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Biomass availability and quality produced by vineyard management during a period of 15 years

Abstract

Agricultural residue could become a potential biomass source for energy production because it is available every year in areas accessible to tractors and vehicles. The aim of this work was to quantify the biomass available and its fuel characteristics, considering pruning residue from management of five main vine varieties planted in northwest Italy (barbera, dolcetto, cortese, cabernet sauvignon, and moscato) for a period of 15 years (from 2000 to 2014). Throughout the test period, pruning residue production ranged between 0.45 and 1.34 kg (1850–5360 kg ha⁻¹) per plant. The average higher heating value of the five vine varieties tested ranged from 17.92 to 18.02 MJ kg⁻¹, whereas the lower calorific value ranged between 7.34 and 7.96 MJ kg⁻¹. The average ash content was approximately 3.85%. No statistical difference in biofuel characteristics was found between the vine varieties considered. This study highlights the high potential of vineyard pruning residue as a biofuel for energy production. In contrast, it is of considerable importance to know that biomass production can vary considerably between vine varieties and between years. This latter aspect is very important because, according to reference years, it is possible to under- or overestimate biomass production.

Keywords: vineyards; pruning residues; productivity; moisture content; calorific value; ash content

24 **1. Introduction**

25 In recent years, thanks to political strategies aimed at reducing environmental pollution,
26 renewable energy production in European countries has increased [1]. Of all renewable
27 energy sources, biomass seems to be one which highlights better results for energy and
28 thermal energy production [2]. Under this profile, agricultural residue could become a
29 potential biomass source for energy production in other European countries [3–4],
30 especially in Italy [5–6]. In fact, that biomass source is available every year and is
31 produced in areas accessible to tractors and vehicles [7]. In addition, the use of
32 agricultural waste shows a low environmental impact compared to dedicated plantations
33 (short rotation coppices) [8]. In detail, vineyard pruning residue, being their flue gas
34 emissions comparable to those obtained from wood chips, can be a suitable fuel for
35 energy production [9], especially in southern Europe which is the location of three major
36 wine producers of the world: France, Italy and Spain [10]. In fact, vines are agricultural
37 crops more diffused in Europe, especially in Italy (about 700,000 ha) [11]. In contrast to
38 orchards, in order to improve the quality and quantity of vine production, vineyards require
39 a substantial pruning of all plants every year, which produces a significant amount of
40 residue [12].

41 At present, this residue becomes mulched into the vineyards or piled outside the vineyards
42 and burned [13]. Both solutions present problems in terms of time consumption, economic
43 sustainability, and environmental impact. Mulching, as well as contributing to maintaining
44 organic matter, nutrients and moisture content in the soil, is very dangerous for
45 proliferation of disease [4], while burning, besides being labour-intensive, is low cost [14],
46 but produces significant particulate emissions in the atmosphere [15].

47 As an alternative, pruning residue, similar to other agricultural and forestry wood biomass,
48 could be used as a fuel in substitution for fossil oil for electrical energy production [16] or in
49 small-scale boilers for thermal energy production [9]. In addition this fuel, being
50 characterised by a positive energy balance and low-pollution emissions, is able to offer
51 higher benefits in environmental protection [17].

52 Until now, studies carried out on this topic were mainly focused on technology available for
53 harvesting residue directly in the field [18-19] or on fuel emissions during combustion [20].
54 Little was made of the biomass present and available in the vineyards in the course of the
55 years. In fact, the experimentations performed on biomass quantification up to now
56 considering different shape of vine stock [21], crop geographic position [19] and different
57 vine variety [21] showed a duration of only one year. This aspect is very important
58 because, during the drawing up of a power station business plan, this value is a key
59 parameter to verify its feasibility and economic sustainability on the long-time [22-23] .

60 In order to verify eventual difference on biomass production and fuel characteristics in the
61 course of the years, the aim of this work was to analyse the amount of the biomass
62 available and its fuel characteristics, by management of five main vine varieties planted in
63 northwest Italy over a long period of (15 years).

64

65 **2. Materials and methods**

66 The study was carried out on the Tenuta Cannona farm situated in north-western Italy,
67 near the town of Alessandria (44.68 N; 8.62 E). The tests were carried out for a period of
68 15 years (from 2000 to 2014) in a vineyard growing barbera, dolcetto, cortese, cabernet
69 sauvignon, and moscato vines. These are the main vine varieties of north-western Italy
70 and five of the main vine varieties cultivated in Italy [24]. The vineyard chosen for the tests

71 was 15 years old and had an area of 1.5 ha (0.3 ha for each vine variety) with a north-
72 eastern exposure. It had a slope of 20% and a plant layout of 2.5 m × 1.0 m (4000 plants
73 per hectare). In detail, each vine variety was represented by 6 rows 200 m in length. All
74 vine varieties were trained using the Guyot system.

75 For each vine variety, pruning residue was harvested in three different areas (plots) and in
76 each area three measurements (replications) were performed. Each area had a surface of
77 100 m² (50 plants) and was allocated in representative zones with a distance at least 20 m
78 from the head of the field. That precaution was performed in order to eliminate an eventual
79 'board effect' caused by different environmental conditions (e.g. different sun exposure).
80 The sampling areas were individuated at the beginning of the experiment (2000) and were
81 maintained for the whole period studied (15 years). The complete experimental design
82 constituted 675 replications.

83 In each area, in addition to pruning residue, grape bunches were also harvested in order to
84 verify a potential correlation between biomass and fruit production. In this study, biomass
85 and fruit production were expressed in terms of unit surface area (ha) and single plants. In
86 the first case, the value obtained for the sample area (3000 m²) was extended to a hectare
87 using an arithmetical proportion, and in the second case the value was obtained by
88 dividing the sample area production by the number of plants present in the area (50).

89 Pruning residue was collected immediately after cutting using a manual method.
90 Successively, it was weighed by a dynamometer (Sicutool® SCU 4488B) adopting an
91 accuracy of 0.02 N for all measurements.

92 The moisture content of the biomass was estimated using the gravimetric method following
93 European Standard UNI EN 14774-2 [25]. It was performed on 1 kg samples dried in a
94 ventilated oven.

95 Grape bunches were weighed using an Atex Signum® Ex Supreme digital scale (0.01 kg
96 accuracy).

97 In order to compare the energy potential of the biomass for the different vine varieties, ash
98 content and calorific values were determined. In fact, ash content is a key parameter for
99 biofuel classification because it indicates the amount of non-combustible material present
100 in the biomass, and a high value can affect the useful life of equipment (slag presence)
101 [26]. The ash content was measured following European Standard UNI EN 14775 [27]. In
102 detail, 20 g of dried biomass was incinerated at 570 °C for a period of 5 h, using a muffle
103 furnace (Sinergica® ZE). Samples were weighed before and after incineration using a
104 digital scale with an accuracy of 0.0001 g (PCE® AB 100). The ash content was expressed
105 as a percentage of the initial value [28] and calculated according to the formula:

106

$$107 \quad \quad \quad Ac = W_f / W_i \times 100$$

108

109 where:

110 Ac = Ash content (%)

111 W_f = Weight of the sample after incineration (g)

112 W_i = Weight of the sample before incineration (g)

113

114 Finally, following European Standard UNI EN 14918 [29], the heating value was
115 measured. In particular, the higher heating value (HHV) of the biomass was determined
116 using an oxygen bomb calorimeter (IKA® C200) on 1 g of dried wood sample.

117 Subsequently, the lower heating value (LHV) was calculated on based on the HHV and the
118 moisture content of the biomass, following the formula:

119

120
$$\text{LHV} = \text{HHV}(1 - M) - KM$$

121

122 where:

123 LHV = lower heating value (MJ kg^{-1})

124 HHV = higher heating value (MJ kg^{-1})

125 M = wet basis moisture content (%)

126 K = latent heat of water vaporisation (constant: 2.447 MJ kg^{-1})

127

128 For the whole test period, a weather station was mounted near the vineyard and the air
129 temperature ($^{\circ}\text{C}$), air humidity (%) and precipitation (mm) were monitored at 1 h intervals.

130 All measuring devices were fixed at a height of 1.8 to 2.1 m.

131 The data were processed using Microsoft Excel and SPSS (2014) statistical software,
132 using an ANOVA procedure and adopting a significance level of $\alpha = 0.05$. Eventual
133 differences between treatments were checked with the Ryan–Einot–Gabriel–Welsch
134 (REGW) test because it has a higher statistical power given this data distribution [30]. The
135 REGW-F is a multiple step-down procedure used when all simple means are equal. This
136 test is more powerful than Duncan’s multiple range test and Student-Newman-Keuls
137 (which are also multiple step-down procedures).

138

139 **3. Results**

140 **3.1. Weather conditions**

141 Data analysis showed that over the course of the test period (2000–2014), the annual
142 average air temperature ranged from 12.2 to 15.2 $^{\circ}\text{C}$, with a mean value of 13.7 $^{\circ}\text{C}$. The
143 relative humidity values were also fairly constant, with an annual average between 58%

144 and 78% (Table 1). In contrast, precipitation values were inhomogeneous, ranging from
145 615.4 to 1408.6 mm. It is important to highlight that in all years, in the period available to
146 prune the vines and harvest the residue (October–February), about 50% of the annual
147 precipitation was observed.

148

149 3.2. Pruning residue production

150 Over the whole test period, pruning residue production ranged from 0.45 kg of fresh matter
151 per plant (1850 kg ha⁻¹ of fresh matter considering a planting density of 4000 plants per
152 hectare) – observed for the dolcetto variety in 2003 – and 1.34 kg of fresh matter per plant
153 (5360 kg ha⁻¹ of fresh matter) – obtained for the cabernet sauvignon variety during 2002.

154 That biomass production difference can be mitigated if average values calculated for the
155 whole investigation period are considered. In fact, in that case, production for the dolcetto
156 variety increased to 0.61 kg of fresh matter per plant, while that for the cabernet sauvignon
157 variety decreased to 1.04 kg of fresh matter per plant. In addition, a considerable data
158 dispersion over the years was observed for the cortese vine variety (coefficient of variation
159 (CV) = 24%), while variation for the other vine varieties was never greater than 20%.

160 Significant differences in pruning residue production using the REGW test were found only
161 for cabernet sauvignon (Table 2). Furthermore, no data correlation between weather
162 conditions and pruning residue production was found ($R^2 < 0.3$). In detail, correlations
163 were checked comparing the biomass production to monthly average, monthly total,
164 annual average, annual total, seasonal average, seasonal total and coupling the values of
165 the singular month of air temperature, rain events, and relative humidity.

166

167 varieties, with an average value of 3.70 kg of fresh matter per plant. The lowest value
168 (1.93 kg) was recorded for the cabernet sauvignon variety. In addition, this study

169 highlighted a correlation between grape and biomass production. In fact, ratios were
170 statistically different as a function of the vine variety considered: about 3.85 for cortese,
171 dolcetto and moscato, and only 1.77 for cabernet sauvignon. The highest value was
172 obtained for the barbera vine variety with a value of 4.59.

173 CV values calculated for the whole period considered ranged between 14 and 19 (Table
174 3).

175

176 3.3. Moisture content

177 The pruning residue produced from the different vine varieties during harvesting displayed
178 a similar moisture content for the whole period considered: approximately 50%. In fact, no
179 statistical difference was found between the vine varieties and the years investigated
180 (Table 4).

181

182 3.4. Heating value

183 The HHV of the five vine varieties tested ranged from 17.92 to 18.02 MJ kg⁻¹
184 (Table 5), whereas the LHV ranged between 7.34 and 7.96 MJ kg⁻¹ (Table 6). Data
185 processing highlighted no significant difference between the vine varieties tested and the
186 annual production of each vine variety, considered both in terms of HHV and LHV.

187

188 3.5. Ash content

189 The average ash content calculated for the whole period considered (2000–2014) was
190 approximately 3.85%. The lowest value (3.80%) was obtained for dolcetto, while the
191 highest value (3.93%) was observed for moscato biomass. Also, for this parameter

192 statistical analysis did not show any difference between the vine varieties for annual
193 production investigated, adopting a significance level of $\alpha = 0.05$ (Table 7).

194

195 **4. Discussion**

196 The pruning residue production observed during the test (from 1.85 t ha^{-1} to 5.36 t ha^{-1}) is
197 in line with other studies carried out in Chile [28] and Italy [13], which considered other
198 vine varieties. In this study, a high variability ($\text{CV} \leq 16$) of annual biomass production for
199 four vine varieties (cortese, dolcetto, barbera, and moscato) over the course of the years
200 investigated is also highlighted. In some cases the biomass availability could vary by up to
201 50%. This could become a big problem for drawing up a power station business plan
202 because a fuel variation of 50% could cause an interruption in energy production or the
203 need to have a large reserve of material. In this regard, however, readers must remember
204 that wood biomass storage could in turn cause energy losses and higher costs [31].

205 Furthermore, in an absence of correlation between annual biomass production and
206 weather conditions, and the high variability of the grape/biomass ratio, it is very difficult to
207 estimate the amount of biomass available, not only for future years, but also for the current
208 year.

209 In addition, another problem linked to a high variety of biomass production in different
210 years is the difficulty of calculating the real potential of the vineyard considered because,
211 depending on the reference year, it is possible to overestimate or underestimate biomass
212 production.

213 The moisture content values obtained in this work are more homogenous than those
214 obtained in other studies conducted with other vine varieties [18, 28, 32-33]. These
215 differences could be caused by the different geographic areas in which the trials were

216 carried out (Spain [31], Chile [28], and Saudi Arabia [32]), the different seasons in which
217 the tests were performed (August [28], January–February [18], December [32]), or the
218 different amount of time between cutting and moisture content determination (immediately
219 in this work, but not accountable for other works). In this experiment, no variation in
220 moisture content was observed between the vine varieties tested during the whole 15 year
221 period. This result highlights that it is possible to predict the initial biomass moisture
222 content with good accuracy.

223 Moisture content values found in this study (approximately 50%) were lower than poplar
224 wood (approximately 60%) [34] and higher than black locust wood (approximately 45%)
225 [30], the main tree species used for woodchip production in northwest Italy [31].
226 Nevertheless, the values are 30% greater than the commercial value admitted for dried
227 wood biomass used as a biofuel.

228 The HHV of the pruning residue observed in this study is in line with that found in other
229 works [18, 32–33]. The average value (18.00 MJ kg^{-1}) obtained for all vine varieties tested
230 was similar to that of hardwood tree species (18.04 MJ kg^{-1}) [34], but lower than that of
231 softwood forest trees (20.20 MJ kg^{-1}) [35]. This variation could be due to the high resin
232 content of conifer wood [36].

233 Many researchers have determined the ash content of pruning residue, and its value
234 ranged from 2.4% to 5.3% [18, 20, 32–33], as did the values found in this work
235 (approximately 3.86%). In contrast to other experiments, in which authors studied different
236 vine varieties, in this work low data variability was found between the vine varieties tested.
237 This situation could be caused not only by different vine residue types but also by their
238 contamination with inert materials like soil dust or small stones [37]. Nevertheless, it
239 highlights that the agricultural residue shows an ash content greater than forestry wood

240 (about 1%) [38]. Unfortunately, this physical characteristic of vineyard pruning residue
241 makes it less suitable for use in boilers or stoves because ash accumulation can cause
242 some problems in biomass combustion [39].
243

244 **5. Conclusions**

245 This study has highlighted the good potential of vineyard pruning residue as a biofuel for
246 energy production because it presents values of moisture content (during harvesting) and
247 calorific value in line with those obtainable from woodchips produced by dedicate
248 plantations (SRC). In addition, its physical characteristics do not change as a function of
249 the vine varieties considered or over the course of time. In contrast, biomass production
250 can show sensible variation between vine varieties and between years. This latter aspect
251 is very important because, according to the reference year considered, it is possible to
252 under- or overestimate the real biomass production of the vineyard considered in the
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254

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