ANALYSIS OF A TRANSFORMATION PROCESS OF VINEYARD PRUNING INTO CHIPS BY A MICRO PLANT

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ABSTRACT: The Italian wine making covers 18.4% of the global production representing the world's largest production. The cultivation of the vineyards foresees the winter pruning that's necessary for the preparation to the next year's production. The annual pruned biomass (1-3 t ha^{-1}) is considered a waste and is removed by shredding or burning. The possibility of take advantage of the pruned material obtaining biomass for heating processes represents an alternative that can turns a waste into a further product of the vineyard. The easiest size to manage the pruned biomass for energy purposes is wood chips; nevertheless it requires specific equipment and has to face the problem of residual humidity. Moreover, the transport to a processing center represents an unsustainable extra cost. A viable solution could be represented by harvesting the pruned biomass in small diameter (450 mm) round-bales, let them dry naturally and then chipping the whole round-bales with a purpose-designed mill, powered by the tractor power take-off (PTO) itself. The present research evaluates the feasibility of such solution and presents a study case carried out in a typical North-West Italy production area.
Keywords: mechanization, agricultural residues, biomass treatment plants, renewable energy production.

1 INTRODUCTION

The continuous increasing of the fossil fuel cost and the relevant problems related to pollution, has pushed on long debates, arguments and lines of research to find energy alternatives that respect the ecosystem.

Several studies have been carried out on the energy use of pruning residues [1, 2, 3, 4, 5, 6, 7], but, at present, activities using residues that have forestry origin are prevailing. Branches left on the ground, as a result of pruning in the vineyard, are a residual biomass that is often conceived by the farmer only as a burden to be disposed.

However, the amount of wooden residues obtained from winter pruning is not negligible and it can be considered interesting for energy purposes. The production potential is significant and, at present, it has been primarily exploited as soil conditioner as it gets, from pruning, a possibility of recovery by about 25% of the needs in organic matter. Residues of pruning estimated on average values of 2.3-2.4 t/ha, can provide up to 0.4-0.8 t/ha of humus together with non-negligible quantities of minerals (10-30% of annual requirements in macronutrients and 30-50% in micronutrients). In some cases, the branches are chopped in the vineyard for their return as organic matter and minerals to the soil with the contraindication, however, related to the risk of grapevine diseases. In other cases, the farmer opts for burning the residues in the field, which is still expensive and without an economic return over that in contrast with some regional regulations on air pollution. The possibility of recovery for energy purposes depends on economic conditions and also on the slope and size of the plots, from the distance between the rows and from canopy management system as well as by logistical issues related to the mechanization of harvesting and location of the site of use. The recovery of residues of pruning can be achieved with different methods [8] and equipment, whose development is derived from the modification of agricultural machinery already intended for other operations, but in principle they are made to collect pruning arranged in swath, treat (chopping or baling) and handle them in an appropriate manner [9]. The baling in the field that can be obtained both through the square and round baler allows packing the agricultural pruning into homogeneous units and adapting to farm needs; moreover, this system is not prone to fermentation risk as in direct chopping operations being possible to chop the baled pruning after a period of natural drying. Moreover, the proposed system doesn't need any supplementary operation of – and device for – mixing and handling of the drying material. One of the issues being studied is the rationalization of the work chains based on balers powered by narrow-track tractors, reduced mass and low-power consumption that can reduce the apparent mass of wood cut and to create regular packages (squared or cylindrical) easy to handle and also used as energy source in commercial heaters. However, one of the critical aspects related to the use of balers is now represented by the need to collect it later the bales produced with a sensitive increasing of the total work time.

The purpose of this study was to test the working capacity of a micro-plan composed by a round baler - provided with an innovative system of accumulation and displacement of formed bales – and a simplified shredder to obtain dried wooden chips.

The baler-accumulator was designed to clean from pruning the inter-row space up to 240 m in length in a single pass. The bales of pruned material are firstly deposed along the headlands and then stocked under a covered building at the farm, for natural drying. Any other device or operation is needed for mixing and handling. Finally, the dried bales are shredded by a simplified mill in order to obtain wood chips ready to be used in heaters.

With this aim, CAEB International (Petosino di Sorisole, Bergamo, Italy) designed and manufactured a novel micro-plant for pruning harvesting, shredding bales and produce pellet intended to be used in vineyards and orchards farms in order to reduce the overall economy of pruning management and energy production. Set up trials were performed in a typical Italian wine production area during the winter pruning season followed by a period of natural drying before the chipping and storage of the material for successive energy use as wood-chips or wood-pellet.

2 MATERIAL AND METHODS

2.1 Prototype plan design and built up

The prototype plan was composed of an harvest machine and a shredder. The harvest machine (Quickpower, CAEB International, Petosino di Sorisole, Italy) is a round baler associable with an accumulator (Fig. 1); this last, is capable of containing 7 bales consequently, this machines combination has a range of 120-240 meters considering 8 bales (7 in the accumulator and 1 in the baler) and 20-30 meters of theoretical average distance for a single bale before discharging into the head. The bale chamber - 450 mm in diameter - is provided with special lateral disks to reduce friction and power requirements. The measured minimum power required by the system was 15.0 kW allowing combining it during tests with a 4 WD narrow-track tractor 36.7 kW nominal power. The speed of the power take off (PTO) was set to operate at values ranging between 400 and 450 min^{-1}.

Figure 1: The harvest machinery combination composed of a narrow-track tractor, a small diameter round baler and a baler accumulator.

The baler was provided, alternatively, with two tie systems: the first one was a net tie arrangement based on polyethylene nets (Fig. 2, left); the second was a twine knotter (Fig. 2, right) based on natural twine (sisal).

Figure 2: The baler was used, alternatively, with a net tying system (left) and a twine knotter (right) in order to obtain bales secured with different products.

For these alternatives, it was considered that the net system is general faster when tying but the net has to be disposed-of as a waste after use while the twine knotter is slower when tying but the natural sisal can be reused (or directly burned if the bales are introduced as-they-are into boilers which door diameter is compatible).

The bales were automatically discharged on the headlands (Fig. 3) and then manually loaded on a trailer to be transported at the farm for drying. The drying of the pruning occurred indoor - for these trials in a barn - and naturally. To facilitate this last operation, the bales were stacked horizontally, in layer up to 5 and over a grid made of simply wood-pallet used for multi-way transport (Fig. 4), but any other operation in needed to handle the drying material. Considered that the bales weights 27.7±1.9 kg (average, standard deviation), these operations (trailer load/unload and staking on layers) were made manually.

Figure 3: The bales' accumulator is able to unload automatically the 7 bales stored into the tunnel, while the bale contained into the baler chamber is discharged at the end of this operation, independently.

Taking into consideration the favorable season during which the drying would have took place (late winter – spring –early summer) before the use of the biomass for energy purposes, a maximum period of 4 month of drying was considered for this operation.

Figure 4: The harvested bales are stored over a grid of wood pallet in up to 5 layers for a natural drying period. Note, on the left, the twine-secured bales and, on the right, the net-tied ones.

After drying, the bales were shredded by means of a simplified mill (Easychipper, Caeb International), tractor powered (Fig. 5), in order to obtain wood chips.

Figure 5: The shredder prototype used for the test was powered by the same tractor used during the field tests and connected to a silo by the conveyor 150 mm diameter supplied.

The shredder can also be powered by an electric engine and has the possibility to mount different grids in order to meet the requirements of the material to be shredded in terms of energy use and final dimensions of the chips. For the tests herewith described, two grids were used (Fig. 6), 26 and 45 mm diameter, respectively.

Figure 6: the grids used during the tests were 26 mm (left) and 45 mm (right) diameter, respectively.

For the storage of the wood chips, different solutions have been evaluated in order to make the system flexible and affordable; the first includes mechanic silo from 2 to 6 m^3 volume from where the chips can be directed toward further processing (i.e. pellet formation). The second storage solution is simply represented by different types of industrial plastic big bags (e.g.: open top and flat bottom, open top and discharge spout, filling and discharge spouts, etc.) suitable, for instance, for storing, storing and discharge or for short-haul transports.

2.2 Field testing

The pruning harvest test was carried out in a vineyard located in Almenno San Salvatore (Bergamo, North Italy 45°44'54.41"N, 9°35'13.88"E, 320 m elev.), in March. The vineyard had the surface partly flat and partly slightly sloping. The harvested material was represented by bales packaged by residues of manual pruning.

A total of 110 bales were collected; 18 bales from the slope of the vineyard where the varieties Merlot and Franconia were cultivated and 13 of those cultivated in the plain; 22 bales from the flat part of the vineyard where the Marzemino variety was cultivated and 57 bales from Chardonnay variety grown in the plan. The characteristics of the plots are shown in Table I.

Table I: Characteristics of the test fields

Field no.	Cultivar	Slope (%)	Bales (n.)
1	Franconia	3	6
2	Franconia	12	7
3	Marzemino	2	22
4	Merlot	3	7
5	Merlot	12	11
6	Chardonnay	3	57

During the harvesting in the field, from each bale were collected data relating to: i) harvesting time and distance covered to complete bale formation and accumulation, ii) forward speed, iii) cultivar of origin and iv) the position in the row or whether the collection has taken place (uphill or downhill) in case of slope.

For the evaluation of the space and the time to prepare each bale, the used experimental unit was the interval between the deposition of two bales and each deposited bale was labelled with a unique code.

The number of bales collected has allowed obtaining at least three repetitions for each condition under study.

The power required by the tractor was evaluated using a torque meter (HBM mod. T30FN, Darmstadt, Germany) 200 kNm nominal torque and 3.000 min^{-1} nominal speed.

2.3 Laboratory testing

The bales from each plot were transported to the CREA-IT facilities of Treviglio, Bergamo, Italy (Lab1) where, before the indoor storing for the drying evaluation period, they were weighed and measured in order to obtain bales density. Samples of the branches constituents the bales were taken to measure the average diameter of the shoots. To determine the dry matter (DM) concentration of the pruning a forced draft oven at 103°C until constant weight was used according to the European standard CEN/TS 14774-2. DM content of pruning was constantly monitored over drying period.

Contextually, on branches taken from each bale of the experimental design, were also collected data about the force required to make the cut, by a shear equipped with six sensors able to detect the force applied in some specific areas of the scissors. The used sensors were the A201 Flexi Force Sensors® from Tekscan (South Boston, MA, USA,). These sensors can measure forces in the range from 0 to 440 N, with a response time of less than five microseconds. The sensing area has a diameter of 9.53 mm. The linearity error is ± 3% and the repeatability is ± 2.5%. Sensors calibration was performed at the beginning of the tests, with three certified masses in order to allow the acquisition software to build the regression line. The validation of the regression was performed with three different OIML R111 E2 class certified masses (200, 500 and 1000 g). Both repeatability and error indicated in the technical specifications of the sensors were confirmed. The sensitive area of sensors was positioned so as to coincide with the point of contact of the fingers of the operator with the handles of the pruning shears; this was carried out to investigate the efforts related to the contact point with the handle of the index, middle and ring fingers and the palm corresponding to three zones closest to the thumb.

The chipping and pelleting tests were carried out at the headquarters of CAEB (Lab2), in July where the hourly cost of the chipping process was assessed. The fuel consumption was estimated starting the work on bales from each of the seven fields with a full tank and topping up the tank at the end of the same field. Therefore consumption was related to the time spent to the same field. Time taken to chip every single bale was also measured.

The cost of insurance, repair and service [10] were obtained directly from the manufacturer's best estimates since the machinery was a pre-series and no historical data were available. Fuel costs for was assumed to be 0.9 € l^{-1} being diesel subsidized for agricultural purposes.

Labor cost was set at 12 € h^{-1} inclusive of indirect salary costs. The calculated operational cost of all teams was increased by 10% to account for overhead costs [11].

2.4 Statistical methodology

R software [12] was used for all statistical analysis. A P value < 0.05 was considered statistically significant.

It was verified the normality of the data by the Shapiro-Wilk test and the homoscedasticity with Levene's test in order to make the best choice among the statistical methods to process the data and verify the influence of the independent variables towards those of dependent.

The experimental design used was a factorial scheme with repetitions, considering as independent variables the cultivar and the direction. The dependent variables considered were the space and the time necessary for the formation of each bale (from where the speed of the machine during the operations was derived), the bale's weight and density, the diameter of the branches, the work rate, the required power and the hourly fuel consumption to chip.

3 RESULTS AND DISCUSSION

Data were recorded in two different periods: period of field operations (Field) and period of laboratories operation (Lab1 and Lab2).

During both these periods, DM content of the material was monitored. Figure 7 shows the natural drying pattern of the round-baled pruning during the relevant period.

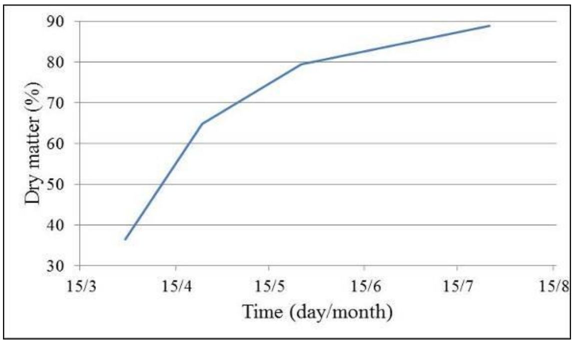

Figure 7: Dry matter recorded during the indoor natural drying period of the round baled pruning.

Data from field operation, as reported in Table II, Field section, showed that the average distance to prepare a bale was 31.9 m with a maximum value (102 m) recorded packing a bale of Franconia downhill and a minimum distance (18 m) recorded harvesting Chardonnay branches on the plain. The average time to prepare a bale was 43.5 s with a maximum value of 154 s recorded packing a bale of Franconia downhill and a minimum time of 18 s recorded harvesting Marzemino pruning on the plain. Consequently, the average harvest speed was 0.8 ms^{-1} with a maximum value of 2.0 ms^{-1} recorded by packing a bale of Merlot on the plain and a minimum speed of 0.5 ms^{-1} reached harvesting Franconia pruning on the plain.

Table II, Lab1 section, shows that the average bale weight was 27.7 kg_{wb} (wb = wet basis) ranging from a maximum value of 31.4 kg_{wb} (Chardonnay pruning) to a minimum of 20.6 kg_{wb} (Marzemino pruning). The mean value of shoot's diameter was 9.5 mm with a maximum value of 10.3 mm for the Marzemino pruning and a minimum value of 8.3 mm for the Merlot. The average force to cut a shoot was 16.1 N and the maximum value of 17.9 N was recorded on Chardonnay while the minimum of 13.1 N was measured on Merlot.

Table II, Lab2 section, shows data obtained from chipping the bales after the drying period. The average time resulted around 50 s ranging from 27 to 61 s (with Merlot and Chardonnay round baled pruning respectively). The maximum power requested to chip an entire bale was 30.1 kW recorded chipping a bale of Chardonnay while the minimum of 21.40 kW was obtained with a bale of Merlot.

Table II: Variables considered during the test (1)

Location	Variable	Av.	Sd.	Min.	Max.
Field	Space (m)	31.9	13.9	18.0	102.0
	Time (s)	43.5	22.4	18.0	154.0
	Speed (ms^{-1})	0.8	0.2	0.5	2.0
Lab1	Weight (kg_{wb})	27.7	1.9	20.6	31.4
	Branches diameter (mm)	9.5	1.1	8.3	10.3
	Force to cut the branches (N)	16.1	1.7	13.1	17.9
Lab2	Time to chip (s)	48.9	11.9	27.0	61.0
	Power to chip (kW)	27.1	3.4	21.4	30.1
	Hourly fuel consumption to chip (lh^{-1})	9.1	0.6	8.1	9.6

(1) variables, where not specified, are referred to single bales.

Data collected from the chipping operations showed that maximum value of hourly fuel consumption of 9.6 lh^{-1} was recorded during the processing of a bale of Chardonnay and the minimum value was recorded with Merlot round bales.

3.1 Statistical analysis

Because all variables studied showed not to have a normally distribution as indicated by the Shapiro-Wilk's test, the significance of the differences between the studied conditions was checked by the Kruskal-Wallis rank sum test. The choice of the post-hoc test was carried out in function of the omoschedasticity based on Levene's test.

Among the three factors in the study, only the cultivar was statistically significant as reported in Table III, while factors related to the slope and the repetition did not show a statistically significant effect on the response values ($P > 0.05$).

The table suggests that the distribution in homogeneous groups generated by post-hoc tests, regarding the three locations of the trials (Field, Lab1 and Lab2), are in agreement with each other.

It is therefore assumed a connection between these variables and the cutting force, from which could be a reasonable dependency. It was, therefore, carried out a search of the correlation between the force required to cut the branches and the forward speed that has shown an inverse correlation, with r = -0.52; between the force and the length of the chips which gave a value of 0.93; between the force and the time necessary to chipping which was equal to 0.97; between the force and the power required to chipping and between the force and the time consumption during the chipping which was equal to 0.99. All these correlation showed a statistical significance at $P < 0.001$.

Table III: Average values grouped by cultivar (2, 3, 4)

Variable	Ch	Fr	Mr	Ml
Space (m)	25.0 b	58.0 a	24.5 b	43.5 a
Time (s)	38.0 b	92.0 a	24.5 c	55.0 a
Speed (ms^{-1})	0.7 c	0.6 c	0.9 a	0.8 b
Weight (kg_{wb})	28.4 a	28.1 a	27.6 a	27.2 a
Branches diameter (mm)	1.0 b	0.9c	1.0 a	0.8 c
Force to cut the branches (N)	17.5 a	16.7 b	14.5 c	13.4 d
Time to chip (s)	58.0 a	51.0 b	40.0 bc	28.0 c
Power to chip (kW)	40.6 a	38.6 b	32.4 bc	29.5 c
Hourly fuel consumption to chip (lh^{-1})	9.6 a	9.3 b	8.4 c	8.1 d

(2) variables, where not specified, are referred to single bales;
(3) numbers with the same letter are not statistically significant;
(4) Ch=Chardonnay, Fr=Franconia, Mr=Marzemino, Ml=Merlot.

This indicates that, with high probability, the greater is the force required to make a cutting of the branches - expression of the strength of the variety – the lowest is the forward speed during the preparation of the bales in field, achieving higher density of the bales.

Moreover the higher is the strength of the branches the greater are the harvesting time, the power requirements and the hourly consumption with increases of the time up to about 50%, of the power up to 30% and of the hourly consumption up to 18% (Fig. 8).

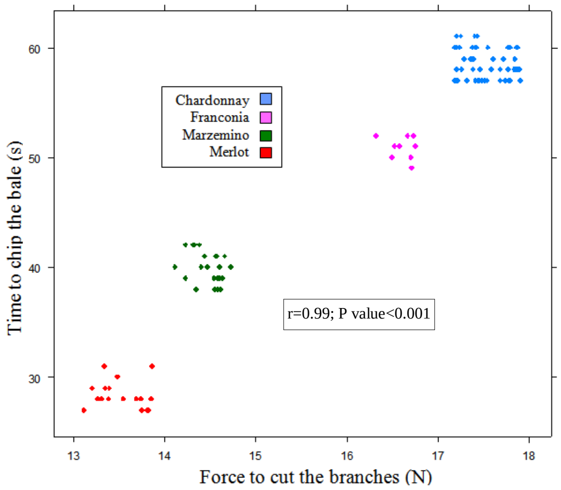

Figure 8: Effect of the cutting force on the chipping time.

The relevant effects of the cutting force in respect of field operations and activities of chipping in Lab2 conditions, have suggested to carry out an assessment of the variables that could better describe the conditions studied, through multivariate analysis (Principal component analysis, PCA) using the response values as descriptors vectors. The obtained biplot is showed in Figure 9.

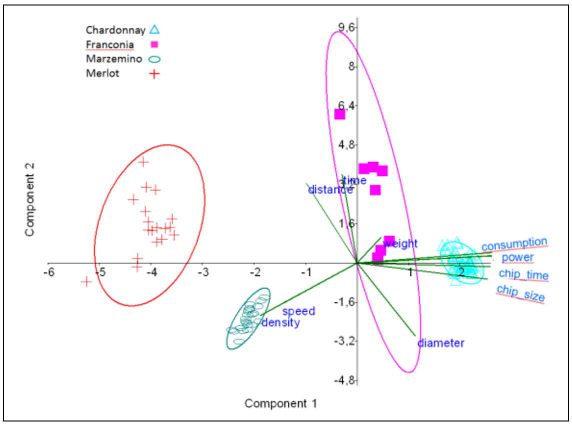

Figure 9: Biplot of the PCA analysis (Proportion of variance: PC1=0.60; PC2=0.26; PC1+PC2= 0.86).

The figure displays that component 1 explains 60% of the variance and the second component explains the 26% of the variance, shows the distribution of the observed samples in four clouds of points, which correspond to the four varieties of populations observed and vectors that contribute to their distribution on the plane (loading 0.40) are the cutting force, the characteristics during the chipping (time, power requirements), and the length of the obtained chips (Fig. 10).

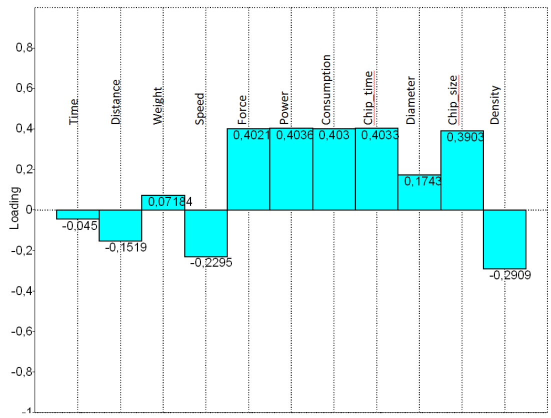

Figure 10: Loading of vectors observed in the PCA analysis.

On the opposite side - but with high effect - are the forward speed (loading = -0.23) and the density of the obtained bales (loading = -0.29). From the results obtained, it was possible to calculate the economic impact of what has been observed. It was therefore possible to calculate the cost for the production (Tab. IV) of each bale in function of the collection cultivars. It is possible to observe how the variation of cultivars increases the cost of production of bales even over 50%.

The feasibility of reducing pruning into woodchips after a period of natural drying and without any supplementary allows to consider not only the direct use of woodchips for energy (thermal) purposes, but also further transformation process in particular for density increasing as pellet formation (Figure 11).

Table IV: Economic characterization of the transformation process studied (5, 6)

Parameter	Ch	Fr	Mr	Ml
Time to chip bales (s)	58 a	51 b	40 bc	28 c
Working rate (bales h^{-1})	62 a	71 b	90 bc	129 c
Hourly cost (€ h^{-1})	22.7 a	22.4 b	21.5 c	21.2 d
Chipping cost (€ $bale^{-1}$)	0.36 a	0.31 b	0.24 c	0.16 d

(5) numbers carrying the same letters are not statistically significant: P<0.05;
(6) Ch=Chardonnay, Fr=Franconia, Mr=Marzemino, Ml=Merlot.

The bottleneck represented by the high content in water characteristic of pruning chipped in field, doesn't represent a limit with the micro plant proposed that can be sufficiently flexible to produce i) directly usable round bales, ii) wood chips or iii) wood pellet from vineyard or orchard pruning.

Figure 11: A further development of the micro plant can foresee a press for pellet production, fed with the previously produced wood chips.

4 CONCLUSIONS

The pruning of the material collected in field trials in bales have shown a high variability as regards the forward speed (CV = 27.3%). While being carried out by the same machine, the speed of preparation of the bales was very different among the cultivars in the study. The statistical analysis of the data showed a significant effect (P <0.001) of the cultivar and not of the field slope. The absence of the effect of the factor related to repetition (P> 0.05) shows the high repeatability of the test and the quality of the sampling plan. The study of the correlation between the dependent variables showed a connection between the forward speed in the field (52%), even more elevated for the characteristics of the bale density (-76%) and the length of the wood chips (93%) against the cutting force. Variables also obtained in the Lab2 conditions showed an high correlation with the cutting force values (99%). All these correlations showed a statistical significance at P <0.001. Moreover, the higher strength of the branches leads to an increase of the time up to about 50%, the power of about 30% and the hourly consumption of about 18%. Multivariate analysis showed that factors that contribute most to the characterization of the analyzed cases are the cutting force, the characteristics during the chipping process (time, power consumption), and the length of the wood chips obtained. On the opposite side, but with high effect, will highlight the forward speed and the density of the bales obtained. These correlations therefore highlight the opportunity of a preliminary survey to estimate the time and the consumption of a process chain for the pruning material valorization, which cannot be separated from the valuation of the cutting force and thus of the hardness of the shoots to be harvested.

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