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EVALUATION OF TEMPORAL VARIATIONS IN MOISTURE AND CALORIFIC VALUE OF VINE AND OLIVE PRUNING

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1. Introduction

The increasing price of fuel, climate change and the related phenomenon of global warming have induced many industrialized countries to reconsider their energy related policies in favour of a wider use of renewable resources.

In this context, agriculture may play an important role by investing in dedicated crops for energy production as well as in the utilization of agricultural by-products. Plant products from the pruning of vine and olive trees may be an interesting example in case. In Italy, vine pruning yields 2.3×10^9 kg of raw material (agricultural area of 8.0×10^9 m^2) while olive pruning yields 2.2×10^9 kg (agricultural area of 11.6×10^9 m^2). These by-products are currently ploughed into the soil or else harvested and burned in open fields. In the first case, any pathogens present may be distributed thus resulting in possible infection in all plants. Moreover, the high C/N ratio of such ligneous-cellulosic material may result in an uptake of N from the soil by the microbial degraders, thus possibly having a negative impact on plants [Epstein 1997]. It is worth mentioning that the burning of the pruning in fields is illegal in Italy due to the evident risks involved.

These considerations suggest that the collection of these organic materials for utilization as a fuel for the generation of heat and electrical energy could be a valid alternative. The combustion of solid biofuels is influenced by the kind of solid biofuel used, its physical characteristics (e.g. particle size, bulk density, moisture content, calorific value) and its chemical composition [Toscano 2009].

If these materials are to be used as fuel, it is important to know their net calorific value (NCV) that expresses the energetic content of the combustible. NCV is the absolute value of the specific heat of combustion, in joules, for unit mass of the biofuel burned in oxygen at constant pressure under such conditions that all the water of the reaction products remains as water vapour (at 0.1 MPa), the other products being as for the gross calorific value (GCV), all at the reference temperature [CEN/TS 14918:2005].

The calorific value is significantly influenced by the moisture content of wood. In fact low calorific values are obtained with increasing moisture content. It is also well-known that after pruning, the organic materials have an elevated water content that subsequently decreases with time.

The aim of the paper is to evaluate the changes in moisture content and calorific value with time for different harvesting and storage conditions. In this way it is possible to identify the time required for these materials to obtain their best energetic performance, and make an important contribution to the energy chain birth.

Finally some considerations about harvesting and forwarding costs were done.

2. Materials and methods

In order to evaluate the changes in moisture content and calorific value with time, five different harvesting and storage systems were considered for both olive and vine pruning. These were:

1. harvesting with shredding machine;
2. harvesting and formation of bundles manually;
3. harvesting with baler (rectangular bales);
4. harvesting with baler (cylindrical bales);
5. harvesting and stocking in heaps at the edge of the field.

The products from the first four systems were stocked in the open under a roofing open on four sides. The shredding produced with system 1 was arranged into two piles, one with vine pruning and the other with olive pruning. The products from system 5 were left at the edges of the field without any protection from atmospheric agents.

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To obtain the shredding and bales, specialized machines were used such as: baler machines and shredding machines. Thanks to a rotation element both of them pick up the pruning from the ground. The former gather the materials and organize them in homogenous units (rectangular or cylindrical bales of regular size and shape) tie the bales and drop them on the ground for later collection, which the latter transform into shredding and send to a storage bin.

The manually made bundles (system 2) were cylindrical in shape with a diameter of 0.30÷0.35 m, a length of 0.60÷0.65 m and an initial weight of 10÷12 kg. The rectangular bales had dimensions 0.30× 0.40×0.60 m and an initial weight of 18÷22 kg, while the cylindrical ones had a diameter of 0.40 m, a length of 0.60 m and an initial weight of 28÷30 kg.

Materials were harvested and stored in the pruning season: in January 2009 for vine and March 2009 for the olive trees. Right after the changes in moisture content and calorific value with time were studied.

Every week, samples were taken from each of the five storage systems according to the standard methods [CEN/TS 14778-1:2006], [CEN/TS 14779:2005], [CEN/TS 14780:2005]. The methods require a minimum number of increments (portion of fuel extracted in a single operation of the sampling device) depending on the type of material being analysed. Every week 10 increments were collected from each of the five storage systems. Each increment had a maximum weight of 3 kg. The increments were picked manually and at random from the lot or the sub-lot. The increments were mixed together to form a combined sample and then were placed directly into one container. The combined sample was then divided into sub-samples of 0.60 kg for laboratory analysis.

Analysis of moisture content was carried out according to the standard method [CEN/TS 14774-3:2004].

Principle is that the analysis sample of biofuel is dried at a temperature of (105±2) °C and the percentage moisture calculated from the loss in mass of the test sample.

The apparatus utilized consisted of:

- drying oven, capable of being controlled at a temperature within the rage of (105±2) °C;
- weighing dish with a well fitting lid;
- balance having sufficient accuracy to weigh the sample within ±1.0×10^{-7} kg;
- desiccator to avoid absorption of moisture from the atmosphere to the sample.

Moisture content (M_{ad}) was calculated using the following formula:

$$M_{ad} = [(m_2 – m_3) / (m_2 – m_1)] \times 100 \qquad (1)$$

where:

m_1 is the mass in grams of the empty dish plus lid;

m_2 is the mass in grams of the dish plus lid plus sample before drying;

m_3 is the mass in grams of the dish plus lid plus sample after drying.

Substantially the procedure consisted of weighing the dish with its lid and heating the uncovered dish and its lid together with the sample at (105±2) °C until constant in mass. Constancy in mass is defined as a change not exceeding 1.0×10^{-6} kg in mass during a further period of heating at (105±2) °C over a period of 1 hour. The drying time required is normally between 2÷3 hours. Replace the lid and transfer the dish and its contents to a desiccator, weigh the dish and its lid with the sample to the nearest 1.0×10^{-7} kg. Two determinations were carried out on the test sample and the average value was defined.

Analyses of moisture content were stopped when no significant differences were observed.

A calorific value evaluation was done according to the standard method [CEN/TS 14918:2005]. At the beginning the sample was milled and sieved with an aperture of 1.0×10^{-3} m. A sieve is necessary to ensure the requisite repeatability and a complete combustion. After the moisture content of the sample [CEN/TS 14774-3:2004] and its hydrogen content [ASTM D 5373:2008] were analysed and the GCV was calculated [CEN/TS 14918:2005].

To evaluate the hydrogen content the sample was burned, with excess pure oxygen, in an instrument provided with an oven (temperature up to 950 °C) and a detector of combustion products: CO_2, H_2O, NO_x then C, H, N were evaluated. Three determinations were carried out on the test sample and the average values were defined.

Due to the low density of solid biofuels the sample, used to evaluate the GCV, was tested in a pellet form using an iperibol calorimeter. The sample was placed in the bomb (Malher bomb) pressurized with excess pure oxygen. The bomb was submerged under a known volume of water before the charge is ignited. The bomb, with sample and oxygen, form a closed system (no air escape during the reaction). The energy released by the combustion raises the temperature of the steel bomb, its contents, and the surrounding water jacket. The temperature change in the water is then accurately measured (accuracy of 1.0×10^{-4} °C).

The GCV_{db} value on dry basis was defined by a calorimeter. To obtain the NCV_{db} (on dry basis) the following formula was used:

$$NCV_{db} = GCV_{db} – 9 \times h \times H \quad [MJ/kg] \qquad (2)$$

where:

GCV_{db} is determined by calorimeter;

9 is the transformation factor of hydrogen in water;

h is the heat of condensation of water (2.44 MJ/kg);

H is the fraction of hydrogen present in the sample (when analytical determinations are absent a value of 0.06 may be assumed).

To take into account that the calorific value is significantly influenced by the moisture content of wood the following formula was utilized [Hartman, 2000]:

$$NCV_w = NCV_{db} \times (1–M_{ad}/100) – h \times M_{ad}/100 \quad [MJ/kg] \qquad (3)$$

where:

NCV_w is the NCV of wood with M_{ad};

h is the heat of condensation of water (2.44 MJ/kg).

3. Results

The shredding obtained from pruning and stocked in heaps, without any kind of mixing or aeration, started to ferment after one week. The temperature of the heap increased and water vapour and malodour generations were observed. For this reason this trial was terminated. Analyses described above were carried out for the other storage systems for a total period of 45 weeks. After this time period no significant differences in the values for moisture content were observed. The moisture content of vine and olive tree pruning right after harvesting was about 50% and decreased to 10% after 45 weeks (Fig. 1-2).

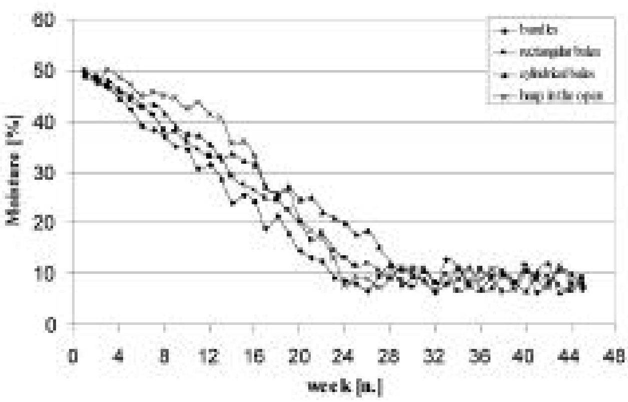

Fig. 1 - Changes in the Moisture content of vine pruning.

Results show that the moisture content depends on compaction of the material. In fact, a lower compaction results in a high circulation of air within the material thus leading to a high loss of water. Although, heaps kept in the open had a low compaction allowing the circulation of air, they were exposed to climatic conditions. In fact, their moisture content decreased slowly during winter and more rapidly during the drier months (spring and summer). Vine pruning

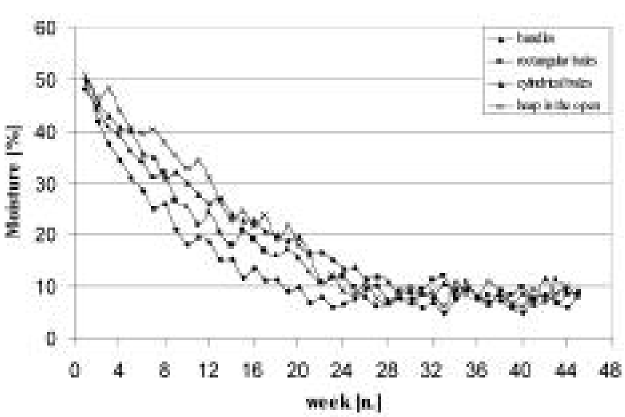

Fig. 2 - Changes in the Moisture content of olive pruning.

reached a moisture content of 10% between the 23rd and 30th week. On the other hand, the olive tree pruning reached this value between the 18th and 27th week. This was probably due to the fact that olive tree pruning is generally carried out about two months after vine pruning. Moreover, the presence of leaves in the olive tree pruning, help water loss by providing a high surface area for exchange with the atmosphere.

Thanks to the laboratory analyses it was possible to determine H and GCV_{db} while NCV_{db} value from the above formula (2) (Tab. 1).

	H [%]	GCV_{db} [MJ/kg]	NCV_{db} [MJ/kg]
Vine pruning	5.78	18.87	17.60
Olive pruning	5.96	19.60	18.29

TABLE 1 - H, GCV_{db}, NCV_{db}, values of vine and olive pruning.

The calorific values, calculated with the above formula (3), of vine pruning were about 8 MJ/kg for a moisture content of 50% and about 16 MJ/kg for a moisture content of 10%. The calorific values of olive tree pruning were about 9 MJ/kg for a moisture content of 50% and about 17 MJ/kg for a moisture content of 10% (Fig. 3-4).

4. Conclusions

Baler and shredding machines provide products with different characteristics. Shredded material compared with bales has the advantage of being relatively easy to move. The work has shown that the storage of wood shredding is difficult due to the risk of fermentation processes. It is thus necessary to have a wider surface area to store the shredding in small heaps. Another alternative is to have systems that enable the turning of the heaps and provide forced aeration. However, such systems would inevitably result in a higher cost.

The work has also shown that bales do not have any stocking problems even though it is more difficult to move them automatically. This problem can be partly dealt with by shredding the bales prior to their use. It is also possible to put bales just the same into ovens, without any self-loading. Because some daily fillings by hand are required, such ovens have a domestic use only.

The results clearly show that materials from vine and olive tree pruning stored in bales reach their maximum energetic potential after around 8 months. This result is important for the realisation of an energy production chain in which pruning produced in January-March may be made available for energy generation in the successive winter season.

Harvesting with	Vine pruning [€/kg]	Olive pruning [€/kg]
Baler (rectangular bales)	4.37×10^{-2}	2.29×10^{-2}
Baler (cylindrical bales)	4.06×10^{-2}	3.00×10^{-2}
Shredding machine	5.29×10^{-2}	3.40×10^{-2}
Forwarding	2.00×10^{-2}	2.00×10^{-2}

TABLE 2 - Operating costs evaluation. Forwarding costs refer to a farm tractor with trailer until 5 km far from the field.

To realize an energy chain the operating costs evaluation is very important (Tab. 2), [Porceddu, 2006].

Harvesting with shredding machines and forwarding costs are about 7.29×10^{-2} €/kg for vine pruning and 5.40×10^{-2} €/kg for olive pruning. Because of the easy fermentation of shredding, without any kind of mixing and aeration systems, harvesting with balers appears to be the best way.

Harvesting with balers and forwarding costs are about 6.21×10^{-2} €/kg for vine pruning and 4.64×10^{-2} €/kg for olive pruning. Such differences depend on the amount of available pruning. Vine pruning is carried out every year, while olive pruning every two years, due to the shortage of skilled labour.

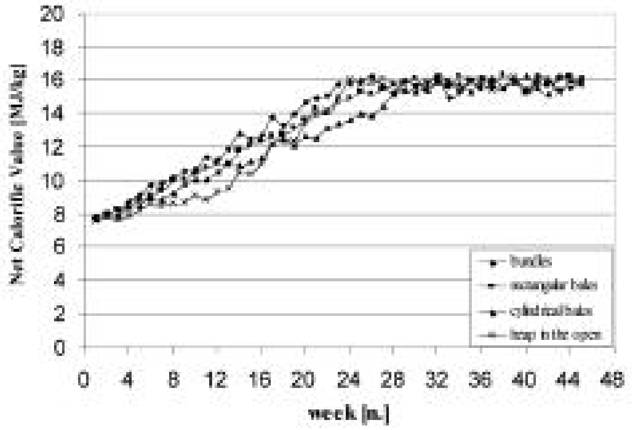

Fig. 3 - Changes in the Calorific value of vine pruning.

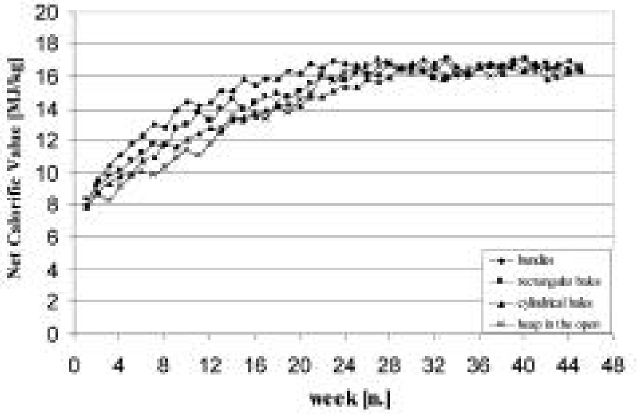

Fig. 4 - Changes in the Calorific value of olive pruning.

These costs are similar to the price currently offered for energy biomass in Italy, which can reach 5.00×10^{-2} €/kg, delivered to the plant [Spinelli, 2010]. While the cost actually paid to plough pruning into the soil amounts to about 2.50×10^{-2} €/kg.

Therefore actually the profit of harvesting and forwarding of olive pruning is very little, while it is nonexistent for vine pruning. The cost of ploughing pruning into the soil is high for farmers, but the energy chain allows to save money.

Forwarding costs play an important role, therefore it is necessary to have a short chain, organized with commission manufacturers to carry out the harvesting, forwarding, storage and exploitation point.

Finally it is important to remember that pruning refers to by-products, not main products of cultivation, and their harvesting for energy use avoids problems produced by their disposal on the field.

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CEN/TS 14918:2005 Solid biofuels – Method for the determination of calorific value.

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SUMMARY

In Italy arboreal crops, in particular vine and olive, cover a surface area of around 19.6×10^9 m^2 from which about 4.6×10^9 kg of pruning are cut.

These by-products are currently ploughed into the soil or else harvested and burned in open fields.

On the other hand such materials would be more useful as an energy source.

If these materials are to be used as fuel, it is important to know their calorific value. The calorific value is significantly influenced by the moisture content of wood.

This work has evaluated the changes in moisture content and calorific value with time for different harvesting and storage systems of vine and olive pruning.

The observed decrease in the moisture content of the vine and olive pruning depended on the storage system utilized, in particular on the product compression ratio and air circulation.

Some differences were observed between the results obtained for vine and olive pruning.

The time required for these materials to obtain their best energetic performance was identified at 32 weeks from their harvesting.

Harvesting with balers and forwarding costs are about 6.21×10^{-2} €/kg for vine pruning and 4.64×10^{-2} €/kg for olive pruning. They are very similar to the price currently offered for energy biomass in Italy (5.00×10^{-2} €/kg). While the cost actually paid to plough pruning into the soil amounts to about 2.50×10^{-2} €/kg. Therefore the energy chain encourages a cost-and-benefit analysis.

Keywords: Solid biofuels, sample preparation, moisture, calorific value, harvesting and forwarding costs.