Recovery of pruning waste for energy use: agronomic, economic and ecological aspects

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Introduction

Grapevine is a typical Mediterranean crop, although it is now common also in Central Europe and in all other continents – wherever the climate offers favourable conditions. In Italy, vine crop also assumes a cultural, historic and aesthetic value, which characterizes specific regions. Overall, the surface of Italian vineyards amounts to almost 2 million hectares [1] and produces considerable wealth. Vine requires much tending, including an annual pruning, which generates the equivalent of at least 1 oven dry ton (odt) of residual biomass per hectare [2]. In Italy, the yearly amount of residues derived from the pruning of olive groves, vineyards and other orchards has been estimated to 2.85 million tons, net of the amounts already recovered for traditional forms of utilization [3]. That explains why pruning waste generally play an important role in any analysis of biomass availability conducted in these regions [4].

The management of pruning residues has generally represented a disposal problem, rather than an opportunity for additional revenue. Pruning wood is usually left in the vineyard after cutting since the practice of burning in the field is forbidden, due to environmental problems caused by short-term concentrations of smoke, dust and odours. When planting a new vineyard, old plants are usually burned in domestic stoves but roots must be conferred to landfill site. Pruning residue is either mulched or piled and burned, at a cost estimated to about 75 € ha^{-1}. The rapid development of bioenergy has been generating a growing demand for energy biomass [5] mainly deriving from forestry and wood processing industry [6, 7] even if agriculture is considered one of the most promising sectors. Agro-energy as producer of valid substitute of fossil fuels can become an integrative relevant economic entry for the farmers, thus providing a potential outlet for pruning residues too [8]. However, such opportunity can be seized only if the biomass is delivered to the end user within set price limits. Hence, the interest in developing cost-effective technologies for the collection, processing and delivery of pruning waste.

Since a few years, a number of machine manufacturers have been offering dedicated implements for collecting pruning residue. Today, the collection technologies can be divided according to the processing technique between comminuting technologies and bundling technologies. Machines designed to pick, comminute and collect the residue derive from conventional mulches, equipped with a storage bin or with a blower, the latter designed to direct the flow of shredded residue to an accompanying trailer. As an alternative, one can resort to balers that pick up the residue, compact into units of regular size and shape, tie the bale and drop it on the ground for later collection. Balers derive from the adaptation of conventional straw balers, or can be designed on purpose for baling pruning residue. Baling represents an extra step in the residue-to-fuel chain, but it offers the benefit of easier storage. On the contrary, fresh chips tend to decay very quickly. Regardless of technology, such implements are designed for being towed or carried by farm tractors in the 50-70 kW class, and are relatively cheap, their acquisition needing an initial investment in the range of 10-15.000 €.

In the present paper the main results of a feasibility study focused on the bio-energetic potential of the vine shoots, the economic advantages of their use, and the possible dispersion of Plant Protection Products (PPP) in the environment from the surface of the shoots themselves due to the different methodology of pruning are exposed [9].

A chemical analysis of the shoots' residual has been carried out with regard to the method of growing and the collecting period. The quality of the combustion fumes have been studied as well, with the first aim of verifying the respect of the law limits in force.

This study represents a first example of an integrated approach where economic and environmental issues are compared with agronomic aspects. In fact a protocol for the evaluation in a medium-time period of the organic matter balance in the soil has been defined, to assess the effects of the substitution of wood residues with other practices aimed at replacing the organic matter (as the old technique of growing covercrops in the Autumn-Spring season).

MATERIALS AND METHODS

Harvesting

The first goal of the study was to determine the performance of different pruning residue harvesters designed for use in vineyards, so as to build a simple model for estimating harvesting productivity and cost under varying work and economic conditions. This model can assist prospective users when checking the profitability of an operation, or when assessing the competitiveness of alternative options. The model should return harvesting costs, as a function of residues density, row length, extraction distance, depreciation schedules etc. In addition, the model may assist with the preparation of reliable biomass production forecasts and machine schedules.

The Authors selected four commercial machines, representative of the main design concepts implemented into commercial pruning residue harvesters. The four machines were respectively: 1) a square baler; 2) a round baler; 3) a comminuter with drop-down re-usable containers (big bags); 4) a comminuter with built-in dumping bin. All machines were light enough for towing or carrying behind compact vineyard tractors. Work in a vineyard is especially constrained by the tight spacing of the crop: vineyards established in espalier (rows) offer a very limited interrow spacing, which prevents the access of any machine wider than 2-2.3 m; on the other hand, plantations designed as a bower will be damaged by machinery taller than 2-2.5 m. The machines on trial were made available by the manufacturers, and are described in Table 1.

Table 1. Characteristics of the machine systems on trial

System	n.	**1**	**2**	**3**	**4**
Implement type		Baler	Baler	Comminuter	Comminuter
Bale shape		Square	Round	-	-
Bale size	cm	40 x 30 x 60	40 x 60	-	-
Container type		-	-	Big bag	Dump bin
Container capacity	m^3	-	-	0.8	1.7
Implement weight	kg	650	498	1,075	1,180
Implement connection		Towed	Carried	Carried	Carried
Implement price*	€	9,900	12,000	9,500	13,450
Tractor power	kW	40	40	77	77
Crew	n°	1	1	1	1

*Excluding Value Added Tax (VAT)

The study was designed to evaluate machine productivity and to identify the most significant variables affecting it. The data collection procedure consisted of a set of detailed time-motion studies conducted at the cycle level, where the harvesting of a full row was considered as a complete cycle. In general, detailed time studies are more discriminating than shift-level studies and can detect smaller differences between treatments [10].

Cycle times for each machine were defined and split into time elements [11] considered to be typical of the functional process analyzed: this was done with the intent of isolating those parts of a routine that are dependent on one or more external factors in order to enhance the accuracy of the productivity models [12]. All time elements and the related time-motion data were recorded with Husky Hunter® hand-held field computers running Siwork3® time-study software [13].

Output was determined by measuring the mass of all bales and all chip containers produced during the tests. The weight of bales was determined with a portable scale, and the mass of chips was obtained by taking all loads to a certified weighbridge. Moisture content was determined on 10 samples per unit: these were collected randomly, put in sealed bags and then weighed fresh and after drying for 48 hours at a temperature of 103° C in a ventilated oven, according to the European standard CEN/TS 14774-2.

Agronomic and environmental quality of the biomass

The yearly production of grapevine wood depends on many factors as the yield (grape), the growing system adopted, the year considered, the variety (Merlot, Cabernet, Chardonnay etc...) and the type of soil. This information is clearly expressed by the ratio between the amount of grape produced every year and the amount of pruning wood (Ravaz index).

Vine fields are often submitted to different types of PPPs, those can leave a discreet amount of residuals on the vine-shoots and on the grapes as well. In this work different vine-shoots samples were collected during Autumn 2007 (1°sampling just cut (from the plant) and Spring 2008 (2°sampling from the plant and the wood left on the ground) from fields under conventional and organic management and two growing systems ("pergola" bower and espalier). The complete list of the samplings is reported in Table 2.

Table 2. Description of the samplings

Farm	Variety	Type of growing	Management	ID Sample		
				I° Plant	II° Plant	II° Ground
A	cabernet sauv.	espalier	Organic	1		
A	cabernet sauv.	pergola	Organic	2		
B	pinot gris	espalier	Conventional	3		4
B	pinot gris	pergola	Conventional	5	6	7
C	pinot gris	espalier	Conventional	8		9
C	pinot gris	pergola	Conventional	10	11	12
C	merlot	pergola	Conventional	13	14	15
D	teroldego	pergola	Conventional	16		
D	teroldego	pergola	Test	17		
E	teroldego	pergola	Conventional	18		
E	teroldego	pergola	Test	19		
F	rebo	espalier	Organic	20	21	22
G	pinot gris	pergola	Conventional	23	24	25
G	merlot	espalier	Conventional	26		

Essentially standard pesticides such as organic-phosphates, sulphur, copper, captan, dicarboxin, cyanamide, pirimidine, triazol, furacon, alchilen bis, piretroids, kresomix-methyl, etofenprox, dimethomorph, and diflubenzuron were investigated. The copper, even classified as heavy metal, is widely used in organic and conventional agriculture as hydroxide, oxychloride, and sulphates.

Combustion tests

The pruning waste necessary to carry on the tests of combustion (100 m^3) was collected and stored at the open for about 50 days in a pile (length 20 m, width 5 m, height 1.8 m), covered with geo-textile (200 g m^{-2}) to limit the rain passage through the mass, to favour the dehydration and thus to avoid the starting of degradation processes. Samples were collected at fixed intervals to detect the moisture reduction during time as well as the possible presence of pesticides.

Table 3. Main characteristics of the 2 boilers used for the combustion tests.

	Plant 1 Industrial boiler	Plant 2 Domestic boiler
Thermal power (installed)	8 MW (4 + 4)	55 kW
Grate	mobile	mobile
Feeding	pusher	auger
Smoke treatment	ESP	--
Management of burning parameters	automatic (fixed % O_2)	manual

Two kind of wood chip boilers have been used for the combustion tests: an industrial boiler with ESP (electrostatic precipitator) and a small scale boiler for domestic use (Table 3). One combustion test was carried out in the big boiler, while two tests were possible in the small scale one.

RESULTS AND DISCUSSION

Harvesting

Overall, 10 ha were harvested, producing 21 tonnes of fresh biomass, which corresponds to an average yield of 2.1 t ha^{-1} (1.2 odt ha^{-1}). Total study time amounted to 40 hours, of which 15 were taken by harvesting and processing and 25 by forwarding the product to a central collection point, 3 km from the field (one-way distance). Main results are reported in Table 4.

Using a spreadsheet model, it was possible to explore the sensitivity of the four systems to annual utilization, which is shown in Figure 1.

The calculation was conducted for the average row length, moving distance and field size of 200 m, 3 km and 2 ha respectively. It was assumed that the total utilization of the farm tractor base never went below 800 hours year^{-1}, since the tractor could be used for other tasks when the pruning season was over. Annual utilization figures were converted from time (hour) to surface area (ha) using the productivities (ha hour^{-1}) reported in Table 4. The graph shows that harvesting-forwarding cost is drastically reduced when the residues collection implement can be used annually on at least 150-200 ha. Beyond that, cost will not drop much as a result of increased utilization, and 200 ha year^{-1} can be taken as a good target utilization level for prospective users. System 4 offers the highest overall efficiency, and its results have been used for all further elaborations.

Table 4. Study summary: surface area, time consumption, productivity and cost (excluding forwarding)

System	n	**1**	**2**	**3**	**4**
Surface area	hectares	2.14	3.29	1.79	3.00
Plantation		Espalier	Espalier	Espalier	Espalier
Interrow distance	m	3.1	3.1	3.1	3.1
Residue mass	t*	4.3	7.5	3.6	5.8
Residue yield	t ha^{-1}	2.0	2.3	2.0	1.9
Net Work time	hours	2.8	3.5	2.6	3.0
Delays	hours	0.9	0.9	0.5	0.9
Total Work time	hours	3.7	4.4	3.1	3.8
Delays	%	25.4	20.2	14.7	23.2
Productivity	t hour^{-1}	**1.15**	**1.68**	**1.18**	**1.50**
Productivity	ha hour^{-1}	0.58	0.74	0.58	0.78
Units**	n°	277	243	22	19
Unit weight	Kg	15	31	164	303
Density	Kg m^{-3}	215	414	208	203
Hourly cost	€ hour^{-1}	32	33	38	40
Unit cost	€ t^{-1}	27.9	19.7	32.3	26.7

* fresh weight of the residue, for a measured moisture content of 44 % (wet base)

** Units are: square bales, round bales, big bags and bins respectively for systems 1, 2, 3, 4

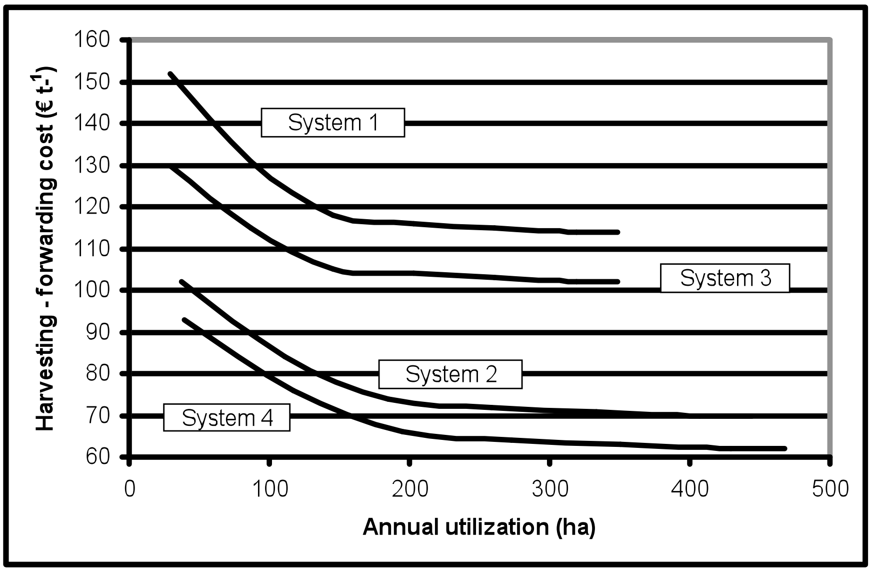

Figure 1. Relationship between annual utilization and harvesting-forwarding costs

Agronomic and environmental quality of biomass

Pruning wood yearly produced in the Trentino vineyards ranges between 1.5 up to 2.5 tons/ha [14]. The water content highly depends on the time of collection: the highest values were registered soon after cutting (45-48%); 40% of moisture was detected after 3-4 months in field. The storage in pile covered with geo-textile permitted the reduction of 10% in the water content and very limited degradation process as the main consequence. The ash content is about 3-4%, a relatively high value with respect to the forestry wood chip (0.2-0.5 %).

With respect to the environmental quality the analyses showed the presence of pesticide residuals both at the cutting and after the remaining on the ground (Table 5). Only sulphur and copper are present in the samples from organic farming, while products against the oidium, grape mildew, and botrytis were found in those collected in conventional vineyards.

Table 5. Changing in the value of the residuals according to the collection
(in the plant and in the ground of the same vineyard)

	Farm	Variety	Growing	Sulfur	Copper	Boscalid	Dimetomorf
From the plant	B	Pinot gris	Pergola	0.9	8.5	0.01	0.03
	C	Pinot gris	Pergola	0.15	12.4	0.03	0.03
	C	Merlot	Pergola		13.4	0.01	0.02
	F	Rebo	Espalier	0.61	7.1		
	G	Pinot gris	Pergola	0.24	11.6		
Average				**0.48**	**10.6**	**0.017**	**0.027**
From the ground	B	Pinot gris	Pergola	0	7.6	0	0
	C	Pinot gris	Pergola	0	7.3	0.02	0.02
	C	Merlot	Pergola		17.5	0	0.01
	F	Rebo	Espalier	0	17.9	0.01*	
	G	Pinot gris	Pergola	0.15	6.2		
Average				**0.04**	**11.3**	**0.015**	**0.015**

* drift

Anyway it can be said that the presence of antibotrytis chemicals have just been found in the Pinot Gris' samples, as this vine variety requires that specific type of treatment. A lesser amount of residuals were found during the second survey with the disappearing of folpet, pirimetanil, azoxistrobin, piroclorstrobin and penconazole. The level of sulfur, ciprodinil, fluodioxonil, mepanipirim, boscalid e dimetomorf is in the order of hundredth of ppm, so very low. The level of sulfur, ciprodinil, fluodioxonil, mepanipirim, boscalid e dimetomorf is in the order of hundredth of ppm, so very low.

A bigger amount of residuals is anyway present in the "pergola" bower than in the espalier, but the differences are not significative. Among all the PPPs only the sulphur seems to decrease more quickly on the vine-shoots left on the ground (Table 5).

3. Combustion tests

All the data reported in the Tables 6 and 7 are the mean values of three replicates (20'/sample) and refer to 11% O_2 concentration. With respect to the combustion in the big boiler (Table 6), all the parameters are within the national limits stated for the combustion of biomass. The comparison with wood chip showed a higher content of dust in the agricultural waste, which remains below the limit (1/5 of the limit). The same consideration is for NO_2, higher in the pruning waste but equal to a half of the law limit. The small size of pruning wood turned out in a limited O_2 diffusion through the biomass and consequently a high CO fluctuations (between 5-263 mg Nm^{-3}).

Table 6. Analytical quality (mg Nm^{-3}) of smoke after combustion in the big boiler. (nd=not detected)

	Combustion		National limits D.lgs 152/06
	Pruning waste	Chipped wood	> 6 MW
Total dust	5.8	0.6	30
Total Org. Carbon	< 1	nd	30
CO	148.5	13.7	250
NO_2	208.2	168.3	400
SO_2	8.1	11.02	200

Table 7. Analytical quality (mg Nm^{-3}) of smoke after combustion in the small boiler.

	Test 1	Test 2	National limits D.lgs 152/06		
Power boiler	55 kW		35-150 kW	150 kW – 3 MW	> 6 MW
Total dust	145.2	169	200	100	30
Total Org. Carbon	3.6	< 1	-	-	30
CO	674.9	418.1	-	350	250
NO_2	233.7	345.3	-	500	400
SO_2	5.2	< 1	-	200	200

The same procedure of sampling and analysis was adopted for the small scale trial; the results are exposed in Table 7. The law distinguish three class of boilers (and limits) on the basis of the power size: in this case (55 kW) only total dust has to be controlled even if TOC, CO, NO_2 and SO_2 were determined. CO seems to be the most problematic parameter due to its relationship with the oxygenation of the mass during the burning. The 2nd trial permitted to improve the combustion conditions and to reduce the CO content. In any case it remains higher than the limit for the medium size boiler.

CONCLUSION

On the economics side, the avoided cost of residues management plays a crucial role. Disposing of the pruning wood entails a cost of about 25 € t^{-1} (50 € ha^{-1} for 2 t ha^{-1}): if this cost is subtracted from the total harvesting-forwarding cost, processed pruning waste could be obtained at the farm gate at a cost of about 30-40 € t^{-1}, under favourable conditions (i.e. short forwarding distance, cheapest recovery system). This cost compares favourable with the price currently offered for energy biomass in Italy, which can reach 50-55 € t^{-1}, delivered to the plant (first semester 2009). However, it is unlikely that farmers offer the same disposal fee once they realize that the residues is being sold, and therefore the commercial viability of recovering vineyard pruning waste depends on a number of conditions, including the eventual redistribution of the savings accrued on residues management.

As far as concerns the environmental aspects the analyses on pruning wood sampled in different vineyards on the provincial territory confirmed the presence of pesticide residues and heavy metals on the wood, even if in a very low content. The biological management of the vineyard turns into reduced concentration of pollutants but a drift effect was noted too.

From the technical point of view the feeding of wood chip boilers with pruning waste did not show any problem; the mixture between forestry wood chip and pruning waste could increase the fluency of the biomass.

The emissions from the combustion in industrial boiler equipped with ESP are widely within the law limits, as well as those obtained from the small scale boiler even if in this case the total dust is the only stated parameter. Despite the respect of the law, the absence of the ESP suggests to address pruning waste to a centralized biomass heating plant, at least up to the introduction of ESP systems on the domestic boilers, which is planned in the next future by the local environmental office.
Finally some considerations on the energy balance are possible: 20 liters of gas oil are needed to collect 2.5 tons of pruning waste. The energy content of wood waste (40% moisture) is equal to 281 kWh, while 1 liter gas oil produces 11 kWh of energy. The final balance is 32:1, so extremely positive for the recovery of pruning wood for energy use.

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