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MECHANIZED MANAGEMENT OF PRUNING RESIDUES IN SWEET CHESTNUT ORCHARDS

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ABSTRACT

In Italy, *Dryocosmus kuriphilus* is a major insect pest of chestnut orchards causing gall formation and significant yield losses. The use of the parasitoid wasp *Torymus sinensis* is an effective biological control method that requires the appropriate management of the pruning residues, to preserve the woody galls in which *T. sinensis* adults overwinter. An innovative tractor-pulled combined mechanical shredder was tested for treating the residues, once the pruning operations are completed. The machine processes the residues in a single-step, picking-up the prunings from the orchard floor, shredding them to appropriate size, and collecting them into a rear container. The shredded residues may then be concentrated into a few piles for the long-term field storage, until next spring. The aim of the study was to evaluate the machinery's operative performance, the quality of the shredded biomass and the impact on gall integrity. In the field trials, the machinery effectively shredded the residues achieving an average operative capacity of 1.19 $ha \cdot h^{-1}$ and a work capacity of 1.79 $t \cdot h^{-1}$. Moisture content, apparent bulk density, and particle size distribution of the shredded biomass were determined. Over 95% of wood chips were included in the 3.15-45 mm size range, making them suitable for use in residential biomass furnaces. The calorific power of the chestnut residues was similar to that reported for other hardwood species (18-20 $MJ \cdot kg^{-1}$). Also, the mechanical action of the shredder preserved at least two thirds of the winter galls, safeguarding the parasitoid's life cycle.

Keywords: *Gall wasp, Castanea sativa, mechanical harvesting, biomass quality, gall integrity.*

INTRODUCTION

Biomasses are an important energy source, that could be further exploited to reduce fossil fuel dependency in energy production. This energy source can play an important role in increasing the share of renewable energy in the global energy mix. Biomass is a widely available energy resource at a local scale, therefore it would allow a delocalized energy production at limited costs and with simple power facilities (McKendry, 2002). At present, bioenergy (energy from organic matter), represents the fourth largest energy source (after coal, oil and natural gas) and, globally, bioenergy (including waste) accounted for 14% of the world's energy consumption in 2012 (WBA, 2014). Recent improvements in combustion technology have increased the efficiency of biomass use. These technological upgrades drastically reduce pollutant emissions and increase furnace combustion efficiency to more than 85%. Biomasses for energy use can be obtained from different sources, as the following: purposely grown woody plantations, forest maintenance operations, wood processing waste, and orchard pruning residues (FAO, 1997). However, pruning residues are rarely removed from the orchard for use in energy production. The main obstacles are the persistence of unresolved technical issues associated with the harvesting operations and, more importantly, the lack of a comprehensive information concerning the quantity and quality of the residual biomass obtainable from different orchards (Velázquez-Martí and Fernández-González, 2009). In this context, the recovery of residual biomass from sweet chestnut orchards would represent a significant contribution on the small scale of a local energy sector. In this paper, we present the results of a test conducted in a chestnut orchard in central Italy (Canepina -VT), in which the pruning residues were collected using the tractor-pulled mechanical shredder 'COMBY TR200', manufactured by FACMA L.t.d. (Italy). With a single pass of the machine along the orchard rows, the pruning residues are mechanically picked up from the orchard floor, fed into the chipping unit for shredding into chips, and loaded into the trailed container. The machine can move the collected biomass towards a desired site in the orchard, to concentrate the shredded wood into piles between the trees. The aim of the field trials was to evaluate the operative performance of the combined machine and to assess the quality of the biomass obtained in the process, in particular to determine if it complies with the quality standards established by the current legislation regarding solid biofuels (wood chips). In addition, the specific chestnut orchard is included in a specialized chestnut growing area in Central Italy, that has been infested by the gall wasp *Dryocosmus kuriphilus* Yasumatsu. In this area, the parasitoid *Torymus sinensis* Kamijo has been introduced for the biological control of the pest. The parasitoid feeds on the gall wasp larva developing in the green galls and later remains in the galls for the rest of the year (overwintering in the withered galls), emerging only the following spring. For this reason, the specific biological control protocol establishes that the pruned wood, carrying the galls, must be left in the orchard until the following spring, so that the parasitoid may complete its biological cycle. The management of the pruning residues in the orchards must be conducted accordingly. In our tests the machine was used to collect the pruning residues in the fields, after having completed the pruning operations in autumn. The aim was to evaluate if the mechanical shredding operations would safeguard a sufficient number of galls within the shredded residues. This method was proposed to collect the pruning residues to keep the field clean. The shredded material could be gathered into few piles, distributed in the orchard, to allow the dispersal of *T.*

sinensis from the intact galls, the following spring. This would favour the "biocontrol" action the parasitic wasp on the one hand, while on the other hand it would allow to keep the orchard floor clean for an efficient mechanization of the succeeding cultural operations.

MATERIALS AND METHODS

The filed test was carried out in a 50-year-old chestnut orchard in October. In this orchard, the pruning operations are managed over a three-year interval, with the major pruning work occurring every third winter. The test field had an irregular rectangular shape, extending over 1.26 ha, with irregular plant spacing. In total 67 plants were pruned in the field trial. During the pruning operations, the pruners leave the pruned material spread out, all over the ground. Once pruning is finished, the plant material lying on the ground is gathered into heterogeneous heaps, either placed along the edge of the field or between the trees along the inter-rows (Figure 1a).

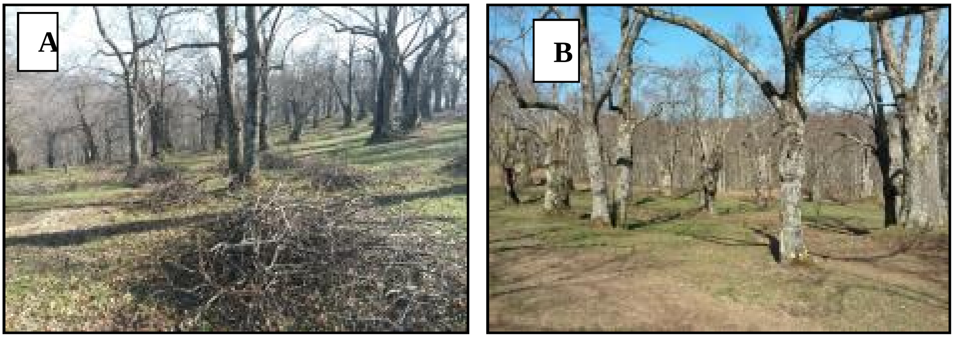

Figure 1. Chestnut prunings gathered in piles (a) and clean orchard floor (b).

In general, the residues are arranged in piles to facilitate the other cultural practices in the orchard, especially the harvesting operations in autumn. These piles can remain in the field for some time, but they must be removed before fruit drop to allow mechanical fruit harvesting. Commonly the residues are simply pushed to the edge of the field, using a tractor with a fork. In our tests, a method is proposed to collect the residues mechanically, using a combined single-pass machinery (pick-up, shredder, loader) to collect the residues and then move the shredded material to selected areas in the orchard, while the volume of the piles is greatly reduced by shredding. This method leaves the orchard clean and ready for harvest (Figure 1b).

The equipment used in the field tests was the COMBY TR 200, which is a high capacity combined machine for picking, shredding and loading the residues onto the integrated trailer. The tractor used in the tests was the TRIFRUT 85 HP, a custom made fully hydrostatic-drive tractor (Figure 2a). Both machines are manufactured by FACMA S.R.L. (Italy). The machinery is connected to the tractor via a drawbar, attached to the tractor’s rear hook. The main characteristics of the equipment (length, height, width, weight) are indicated in Table 1.

Table 1. Principal characteristics of the COMBY TR 200 shredder used in the field trials.

Parameter		Quantity
Length (mm)	*With drawbar*	4870
Length (mm)	*Without drawbar*	3720
Height (mm)		1800
Width (mm)		2230
Flail hammers (n.)		27
Weight (kg)		2200
Power take-off (Rpm)		540
Total volume of trailed container (m^3)		5

The machine assembly consists of the following 3 sections:

- a front pickup device provided with a horizontal rotor carrying metal tines to lift the prunings from the ground and convey them towards the following shredding rotor;
- a shredding unit having a horizontal rotor with 27 flail hammers, to shred branches up to 90 mm in diameter, and a metal grid placed behind the rotor in the opening into the rear container, to adjust the size of the shredded material;
- a rear container in which the shredded material is loaded, having a gross capacity of 5 m^3, that can be raised for unloading up to 2.5 m, via a pantograph lift (Figure 2b).

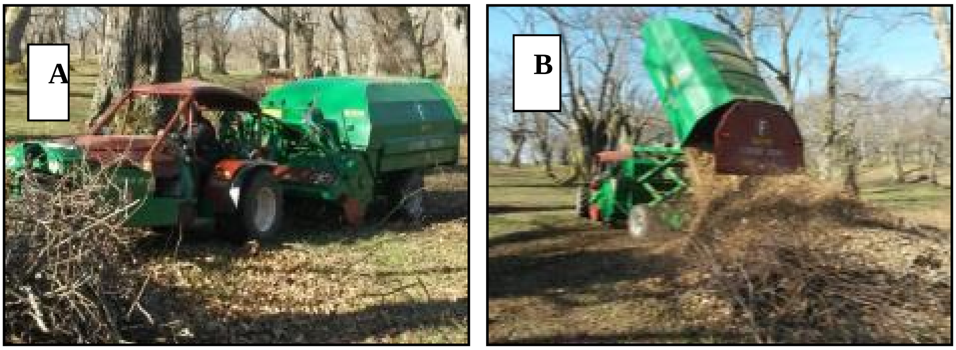

Figure 2. Machinery at work in the field (a), trailer unloading a pile (b).

After the mechanical treatment, the shredded biomass was analysed to determine its quality for use as a solid biofuel in energy production. To start, measurements were made on the height, width and length of the piles of shredded material left in the chestnut orchard, to estimate the overall volume of the piles. Then from each pile, 0.1 m^3 samples of the shredded material were weighed using a field digital dynamometer (D = 1 gr), in order to estimate the total amount of biomass obtainable per hectare in the chestnut orchard.

Samples of the biomass were collected for the assessment of moisture content, using the method described by Uni-En 14774-2: 2010. The shredded samples were weighed and dried in a muffle at 105 ± 2 °C for 24 hours. After removal from the muffle, they were weighed to determine the moisture loss. The apparent bulk density, i.e. the mass per unit of volume expressed in $kg \cdot m^{-3}$, was assessed according to the Uni-En 15103: 2010 standards, collecting the shredded material in a known volume cylinder (0.025 m^3) and then weighing with a field dynamometer. The granulometric distribution of the shredded material was analysed in conformity with UNI-EN 14961: 2010 standards. The dimensional analysis of the shredded material was used to determine the quality of the shredded material for its use as a solid biofuel, according to the technical characteristics required for the use of solid biomass in the furnace. The ash content of the samples was verified in compliance with the UNI-EN 14775: 2010 standard, which applies to all kinds of solid biofuels. The ash content determines the quality of biomass for use in energy conversion. A high ash content reduces the calorific value of the biomass and the combustion performance in the furnace. The calorific value of the pruning residues was measured according to the UNI-EN 14918: 2010 method, to assess the energy value of the biomass. The energy yield of the biomass depends on the calorific value of the material. The calorific value also determines the energy density of the biomass, with obvious implications on the transportation and supply logistics of residues. The assessment of the mechanical action on the integrity of the galls in the pruning residues was determined by taking samples of pruning wood, before and after the mechanical processing and shredding. The percentage of intact galls remaining in the shredded biomass, accumulated in the piles, was calculated by counting the number of intact galls in samples of pruned wood and shredded wood (same weight samples). The operative performance of the machinery in the field work was established according to the recommendations of the Italian Association of Genio Rurale (A.I.G.R.) III[a] R.1 (Manfredi, 1971), which is based on the official methodology of the International Commission of the Organization of the Scientifique du Travail en Agriculture (C.I.O.S.T.A.).

RESULTS AND DISCUSSION

The total amount of biomass obtained from the pruning operations conducted in the chestnut orchard used in the field trials was approximately 1.90 t of pruning residues, which corresponds to a unitary yield of 1.51 $t \cdot ha^{-1}$. The bulk density and the moisture content of the shredded biomass are shown in Table 2.

Table 2. Characteristics of the shredded material.

Parameter	Quantity
Total area of the chestnut orchard (ha)	1.26
Bulk density at field moisture content ($kg \cdot m^{-3}$)	185.9
Fresh shredded production (t)	1.90
Fresh shredded production per hectare ($t \cdot ha^{-1}$)	1.51
Moisture content of the shredded residue (%)	52.4
Yield in dry matter ($t \cdot ha^{-1}$)	0.72

Results of the granulometric analysis of the mechanically shredded material showed that more than 70% of the chips are included in particle size classes ranging from 6 to 25 mm. Therefore, the shredded biomass can be considered suitable for use in energy plants, according to the parameters indicated in the UNI-EN 14961-1: 2010 regulation (Febbi *et al*., 2013; Acampora *et al*., 2013). Moreover, more than 95% of wood chips were included in the 3.15-45 mm size range, making them suitable for use in residential biomass furnaces.
The assessment of gall integrity was another important objective of this work. The results of analysis were positive and supported the idea behind the experimental work. Analysis of the samples taken before the shredding operations showed that the galls accounted for about 12% by weight of the entire sample. Later, the analysis of samples of shredded biomass, randomly picked from the different piles, showed that 8% by weight of the material was represented by intact galls. This percentage (8% by weight) corresponded to about two thirds of the galls initially present in the pruned residues (before shredding).
The calorific value of the shredded biomass was measured on the shredded wood and on the galls alone. the calorific value of the biomass to be used for energy production. The calorific values were 18.33 and 18.08 $MJ \cdot kg^{-1}$, for the wood and the galls, respectively. These calorific values are similar to the values relating to other hardwood species, which are normally ranging from 18 to 19 $MJ \cdot kg^{-1}$.
The ash content of the woody portions of the prunings was 6.26% (± 0.07%), while that of the galls was 6.09% (± 0.029%). The value appears to be slightly above the average, but it is quite plausible considering that the wood/bark ratio for chestnut biomass is generally lower than that of other tree species. Also, the wood taken from young twigs and young branches is typically characterized by a higher percentage of ashes than that found in the wood of the trunk and of the larger tree branches. This is also explained by the fact that the wood/bark ratio characterizing thinner diameter shoots is lower than that of the older and thicker shoots.
The work time for the field operations was considered satisfactory, although some unproductive time was recorded, especially in the initial phases of the pile shredding, which required the frequent repositioning of the machine, mainly due to the excessive height of some heaps. The field operations were made easier by the excellent manoeuvrability of the special three-wheeled hydrostatic-drive tractor used in the tests, also for the presence of a wide spacing in the chestnut orchard, so that the driver could reduce the number of turns between the chestnuts.
The operative performance of the machinery is indicated in the different time categories in Table 3. The work capacity achieved by the machinery in the chestnut orchard is similar to the performance achieved by similar machines in the harvesting of orchard prunings and in other mechanized cultural practises (Colorio *et al* 2009; Spinelli *et al* 2012; Acampora *et al* 2013).

Table 3. Work time analysis and machinery operative performance

Parameter	Quantity
Actual working time (%)	60.94
Time to turn (%)	21.52
Discharge time (%)	14.42
Inevitable dead times (%)	3.12
Working time per surface unit ($h \cdot ha^{-1}$)	0.84
Work capacity ($ha \cdot h^{-1}$)	1.19
Productivity ($t \cdot h^{-1}$)	1.79

CONCLUSION

Chestnut orchards can provide significant amounts of good quality wood for energy purposes, on an annual basis. The biomass obtained from pruning is characterized by high values in apparent bulk density, but the ash content is slightly higher than the average values measured for wood biomass, due to the low wood/bark ratio and to the high moisture content.

The machine tested in this study was suitable for efficiently processing the pruned material by shredding and concentrating the biomass, unloading in selected areas of the orchard. Actual working time (60.94%) and working capacity (1.19 $ha \cdot h^{-1}$) may not appear high, but the data is related to the irregular distribution of plants in the experimental site and to the high amount of biomass to be shredded. The presence of more than 70% wood chips between 6 and 25 mm, makes this shredded material suitable for use as biofuel since it complies with requirements of UNI-EN 14961-1: 2010. For the purpose of the biological control of the gall wasp, the number of intact galls remaining after the mechanical shredding operations was assessed. In our tests, about two-thirds of the initial number of galls present in the pruned material remain intact after shredding. Therefore, the mechanical solution proposed safeguards the presence of *Torymus sinensis* in compliance with the provisions indicated by the Regional Phytosanitary Service of Lazio Region (Italy), that prescribe that the pruning residues must be left in the field and processed only from the end of June, because by that time the adults of *Torymus sinensis* will have already left the galls, to start a new cycle, so that biological control is safeguarded.

Through some modifications to be implemented on the rotor, a higher percentage of intact galls may be obtained. Also we estimate that by decreasing the number of hammers on the rotor, the size of the wood chips could be increased, therefore better preserving the integrity of the galls, still achieving the appropriate dimensional characteristics set by the biofuels standards.

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REFERENCES

Acampora A., Croce S., Gallo P., Assirelli A., Pari L. (2013). Comby Tr200 alla prova su residui di potatura del nocciolo. Supplemento Biomasse a L'informatore Agrario n. 43/2013.

ASAE D497.4. (2003) Agricultural machinery management. In ASAE STANDARDS pp. 373-380. St. Joseph, MI, USA: American Society of Agricultural and Biological Engineers.

ASAE EP496.2. (2003) Agricultural machinery management. In ASAE STANDARDS pp. 367-372. St. Joseph, MI, USA: American Society of Agricultural and Biological Engineers.

Biondi, P. (1999) Meccanica agraria: le macchine agricole. UTET, Torino pp. 547-561.

Colorio G., Tomasone R., Pagano M., Cedrola C., Sperandio G. (2009) Raccolta di potatura di nocciolo con Comby Tr160. Supplemento Biomasse a L'informatore Agrario n. 33.

FAO (1997) The role of wood energy in Europe and OECD, WETT e wood energy today for tomorrow. Rome: FOPW, Forestry Department;

Febbi P., Santangelo E., Assirelli A., Pari L. (2013) La valutazione dimensionale del cippato. Ricerca di un metodo basato sull'analisi d'immagine. Supplemento al numero 192 di Sherwood - Foreste ed Alberi Oggi (anno19 - n.3, Aprile 2013).

ISTAT (2016) Istituto nazionale di Statistica. Available from: http://www.istat.it/it/censimento-agricoltura/agricoltura-2010.

Manfredi E. (1971) Raccomandazione A.I.G.R., IIIa sezione "denominazione, simbolo e unità di misura delle grandezze fondamentali relative all'impiego delle macchine in agricoltura, con particolare riguardo alle colture erbacee". Rivista di ingegneria agraria, anno secondo, 4, 258-260.

McKendry P. (2002) Energy production from biomass (part 1): Overview of biomass, Bioresource Technology. 83: 37-46.

Spinelli R., Cantini C., Lombardini C., Magagnotti N., Nati C., Picchi G., Sani G. (2012) Prove e confronto tra cantieri per il recupero delle potature a fini energetici. Rapporto Coldiretti, novembre 2012.

Velázquez-Martí B, Fernández-González E. (2009) Analysis of the process of biomass harvesting with collecting chippers fed by pick up headers in plantations of olive trees. Biosystem Engeenering; 104: 184 -190.

WBA (2014). Global Bioenergy Statistics 2014. World Bioenergy Association Report.
(https://worldbioenergy.org/uploads/WBA%20Global%20Bioenergy%20Statistics%202014.pdf)