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Energy potential of fruit tree pruned biomass in Croatia

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Abstract

The world's most developed countries and the European Union (EU) deem that the renewable energy sources should partly substitute fossil fuels and become a "bridge" to the utilization of other energy sources of the future. This paper will present the possibility of using pruned biomass from fruit cultivars. It will also present the calculation of potential energy from the mentioned raw materials in order to determine the extent of replacement of non-renewable sources with these types of renewable energy. One of the results of the intensive fruit-growing process, in post pruning stage, is large amount of pruned biomass waste. Based on the calculated biomass (kg ha^{-1}) from intensively grown woody fruit crops that are most grown in Croatia (apple, pear, apricots, peach and nectarine, sweet cherry, sour cherry, prune, walnut, hazelnut, almond, fig, grapevine, and olive) and the analysis of combustible (carbon 45.55-49.28%, hydrogen 5.91-6.83%, and sulphur 0.18-0.21%) and non-combustible matters (oxygen 43.34-46.6%, nitrogen 0.54-1.05%, moisture 3.65-8.83%, ashes 1.52-5.39%) with impact of lowering the biomass heating value (15.602-17.727 MJ kg^{-1}), the energy potential of the pruned fruit biomass is calculated at 4.21 PJ.

Additional key words: bioenergy; heating values; olive groves; orchards; renewable energy sources; vineyards.

Resumen

Potencial energético de la biomasa procedente de árboles frutales podados en Croacia

Los principales países desarrollados del mundo y de la Unión Europea (UE) consideran que las fuentes de energía renovables deberían sustituir parcialmente a los combustibles fósiles y convertirse en el futuro en un "puente" hacia la utilización de otras fuentes de energía. En este trabajo, se planteó la posibilidad de utilizar biomasa cortada procedente de cultivos frutales con el propósito de calcular el potencial energético del mencionado material en bruto, así como determinar el grado de remplazo de fuentes no renovables con este tipo de fuentes de energía renovable. Uno de los resultados del proceso de cultivo de frutales en intensivo, tras la época de poda, es la gran cantidad de biomasa cortada inútil. En base al cálculo de biomasa (kg ha^{-1}) de los frutales leñosos de cultivo intensivo más comunes en el territorio de Croacia (manzano, peral, albaricoquero, melocotonero y nectarino, cerezo, guindo, ciruelo, nogal, avellano, almendro, higuera, viña y olivo) y en base al análisis de partículas combustibles (carbono 45,55-49,28%, hidrógeno 5,91-6,83% y azufre 0,18-0,21%) y de partículas no combustibles (oxígeno 43,34-46,6%, nitrógeno 0,54-1,05%, vapor de agua 3,65-8,83% y cenizas 1,52-5,39%) que influyen en el poder calorífico inferior de la biomasa (15,602-17,727 MJ kg^{-1}), se calcula que la energía potencial de los restos de poda de frutales es 4.21 PJ.

Palabras clave adicionales: bioenergía; los valores de calefacción; olivares; frutales; fuentes de energía renovables; viñedos.

Introduction

During the past ten years the European Commission brought a number of documents and laws regulating a sustainable system of measures with which the member states will promote the realization of the proclaimed goals. Directive 2009/28/EC (OJ, 2009a), deals with promoting of use of renewable energy, defines the goals as well as the obligations of the member states in the area of promoting and use of renewable energy sources

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in final consumption of electricity and heat energy and of transportation fuels. The biofuel production and use fulfil two more goals: they contribute to security of supply and boost economic activity and regional development, which are of crucial importance for Croatia. Pursuing these goals and based on the Law on Biofuels the Croatian government developed the National Action Plan on Promoting the roduction and Use of Biofuels in the period from 2001 to 2020 (OJ, 2009a,b).

Given the fact that starting from 2013 Croatia will be full member of the EU, it is necessary to work on meeting the biofuel target. Until 2020 in each EU member state, Croatia included, biofuels should make 20% of total energy consumption, while it is foreseen that in 2030 biofuels will substitute as much as 25% of oil (Tomic & Kricka, 2007; Tomic *et al.*, 2008).

During the past few years the global interest in renewable energy sources, especially energy from biomass, has been growing significantly. There are several reasons for this: biomass is a renewable resource which is largely available and has a good potential as a source of energy products, such as electricity and heat as well as liquid fuels. Biomass is also a material which is practical and easy to use (Hoogwijk *et al.*, 2009).

Biomass is the third largest primary energy source in the world following coal and petroleum. It is still the main source of energy for more than half of the world's population and provides about 1.25 billion toe (tons of oil equivalent) of primary energy, or about 14% of the world's annual consumption of energy (Purohit *et al.*, 2006; Zeng *et al.*, 2010).

The primary sources of biomass are agricultural and forest residues, energy crops, and organic waste. These sources have been relatively widely used in the EU for long time already, and the future growth in biomass production should be connected to a more intensive use of energy crops (van Dam *et al.*, 2007).

Lately, biomass has been increasingly used in the energy production, in the cogeneration plants *i.e.,* combined heat and power generation. The combined heat and power generation represents a very valuable potential for significant improvements of the overall efficiency of fuel utilization. There are different estimates of the potentials and the role of biomass in the global energy policy of the future, but all current scenarios give biomass a growing role in energy consumption and envisage its significant growth (Voca *et al.*, 2008).

Although biomass as energy source is primarily used in rural areas, it is also an important energy source in urban energy systems as well (Kricka *et al.*, 2007). The interest in conversion of biomass in to power and heat comes not only from the fact that it represents a low-cost and renewable energy source but also because it provides various advantages in terms of development and environmental protection (Perlack & Wright, 1995).

The utilization of renewable energy sources is becoming increasingly important in the light of its potential to mitigate the effects of global warming and because of its role in fuel supply (Cuiping *et al.*, 2004). Namely, in complete biomass-based fuel combustion the only by-products are carbon dioxide (CO_2) and water (H_2O), while incomplete combustion generates health damaging gases and greenhouse gases (GHG), such as carbon monoxide (CO), nitrogen dioxide (NO_2), methane (CH_4), polycyclic aromatic hydrocarbons (PAH), etc. (Bhattacharya & Salam, 2002).

Biomass contains less sulphur and ashes than coal, thus generates low emissions of SOx and particles. Although, in some cases, biomass fuels have high nitrogen content which may give rise to rather high NOx emissions (Klason & Bai, 2007; Van den Broek, 2000).

In order to calculate energy potential of biomass in general, including horticultural pruned biomass, it is necessary to investigate combustible and non-combustible matters. In biomass, the combustible matters are carbon, hydrogen, and sulphur; while oxygen, nitrogen, moisture and ash are non-combustible matters. Carbon is the most important combustible element and the heating value of biomass increases as carbon levels rise. Hydrogen is the next most significant component; a part of hydrogen that is bonded to carbon, so called non-bonded hydrogen, is one the factors of biomass building, generating water and releasing heat in the process, *i.e.,* increasing the fuel heating value. Sulphur is an undesirable element and is present in biomass in traces. If bonded to an organic matter, it is highly damaging for the environment (Obernberger & Thek, 2004).

Oxygen is also an undesirable element since it bonds carbon and hydrogen and, thus, decreases the heating value of fuel, while nitrogen does not develop heat. It is not a part of the combustion process and thus, like oxygen, lowers the heating value of fuel (Vassilev *et al.*, 2010).

Higher moisture content lowers the fuel value of biomass. However, moisture can be reduced by drying, which increases the cost of the whole process. Ash consists of non-combustible mineral particles: with increasing the ash content the quality of fuel becomes lower. Additional elements which must be investigated in terms of the fuel quality are: coke, fixed carbon, volatile matters and fuel (Wiinikka *et al.*, 2007). Fixed carbon is one the most important parts of fuel and represents firmly bonded carbon. The fuels with higher content of volatile matters have lower energy value and need more energy for burning than the fuels with lower volatile matters content (Holtz, 2006). All these elements influence the fuel value (MJ kg^{-1}), which represents the amount of heat generated in the combustion process (Obernberger & Thek, 2004).

The investigation of the energy potential of biomass obtained by pruning of different sorts of fruit trees and grapevine should be carried out in the period of mature pruning, because in case of green pruning the pruned mass, given its substance, is not a significant source of energy. Because of their properties and quantities, the residues of mature pruning are very interesting as a source of energy (Radojevic *et al.*, 2007). Orchards and vineyards require annual pruning, which gives large amounts of biomass that might be available as a source of bioenergy. The residues generated from the pruning of orchards and vineyards consist of small branches and biomass resulting from regular cleansing operation (Scarlat *et al.*, 2011).

In the light of the above premises, the aim of this analysis is to establish the quantities of combustible and non-combustible matters in pruned biomass of all significant woody fruit crops in the territory of Croatia and to calculate, on the basis of the obtained data, the energy potential of pruned biomass of the observed crops. Given the fact that norms for energy utilization of pruned biomass from different fruit crops have not been defined yet, the analysis results were weighed against the values applicable to broad-leaf wood under the norm ISO CEN/TS 14961 (2005), because this biomass category is most similar to the investigated crops.

Material and methods

The crops for this study were selected on the basis of the data published in the Statistical Yearbook of the Republic of Croatia 2010 (Croatian Bureau of Statistics, 2010), as representatives of the most wide-spread intensively-grown fruit crops in the whole country. They are: apple (*Malus domestica*), pear (*Pyrus domestica*), peach (*Prunus persica*) and nectarine (*Prunus persica* var. *nectarina*), apricot (*Prunus armeniaca*), sweet cherry (*Prunus avium*), sour cherry (*Prunus cerasus*), plum (*Prunus domestica*), walnut (*Juglans regia*), hazelnut (*Corylus avellana*), almond (*Prunus dulcis*), fig (*Ficus carica*), olive (*Olea europaea*), and grapevine (*Vitis vinifera*). Mature pruning of the observed continental crops was carried out in the orchards near the town of Daruvar (45° 35' 20.75" S 17° 13' 28.84" E), while the pruned biomass of the Mediterranean crops was taken from the orchards, vineyards and olive groves at different locations near the town of Zadar (43° 54' 36.53" S 15° 30' 27.85" E). These sites are chosen on the basis of the fact that they are located in the centres of their respective areas, *i.e.,* they are the respective centres of the continental Croatia and of the Mediterranean area of the country.

The samples were taken directly after pruning of continuous plantations, where pruned biomass was weighted immediately after pruning. After sampling, all observed biomass was ground at < 0.5 mm in a laboratory mill (IKA MF 10, Germany). The ground samples were spread in a thin layer and kept in these conditions for several days, so that their moisture could be levelled up to the atmosphere moisture content. Since the pruned biomass was taken from various crops and cultivated forms and from the plantations of various ages (between 5 and 10 years old), the samples were separated after grinding and drying in order to obtain a representative homogenous sample for further analysis. The samples of individual fruit crops were collected and then separated in the separator *via* two separations, each of them consisting of eight sub-separations (OJ, 2004).

In the biomass calculation, the data from the Statistical Yearbook of the Republic of Croatia 2010, page 262, were used. According to the statistics, the most significant crops in intensive farming were: grapevine (34,000 ha) and olive (14,971 ha), walnut (6,945 ha), apples (6,604 ha) and plum (4,754 ha), followed by sour cherry (2,430 ha), hazelnut (1,877 ha) peach and nectarine (1,225 ha), sweet cherry (836 ha), pear (484 ha), almonds (455 ha), figs (394 ha) and apricot (314 ha). This investigation used the pruned samples of thirteen different fruits mentioned above, which were obtained after winter-time pruning of branches.

The biomass samples were analysed in order to obtain the data on: lower heating value (adiabatic calorimeter C IKA 200, Germany); moisture (CEN/TS 14774-2:2004); ash (CEN/TS 14774:2004); volatile matter, coke and fixed carbon (CEN/TS 15148:2005). Levels of carbon, hydrogen, nitrogen, and sulphur were determined by use of a CHNS analyser (CEN/TS 15104:2005; CEN/TS 15289:2006) (Table 1).

Table 1. Average values (dry matter) of pruned biomass chemical analysis of investigated horticultural species

Crops	Moisture (%)	Ash (%)	Analyses (%)					Coke (%)	C_{fix} (%)	Volatile matter (%)	Lower heating value (MJ kg^{-1})
			C	H	N	O	S				
Apple	6.73b ± 0.85	1.52f ± 0.22	47.36c ± 6.53	6.42a ± 0.96	0.74b ± 0.08	45.3a ± 4.82	0.18a ± 0.02	19.77c ± 2.32	18.25b ± 2.29	73.50c ± 10.29	17.06ab ± 1.73
Pear	5.57c ± 0.81	3.98bc ± 0.42	46.53cd ± 6.04	5.91a ± 0.82	0.76b ± 0.13	46.6a ± 5.01	0.20a ± 0.01	20.57b ± 2.54	16.59c ± 2.09	73.86c ± 9.98	16.76b ± 1.85
Peach and nectarine	6.77b ± 0.80	1.59e ± 0.23	48.46ab ± 5.86	6.34a ± 0.79	0.61b ± 0.09	44.4a ± 4.79	0.19a ± 0.01	18.83d ± 2.71	17.24c ± 1.83	74.40c ± 11.03	17.73a ± 2.45
Apricot	6.09bc ± 0.63	1.99e ± 0.30	48.16b ± 6.23	6.47a ± 0.96	0.54c ± 0.09	44.64a ± 4.42	0.19a ± 0.01	18.09d ± 2.87	16.10d ± 1.75	74.42c ± 11.15	17.19a ± 2.58
Sweet cherry	6.09bc ± 0.79	2.64d ± 0.33	46.11d ± 5.78	6.69a ± 1.01	1.02a ± 0.10	45.98a ± 4.71	0.20a ± 0.01	20.94b ± 3.05	18.30b ± 2.01	72.97c ± 10.09	16.76b ± 2.02
Sour cherry	6.88b ± 0.98	2.69d ± 0.29	45.76d ± 5.23	6.83a ± 0.94	0.92a ± 0.12	46.3a ± 5.01	0.19a ± 0.01	21.69a ± 3.11	19.00a ± 2.72	71.43d ± 9.83	17.13a ± 2.33
Plum	5.94c ± 0.87	3.89bc ± 0.55	48.15b ± 7.24	6.52a ± 0.87	0.81b ± 0.10	44.34a ± 4.95	0.18a ± 0.01	20.24b ± 2.89	16.35bc ± 1.99	73.82c ± 9.03	17.12a ± 2.51
Walnut	3.65d ± 0.42	5.39a ± 0.58	47.92bc ± 6.11	6.51a ± 0.92	0.99a ± 0.12	44.38a ± 4.87	0.20a ± 0.02	20.90b ± 2.62	19.00a ± 2.54	71.43d ± 8.95	16.31b ± 2.05
Hazelnut	5.12c ± 0.56	3.81bc ± 0.52	46.46d ± 5.55	6.57a ± 1.01	0.78b ± 0.11	45.98a ± 6.85	0.21a ± 0.02	16.81e ± 2.33	13.05e ± 1.67	78.02a ± 8.43	17.47a ± 2.11
Almond	6.68b ± 0.69	3.38c ± 0.50	49.28a ± 6.78	6.51a ± 0.83	0.67b ± 0.07	43.34a ± 5.55	0.20a ± 0.01	20.55b ± 2.57	13.87e ± 2.02	76.07b ± 9.11	17.63a ± 2.46
Fig	8.83a ± 1.24	5.19a ± 0.76	45.55d ± 5.01	6.35a ± 0.68	1.05a ± 0.09	46.86a ± 6.04	0.19a ± 0.01	21.79a ± 3.02	16.60d ± 2.02	69.38d ± 9.70	15.60c ± 2.22
Olive	6.37b ± 0.69	4.44b ± 0.56	46.54cd ± 6.01	6.45a ± 0.75	0.77b ± 0.10	46.04a ± 5.99	0.20a ± 0.01	16.72e ± 2.32	12.30f ± 1.68	76.07b ± 9.01	16.91ab ± 2.19
Grapevine	8.01a ± 1.09	2.12de ± 0.28	47.46bc ± 5.59	6.81a ± 0.92	0.62b ± 0.07	44.91a ± 5.79	0.20a ± 0.02	21.12a ± 2.93	19.01a ± 2.22	73.25c ± 8.63	17.05ab ± 2.06

Values followed by the same letter in a column are not significantly different according to LSD test ($p < 0.05$).

As for the quantification of the biomass in this investigation, it was performed on the selected continuous plantations that had been set up based on the instructions from the literature (± 0.5 m). After pruning and weighting of the pruned biomass, mean values of each investigated fruit crop were determined. Based on these values and the data on planting distances total number of trees or vines of each investigated crop were determined, which was the basis for calculating the total annual quantity of pruned biomass for each crop. These methods and values are contained in Table 2.

All analyses were carried out in three replications, and average values were calculated for each individual analysis on the basis of the data obtained from these analyses.

Results

Table 1 shows the average lower heating values, proximate and ultimate analysis of thirteen different fruit pruned samples. Moisture, ash content, coke, volatile matter and fixed carbon are considered as proximate analysis and they were determined on weight fraction on dry basis (wt.% on dry basis). Carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulfur (S) contents are considered as ultimate analysis. They also were determined using the weight fraction on dry basis (wt.% on dry basis).

It can be observed that ash content varied from 1.52% weight on dry basis in apple to 8.83% weight on dry

Table 2. The highest possible amount of pruned biomass from intensive farming areas in Croatia

Crop	Planting distance (m)	Number of trees or vines	Number of trees or vines ha^{-1}	Average biomass (kg per tree or vine)	Total biomass (kg ha^{-1})
Apple	3.50 × 1.20	15,684.500	2,375	2.34	5,557.5
Pear	3.50 × 1.20	1,149.500	2,375	2.45	5,818.7
Peach and nectarine	5.5 × 4.5	486.325	397	7.23	2,870.3
Apricot	6.5 × 5.5	87.920	280	5.79	1,621.2
Sweet cherry	6.5 × 6.5	281.732	337	5.90	1,988.3
Sour cherry	5.5 × 4.5	981.720	404	5.37	2,169.5
Plum	6.5 × 5.5	1,331.120	280	7.34	2,055.2
Walnut	8.5 × 7.5	1,090.365	157	3.43	538.5
Hazelnut	5.5 × 3	1,137.462	606	3.05	1,848.3
Almond	6.5 × 5.5	127.400	280	5.81	1,626.8
Fig	6.5 × 5.5	110.320	280	4.58	1,282.4
Olive	6 × 6	4,161.938	278	9.08	2,524.2
Grapevine	1.90 × 1.10	162,554.000	4,781	0.89	4,255.1

basis in fig. Volatile matter varied between 69.38% in fig and 78.02% in hazelnut. Fixed carbon varied between 12.30% in olive and 19.00% in walnut. The contents of C, H, O, N and S show that these biomass fuels have a higher share of carbon content compared to hydrogen and oxygen, which increases their energy value. With the exception of pear, in sour cherry and fig the oxygen content is higher than carbon content. The weight fraction of carbon ranged from 45.55 in fig to 49.28% in almond, hydrogen from 5.91% in pear to 6.83% in sour cherry, oxygen from in almond 43.34 to 46.86% in fig. The nitrogen content ranged from 0.54% in apricot to 1.05% in fig, sulphur ranged from 0.18% in plum to 0.21% in hazelnut.

Based on the presented distance between and within the plantations and average number of trees and vines per hectare, Table 2 presents the pruned biomass for each investigated crop (kg per tree or vine) and for total quantity of potential pruned biomass per hectare (kg ha^{-1}).

On the whole, the pruned horticultural biomass of Croatia in intensive farming amounts to average 60.04 tons per hectare in mature pruning, or slightly above 4.5 million tons per year.

In terms of crops, the largest amount of biomass after pruning remains in fig, with 9.08 kg of biomass per tree; in plum with 7.34 kg of biomass per tree; and in peach and nectarine with 7.23 kg of biomass per tree. Taking into account the planting distance*, i.e.,* number of trees or grapevines per hectare, it can be established that the largest amounts of biomass remain on the continuous plantations of peach and nectarine (28,760.3 kg ha^{-1}), plums (5,818.75 kg ha^{-1}), and apples (5,557.5 kg ha^{-1}).

Based on the analysis of energy values (MJ kg^{-1}) of all investigated pruned biomass samples, Table 3 presents total energy potential for each crop and the overall potential for Croatia. The resulting energy values varied from 17.727 MJ kg^{-1} (peach and nectarine) to 15.602 MJ kg^{-1} (fig). In terms of quantity of the pruned biomass by tree the largest potential is obtained from: olive (153.497 MJ ha^{-1}), peach and nectarine (128.164 MJ ha^{-1}), and plum (125.333 MJ ha^{-1}). However, in terms of pruned biomass by one hectare of surface the largest amount of energy would be obtained from the continuous plantations of pears (97,498.50 MJ ha^{-1}), apples (94,814.75 MJ ha^{-1}) and grapevine (72,546.89 MJ ha^{-1}). Also, on the basis of the data from Table 3 for the year 2010 the energy values of the pruned biomass in the Croatian continuous plantations were as follows: grapevine 2466.59 TJ, olive 638.84 TJ, apple 626.13 TJ, plum 166.82 TJ, peach and nectarine 62.32 TJ, walnut 60.90 TJ, hazelnut 60.60 TJ, pear 47.17 TJ, sour cherry 31.07 TJ, sweet cherry 27.85 TJ, almond 13.04 TJ, fig 7.88 TJ and apricot 7.84 TJ; which is totals 4217.05 TJ or 4.21 PJ.

Table 3. Potential amount of useful energy from investigated crops

Crop	MJ tree^{-1}/ grapevine^{-1}	MJ ha^{-1}	Potential of Croatia (TJ)
Apple	39.92	94,814.75	626.13
Pear	41.05	97,498.50	47.17
Peach and nectarine	128.16	50,881.10	62.32
Apricot	89.22	24,981.88	7.84
Sweet cherry	98.86	33,315.82	27.85
Sour cherry	91.99	37,167.19	31.07
Plum	125.33	35,092.40	166.82
Walnut	55.93	8,781.01	60.90
Hazelnut	53.28	32,287.68	60.60
Almond	102.42	28,678.72	13.04
Fig	71.45	20,006.28	7.88
Olive	153.50	42,672.16	638.84
Grapevine	15.17	72,546.89	2,466.59
Total			4,217.05

Discussion

As explained in the introduction, the investigated pruned biomass was measured against the norm CEN/TS 14961 (2005) for broad-leaf wood because the norm for fruit and viticulture production has not been defined yet. According to (CEN/TS 14961, 2005) typical GCV value for broad-leaf wood on dry basis is 18.9 MJ kg^{-1}. The proximate analysis of broad-leaf wood on dry basis is 0.3% to ash (CEN/TS 14961, 2005). The quantity of volatiles in biomass fuels is high and usually varies between 76% and 86 % on dry basis in woody biomass (Vanloo & Koppejan, 2002); quantity of fixed carbon varies from 15% to 25% according to the same literature sources, but they are not defined in CEN/TS 14961 (2005), same as the weight fraction which was investigated by Suárez-García *et al.* (2002) and Fernandez-Llorente & Carrasco-García (2008). They established that weight fraction was in the range between 38.9% and 46.23% in pruned grapevine and olive biomass. In general, the ultimate analysis of broad-leaf wood species is as follows: 49% carbon, 6.2% hydrogen, 44% oxygen, 0.1% nitrogen, 0.02% sulfur (CEN/TS 14961, 2005).

The presented ranges of the lower heating values indicate that the values obtained in fruit crops are somewhat lower than those reported in the CEN/TS 14961 (2005) norm for broad-leaf wood. The data of this technical specification were obtained mainly from a combination of the researches carried out in Sweden, Finland, Denmark and Germany. These values describe properties that can be found in Europe in general. It is also evident that the found ash content values are significantly different from the prescribed levels. The reason for such discrepancies in lower heating values and especially ashes levels could be found in higher lignin content in the investigated fruit crops. In general, the ash content can be connected to the average temperatures of the sites from which the samples were taken. However, this should not be considered as a rule. The samples of olive biomass and grapevine biomass were taken from the Mediterranean areas of Croatia, and together with hazelnut, they contain more ashes than any other investigated crop. The values of volatile matter are somewhat lower that the ones set out by the norms, while the percentage of fixed carbon is within the range of the values set for almost all fruit crops. The ultimate analysis is essential as it determines the theoretical air–fuel ratio in thermo-conversion systems and calculates the heating values; it also indicates the pollution potential. This study shows that the major elemental constituents of biomass are carbon, oxygen, and hydrogen. The measured values of these three components for specific crops slightly differ from the range reported in the CEN/TS 14961 (2005) norm for broad-leaf wood. By comparing the results for nitrogen and sulphur against the norm-based values, it could be noticed that there were minor differences in nitrogen but more substantial values were found in sulphur. These two elements were not within the accepted limits according to the CEN/TS 14961 (2005) norm. However, when comparing the obtained values with those of Suárez-García *et al.* (2002) and Fernandez-Llorente & Carrasco-García (2008) found in grapevine and olive, we can notice that in most measurements the results from this study do not significantly differ from those found in the relevant literature, except in percentage share of carbon (grapevine 47.46; olive 46.54) and sulphur (grapevine and olive 0.20). The analysed values of combustible and non-combustible matters showed that pruned horticultural biomass residues can be considered as an ecologically acceptable biofuel.

The available data on pruning residues are scarce, as corroborated by Scarlat *et al.* (2011). However, several studies proposed some figures for the ratios of residue to product yields for pruning (Di Blasi *et al.*, 1996; Radojevic *et al.*, 2007; Spinelli *et al.*, 2010). These data show certain discrepancies and must be used with caution, as well as the results obtained in this study.

Comparing the results obtained by Spinelli *et al.* (2010) who collected pruned biomass in the olive-groves (2.8 t ha^{-1}) and Radojevic *et al.* (2007) who also carried out similar investigations in the orchards (peach 3.5 t ha^{-1}; apple 4.9 t ha^{-1}; plum 2.8 t ha^{-1}), some divergences are evident in the collected biomass of fruit crops, which may be the result of different climate conditions, pruning methods and land reclamation on the continuous plantations. The obtained results of the heating values are in accordance with Cao *et al.* (2006), Di Blasi *et al.* (1996) and Kricka *et al.* (2010). In terms of quantity of the pruned biomass similar values were obtained by Radojevic *et al.* (2007).

The fruit growers in Croatia in general have no experience in preparation and use of pruned biomass for producing energy. Burning was the only method of dealing with the pruned biomass after collection. Therefore, now there is a need for introducing new technologies in the use of this material. The introduction of new technologies for energy use of biomass, contributing to environmental protection as well, is the most important task in the future utilization of this sort of biomass in the EU, Croatia included. At today's marketplace there is a wide selection of equipment and machinery that facilitate the use of this sort of biomass, but for most of the farmers these products are still hardly affordable either because they require relatively high initial investments or because of insufficient education in this matter. However, the producers' rings, clusters or large-scale producers should recognize the value of this way of using the pruned biomass mainly because of its long-term economic and environmental benefits.

According to the Croatian energy strategy of 2010, the Croatian energy consumption in all sectors would amount to about 310.6 PJ. If potential energy from pruned biomass of 4.21 PJ is accounted, it can be calculated that this sector of agriculture contributes to the energy independence of Croatia and to the country's meeting the biofuels targets in total consumption with slightly more than 1%.

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