel [17] which may partly cover the costs of tending operations. Due to the high logistic costs of this feedstock, typically scattered over the landscape in low density, it is generally unsuitable for large power and CHP plants [18], which often rely on imported biomass [19]. But orchard residual biomass can be successfully deployed in smaller residential heating systems which mainly use domestic biomass, fulfilling two goals of the European policies on renewable resources: decreasing of dependency on imported fossil energy carriers, and shortening the supply chains for a lower environmental and social impact.

For the treatment of woody residues, many models of harvesters are available on the market differing in size, power and price. Machines are mostly designed for collecting vineyard pruning residues [17,20], or for tapping with a single-pass olive grove stands [21]. Vineyard material is soft and sinewy, while olive one is tough, especially when the size of branches exceeds 4–5 cm in diameter. Since it is usually less expensive to collect residues in one step instead of two, the simultaneous comminution and collection of pruning must be considered preferable to baling [22,23]. Nowadays the endeavor of manufacturers is to design machines strong enough to treat wood material harder than vineyard residues, such as olive and apple ones. The final quality of the produced biomass is a further challenge, as the small sized boilers used for residential and farm heating are particularly demanding [24]. In general terms, fuel shall feature an adequate and homogeneous particle size distribution and low ash content. While the first aspect is mostly related to the comminuting device [25], the latter is linked to several factors such as the crops considered and the settings of the pick-up system, which should limit as much as possible the inclusion of soil [22]. Compared to forest biomass, orchard residues may also present traces of chemicals sprayed on the crops during cultivation (mostly insecticides and fungicides products), but these substances do not hinder the energy use, since have a negligible influence on the flue-gases quality during combustion [26].

Finally, considering the area covered, apple orchards can be regarded as a very important source of biomass, mostly still unused. According to the statistics collected by the Food and Agriculture Organization [27], apple-tree cultivation is present on all of the 5 continents. Asia leads the world's harvested area of apple with 3,643,720 ha (ha), followed by the EU with 552,622 ha and the Americas with 351,557 ha. In the EU, Italy is ranked third after Poland and Romania, with 55,274 ha concentrated mostly in the North, and producing a relevant amount of woody residues every year [13].

In order to achieve a real change in the common management of apple orchards, it is important to develop an effective supply chain. This shall be based on machines capable of comminuting the harder apple wood, providing high quality biomass if a local use is envisaged. In fact, the best way to motivate farmers to change their common practices is to propose an alternative system competitive with the mulching disposal both from the economic and environmental point of view.

The potential of harvesting apple residues for energy was verified by the Authors testing a harvester prototype designed for collecting and comminuting apple pruning residues. This work system, which includes a shuttle unit for transporting the biomass to the boiler located at the farm center, was compared with the common practice of leaving the biomass triturated onto the soil using a mulcher attachment, whose performance was also evaluated. Indeed, despite mulching is the most common option chosen by farmers to dispose of pruning residues, in literature there are no studies about costs and productivity of this activity. In particular, the study aimed at: 1) quantifying productivity and costs of the two systems, 2) evaluating the possible influence of apple variety, tree age and machine type on the productivity per hectare, and 3) estimating and comparing the energy balance of residues recovery vs mulching in the field.

2. Materials and methods

2.1. Study site

Tests were conducted on apple orchard stands in the Autonomous Province of Bozen-Bolzano (Italy) in the land-tenure of Laimburg Research Center for Agriculture and Forestry (46° 22′ 59″N, 11° 17′ 18″E) in March 2014. This Province hosts the largest continuous apple orchards area of Europe, spread on about 18,000 ha [28]. The surface interested by the trials amounted to 12.1 ha, located on flat terrain, formed by 5 fields containing 7 different varieties of apple. The characteristics of the fields are shown in Table 1. The studied orchards were spaced at a distance of about 3.2 m × 0.8 m and all of them were trained with the Slender Spindle system.

Trial area was measured with a navigational hand-held GPS device. Row spacing was measured with a tape, whereas the apple variety and the length of each row were acquired by the Laimburg maps. The latter figure was also randomly checked using a hip-chain. Time of establishment was retrieved from the owner's records in order to assess the potential effect of tree age on pruning-biomass production. Since generally the apple production cycle lasts for about 20 years, two different age classes were considered: above and below 10 years old respectively (Table 1).

2.2. Experimental design and data collection

Pruning recovery was carried out by the prototype CP CR140 made by Da Ros firm (Fig. 1), based on a small corn forager modified for comminuting and collecting agricultural woody residues. The machine was constituted by a trailer with an empty mass of 1570 kg and the following dimensions: 1.9 m wide, 4.2 m long, and 1.8 m

Table 1
Characteristics of the apple orchards under test and total number of tree rows treated by the harvester or the mulcher.

Field(no.)	Area(ha)	Treated rows(number)	Variety	Age class	Row spacing(m)	Yield(tFM ha-1)	m.c.(%)	Yield(tDM ha-1)	Harvest losses(%)
1	2.7	173	Braeburn/Granny Smith	1	3.2	1.76	49	0.90	41.9
2	3.1	100	Fuji/Gala/Golden	2	3.3	1.14	46	0.62	41.5
3	2.0	63	Gala/Golden	2	3.3	1.21	46	0.64	49.0
4	2.5	76	Kanzi/Granny Smith	1	3.2	0.99	48	0.52	48.8
5	1.8	62	Braeburn/Pink	2	3.2	2.11	45	1.17	26.3
Total	**12.1**	**474**		**Mean**	**3.2**	**1.44**	**46.7**	**0.77**	**41.5**

Notes: tFM = Tonnes of fresh matter; m.c. = Moisture content; tDM = Tonnes of dry matter; Age class: 1 < 10 years, 2 > 10 years.

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