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

1. Introduction

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

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

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

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

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

2. Materials and methods

The study was carried out on the Tenuta Cannona farm situated in north-western Italy, near the town of Alessandria (44.68 N; 8.62 E). The tests were carried out for a period of 15 years (from 2000 to 2014) in a vineyard growing barbera, dolcetto, cortese, cabernet sauvignon, and moscato vines. These are the main vine varieties of north-western Italy and five of the main vine varieties cultivated in Italy [24]. The vineyard chosen for the tests was 15 years old and had an area of 1.5 ha (0.3 ha for each vine variety) with a north-eastern exposure. It had a slope of 20% and a plant layout of 2.5 m $\times$ 1.0 m (4000 plants per hectare). In detail, each vine variety was represented by 6 rows 200 m in length. All vine varieties were trained using the Guyot system.

For each vine variety, pruning residue was harvested in three different areas (plots) and in each area three measurements (replications) were performed. Each area had a surface of 100 m^2 (50 plants) and was allocated in representative zones with a distance at least 20 m from the head of the field. That precaution was performed in order to eliminate an eventual 'board effect' caused by different environmental conditions (e.g. different sun exposure). The sampling areas were individuated at the beginning of the experiment (2000) and were maintained for the whole period studied (15 years). The complete experimental design constituted 675 replications.

In each area, in addition to pruning residue, grape bunches were also harvested in order to verify a potential correlation between biomass and fruit production. In this study, biomass and fruit production were expressed in terms of unit surface area (ha) and single plants. In the first case, the value obtained for the sample area (3000 m^2) was extended to a hectare using an arithmetical proportion, and in the second case the value was obtained by dividing the sample area production by the number of plants present in the area (50).

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

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

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

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

$$Ac = Wf / Wi \times 100$$

where:

Ac = Ash content (%)

Wf = Weight of the sample after incineration (g)

Wi = Weight of the sample before incineration (g)

Finally, following European Standard UNI EN 14918 [29], the heating value was measured. In particular, the higher heating value (HHV) of the biomass was determined using an oxygen bomb calorimeter (IKA® C200) on 1 g of dried wood sample. Subsequently, the lower heating value (LHV) was calculated on based on the HHV and the moisture content of the biomass, following the formula:

$$LHV = HHV(1 - M) - KM$$

where:

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

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

M = wet basis moisture content (%)

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

For the whole test period, a weather station was mounted near the vineyard and the air temperature (°C), air humidity (%) and precipitation (mm) were monitored at 1 h intervals. All measuring devices were fixed at a height of 1.8 to 2.1 m.

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

3. Results

3.1. Weather conditions

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

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

3.2. Pruning residue production

Over the whole test period, pruning residue production ranged from 0.45 kg of fresh matter per plant (1850 kg ha^{-1} of fresh matter considering a planting density of 4000 plants per hectare) – observed for the dolcetto variety in 2003 – and 1.34 kg of fresh matter per plant (5360 kg ha^{-1} of fresh matter) – obtained for the cabernet sauvignon variety during 2002. That biomass production difference can be mitigated if average values calculated for the whole investigation period are considered. In fact, in that case, production for the dolcetto variety increased to 0.61 kg of fresh matter per plant, while that for the cabernet sauvignon variety decreased to 1.04 kg of fresh matter per plant. In addition, a considerable data dispersion over the years was observed for the cortese vine variety (coefficient of variation (CV) = 24%), while variation for the other vine varieties was never greater than 20%. Significant differences in pruning residue production using the REGW test were found only for cabernet sauvignon (Table 2). Furthermore, no data correlation between weather conditions and pruning residue production was found ($R^2 < 0.3$). In detail, correlations were checked comparing the biomass production to monthly average, monthly total, annual average, annual total, seasonal average, seasonal total and coupling the values of the singular month of air temperature, rain events, and relative humidity.

varieties, with an average value of 3.70 kg of fresh matter per plant. The lowest value (1.93 kg) was recorded for the cabernet sauvignon variety. In addition, this study highlighted a correlation between grape and biomass production. In fact, ratios were statistically different as a function of the vine variety considered: about 3.85 for cortese, dolcetto and moscato, and only 1.77 for cabernet sauvignon. The highest value was obtained for the barbera vine variety with a value of 4.59.

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

3.3. Moisture content

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

3.4. Heating value

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

3.5. Ash content

The average ash content calculated for the whole period considered (2000–2014) was approximately 3.85%. The lowest value (3.80%) was obtained for dolcetto, while the highest value (3.93%) was observed for moscato biomass. Also, for this parameter statistical analysis did not show any difference between the vine varieties for annual production investigated, adopting a significance level of $\alpha = 0.05$ (Table 7).

4. Discussion

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

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

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

The moisture content values obtained in this work are more homogenous than those obtained in other studies conducted with other vine varieties [18, 28, 32-33]. These differences could be caused by the different geographic areas in which the trials were carried out (Spain [31], Chile [28], and Saudi Arabia [32]), the different seasons in which the tests were performed (August [28], January–February [18], December [32]), or the different amount of time between cutting and moisture content determination (immediately in this work, but not accountable for other works). In this experiment, no variation in moisture content was observed between the vine varieties tested during the whole 15 year period. This result highlights that it is possible to predict the initial biomass moisture content with good accuracy.

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

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

Many researchers have determined the ash content of pruning residue, and its value ranged from 2.4% to 5.3% [18, 20, 32–33], as did the values found in this work (approximately 3.86%). In contrast to other experiments, in which authors studied different vine varieties, in this work low data variability was found between the vine varieties tested. This situation could be caused not only by different vine residue types but also by their contamination with inert materials like soil dust or small stones [37]. Nevertheless, it highlights that the agricultural residue shows an ash content greater than forestry wood (about 1%) [38]. Unfortunately, this physical characteristic of vineyard pruning residue makes it less suitable for use in boilers or stoves because ash accumulation can cause some problems in biomass combustion [39].

5. Conclusions

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

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