WFL Publisher
Science and Technology
Meri-Rastilantie 3 B, FI-00980
Helsinki, Finland
e-mail: info@world-food.net

Journal of Food, Agriculture & Environment Vol.11 (3&4): 1485-1491. 2013
www.world-food.net

Prediction and evaluation of biomass obtained from citrus trees pruning

B. Velázquez-Martí [1], E. Fernández-González [1], I. López-Cortés [2] and A.J. Callejón-Ferre [3]*

*[1] Departamento de Ingeniería Rural y Agroalimentaria, [2] Departamento de Producción Vegetal, Universidad Politécnica de Valencia, Camino de Vera s/n, 46022 Valencia, Spain. [3] Departamento de Ingeniería, Universidad de Almería, Ctra. Sacramento s/n 04120, La Cañada de San Urbano, Almería, Spain. *e-mail: borvemar@dmta.upv.es, islocor@esp.upv.es, acallejo@ual.es*

Received 18 June 2013, accepted 22 October 2013.

Abstract

The aim of this work was to evaluate the amount of residual biomass obtained from citrus tree plantations. This amount is influenced by the variety and aim of the pruning. The trials show that the amount of pruned biomass can be considered similar in the varieties Naveline and Washington Navel, giving an average 4.73 kg per tree and 2.68 tons per hectare. The Valencia Late produced about 48% more than the other evaluated varieties. The amount of residual biomass per tree obtained in formation pruning was about 49% lower than the trees in full production, giving 4.7 tons of dry biomass per hectare. Furthermore, the amount of pruned biomass from mandarin varieties studied show that they can be classified two groups. Varieties Clemenvilla and Owall form the first homogeneous group with bigger amount of residues with average 9.6 kg per tree and 6.9 tons per hectare, while the second homogeneous group included by the rest of varieties, with 3.8 kg per tree and 2.9 tons per hectare. Factors, such as age or growing space per tree increase the wood residues production to 66% and 53.3%, respectively, in mandarin trees. Regression equations have been modeled to predict the available biomass per tree and per hectare from dendrometic characteristics of the trees. The coefficients of determination have been acceptable. The drying process of pruned materials has been depicted. The density and gross power heat have been measured. The information offered by these equations is of vital importance to estimate the amount of biomass that is generated in a given area, and for implementing GIS maps. In addition, logistic algorithms can be applied.

Key words: Bioenergy, agricultural wastes, wood energy, biomass.

Introduction

Annual pruning is a necessary operation in citrus trees that means of physiological control to foster optimal and continual production in plants [1]. On eliminating branches, the number of fruits per plant is reduced and the nutrients are better distributed, as achieving bigger fruits. Badly formed or damaged branches that are going to produce defective fruit are eliminated. The inner part of the tree is better illuminated, generally improving the quality of production and reducing the alternate bearing [2, 3]. The search for alternatives to fossil fuels makes necessary the evaluation of biomass resources by means of spatial inventories, which allow planning the supply to facilities for combustion, pyrolysis, or other uses such as production of processed products. A big quantity of residual biomass can be obtained from the management of agricultural systems in Mediterranean areas but the residual biomass coming from fruit-bearing or herbaceous plants is very variable according to species, varieties, planting distances or systems of cultivation. For this reason specific studies are necessary. This work continues the studies presented by other authors [4-6], where equations to predict residual biomass from pruning of the several fruit trees were shown. In these works, it is shown that these wood residues depend on a lot of variables, some of them related with dendrometric parameters, other of cultivation factors such as irrigation, or climatology. The information offered by these equations is of vital importance to estimate the amount of biomass that is generated in a given area, and for implementing GIS maps. In addition, logistic algorithms can be applied, such as Borvemar model, which locates biomass concentration points for its distribution from GIS digital maps [7]. This algorithm is based on searching points with a minimum amount of available biomass in a limited area. Therefore the amount of biomass in every plot in an area must be studied to apply the method. Another possible model is bioloco model (Biomass Logistics Computer Optimization) [8, 9]. This algorithm provides a logistic model based on graphs, where source (sources of biomass) and destination nodes (biomass processing plants) exist, connected by arcs that represent costs or distances. This model calculates the optimal nodes which must supply the destination nodes at a given time depending on the seasonality of the sources. Bioloco can use Borvemar model to determine the nodes and then, select which ones are the best at all times. The implementation of these models is only possible if the amount of biomass can be calculated. A lot of studies have been carried out in forest areas [10, 11], but few tools have been studied in agricultural systems, especially in fruit trees [12], and some of the most important were carried out by more authors [13-16]. This study is focused on the quantification of the residues obtained in the pruning of citrus trees. Some factors that influence in the amount of biomass obtained are evaluated.

Materials and Methods

The amount of residual biomass to draw from the orange and mandarin tree orchards depends on its cultivation characteristics. The quantification carried out in this study is based on typical pruning operations performed annually in the Spanish

Mediterranean plots. The trees were pruned with the following criteria: Twigs, stumps, pacifiers or branches with breaking risk were removed. Branches hindering access and low lighting were also cut. The crown was cleared of excessive branches. Sprouts (also known as "water sprouts", "shoots", or "suckers"), that arise almost perpendicularly from above the bud union and the trunk, or large limbs are usually unproductive and should be pruned off, were removed. Some larger branches were removed to allow light penetration in areas of excessively dark interior canopy, where no fruit is produced. For formation pruning in small trees, weak branches were removed in order to favour larger branches that will form the scaffold lambs of the tree.

300 productive plots were evaluated, of which 150 belong to orange tree plantation and 150 to mandarin tree plantation. All of them were irrigated by drip irrigation. These plots were older than 10 years. In addition, the pruning of other 12 plots orange tree and 10 plots mandarin in formation process were also measured. These were plots between 4 and 10 years old. Tables 1 and 2 show the levels of studied factors. The chosen varieties are most produced in Spanish Mediterranean region, as can be observed in the Figs. 1 and 2 [17].

Before the pruning, the following data were determined:

Table 1. Factors and levels tested for the quantification of biomass from pruning in orange trees.

Factor	Number of levels	Number of plots	Levels
Variety	3	150	Valencia Late (36), Washington Navel (75), Naveline (39)
Tree growing space	2	76	$<15m^2$
		74	$>15m^2$
Fruit yield	2	98	<50 t ha^{-1}
		52	>50 t ha^{-1}
Aim of pruning	2	12	Formation pruning
		150	Production pruning

Table 2. Factors and levels tested for the quantification of biomass from pruning in mandarin trees.

Factor	Number of levels	Number of plots	Levels
Variety	13	150	Clemenules (16), Clemenpons (10), Clemenvilla (14), Fortune(8), Marisol(14), Mioro(8), Nova(8), Okitsu(12); Orogrande(12), Oronules(16), Ortanique(16), Owall(8) and Primosol(8)
Tree growing space	2	76	$< 15m^2$
		74	$> 15m^2$
Fruit yield	2	98	< 50 t ha^{-1}
		52	> 50 t ha^{-1}
Aim of pruning	2	10	Formation pruning
		150	Production pruning

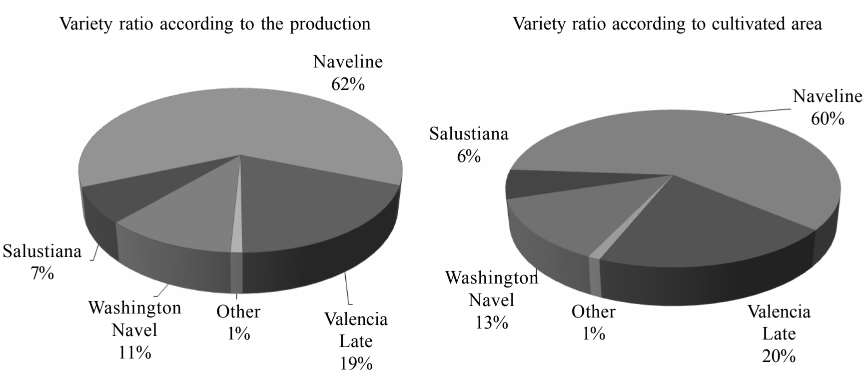

Figure 1. Ratio of the orange varieties produced in Spain.

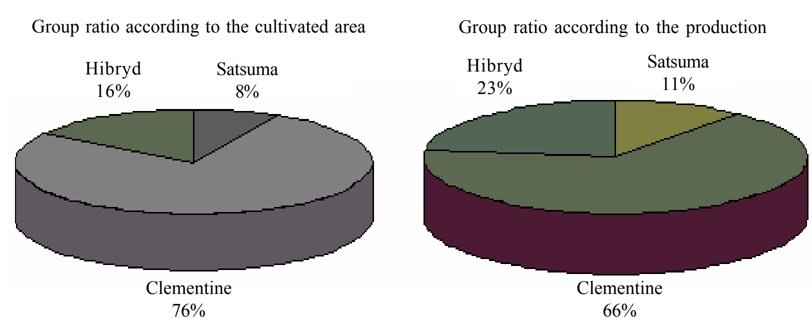

Figure 2. Ratio of the mandarin varieties produced in Spain.

(1) Plot data: Variety, planting distances, presence or absence of irrigation, plantation age, fruit production, intensity of the last pruning and frequency.
(2) Tree data: Stem diameter, crown diameter, total tree height and height from the soil to first. Tables 3 and 4 show the sizes of the evaluated trees.

Given the large number of existing varieties of mandarins, we proceed to include them in their corresponding taxonomic group:
(1) Clementine: Clemenpons, Clemenules, Marisol, Mioro, Orogrande, Oronules, Primosol.
(2) Satsuma: Okitsu, Owall.
(3) Hybrid: Clemenvilla, Fortune, Nova, Ortanique.

After pruning, bundles of the residual materials were weighed by means of a dynamometer. Mass measurement in the field was carried out with moist materials for each sampled tree. Five branches of each tree were manually defoliated and weighed to determine the percentage mass of leaves and wood. Samples of wood were then put into plastic containers to measure moisture content and to calculate dry ligneous biomass of all pruned materials. The moisture content wet basis was measured for each sampled orchard. From this value the dry matter was calculated for each tree. From the distance between the trees (space of plantation) and the average biomass obtained for each variety in each orchard, the amount of dry biomass per hectare was estimated.

The evolution of the drying process was studied under two types of conditions: open-air drying at an average temperature of 17ºC and relative humidity of 35%; and stove-dried at 105ºC, as is indicated in the norm UNE-CEN/TS 14774 2004. Solid biofuels. Method for the determination of moisture content. Daily measurements were carried out until the weight of the samples was stabilized. After the process of dried the density was measured by means of the norm UNE-CEN/TS 15103 EX: Solid biofuels. Method for the determination of bulk density. Finally, there have been realized tests of determination of the gross heating power. Wood from pruning trees was analyzed in the laboratory by means of a calorimeter, following the norm UNE 164001 EX: Solid biofuels. Method for the determination of caloric value. Ultimately, the ratio of bark in the branches of the orange trees according to the diameter was analyzed to verify the aptitude of the material for some applications in the wood industry. Sometimes they are rejected by the industry because of the high amount of bark. To determine the percentage of bark of the samples, the diameter of the stem with bark, and the diameter without bark were measured by means of a digital calibre of precision.

Results and Discussion

The quantification of residual biomass obtained from pruning operations is shown in the Table 4. It can be observed that the dried wood biomass per tree can be between 4 and 9 kg per tree. About the 50% weight of fresh biomass were leaves. The moisture content of the wood biomass was between 35 and 45%. These results do not differ of the data obtained by other authors [18, 19]. Leyva [18] pointed an average residual biomass of 4.6 t ha^{-1} of dry biomass in oranges, but he doesn't specified the varieties tested. On the other hand, Ferrer [19] pointed out that the amount of residual dry biomass obtained in the pruning of orange trees is 3.5 t ha^{-1}.

Orange trees: The Least Significative Difference intervals (LSD) were obtained from ANOVA analysis of the varieties (Fig. 3). According to residual biomass obtained per tree, they points out that differences between Washington N. and Naveline do not exist. Nevertheless, residual biomass from Valencia Late, which is a white variety, is significantly bigger than biomass from Washington N. and Naveline. This could be becauseValencia Late trees were generally larger than the other trees.

To compare the amount of pruned biomass in the trees in production and the formarion stage, the type of pruning was analyzed by LSD intervals, which are depicted in the Fig. 4. Obviously, significative differences are shown. The amount of residual biomass per tree obtained in formation pruing is about 65% lower than the trees in full production, giving as mean 1.3 tones of dry biomass per hectare.

Fig. 5 shows the results obtained by analyzing the effect of the tree growing area in the production of biomass in orange trees. The LSD of the ANOVA analysis indicate that there are no significant differences between the selected areas, and large dispersion exists in the amount of pruned biomass for short distances of plantation (lower than 15 m^2 per tree). This could be related to more pruning intensity in those situations, where the crown touch the crown of other trees, and the farmer looks for bigger lighting with this operation.

Table 3. Characteristics of the measured of the orange trees.

	Oranges						Mandarins					
	Valencia Late		Washington Navel		Naveline		Clementine		Satsuma		Hibryd	
	Av.	S.D.	Av.	S.D.	Av.	S.D.	Av.	S.D.	Av.	S.D.	Av.	S.D.
Stem diameter (cm)	16.35	0.95	10.90	3.18	16.06	5.24	14.31	5.20	18.72	6.88	16.73	4.51
Diameter of crown (m)	4.00	0.52	3.05	0.74	3.38	0.72	3.31	0.66	3.89	1.01	3.51	0.78
Height of the crown (m)	0.47	0.05	0.39	0.15	0.35	0.12	0.45	0.11	0.42	0.08	0.36	0.11
Height of the tree (m)	3.58	0.26	2.14	0.55	2.76	0.52	2.64	0.47	2.69	0.43	2.73	0.48
Yield (t ha^{-1})	30.00	10.12	22.38	16.43	47.28	21.25	55.69	40.88	43.44	1.02	29.25	13.82
Age of trees (years)	8.00	1.25	6.00	2.94	16.76	7.80	12.38	7.40	21.21	11.71	13.03	5.01

Table 4. Quantified in pruned biomass from orange trees in full production.

	Variety	kg fresh wood biomass with leaves $tree^{-1}$	kg biomass without leaves $trees^{-1}$	kg dried wood biomass $tree^{-1}$	t dried wood biomass ha^{-1}	Standard deviation t dried wood biomass ha^{-1}
Oranges	Valencia Late	28.76	15.70	9.41	4.70	0.56
	Naveline	16.47	9.00	5.39	2.97	1.47
	N. Washington	12.45	6.80	4.08	2.40	1.75
Mandarins	Clementine	14.97	8.62	5.14	3.49	2.92
	Hibryd	15.02	8.65	5.16	4.05	3.77
	Satsuma	14.21	8.19	4.88	3.33	3.73

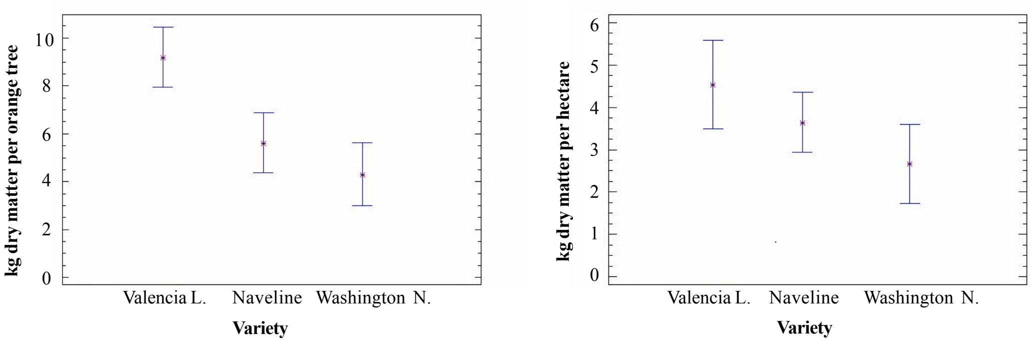

Figure 3. LSD intervals for factor "variety" in orange with a confidence level of 95%.

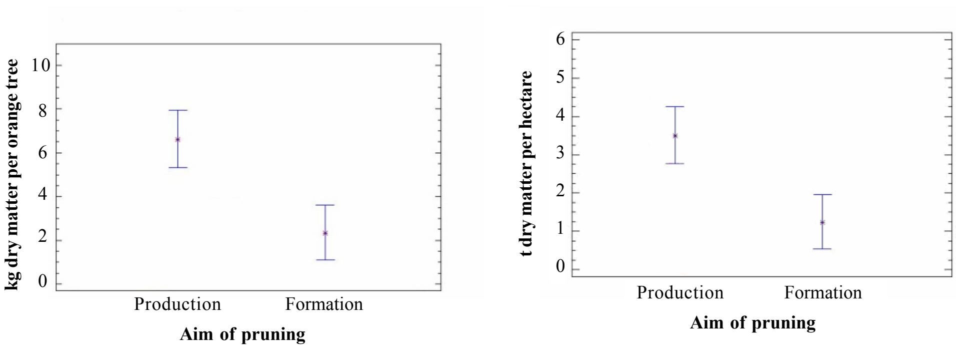

Figure 4. LSD intervals for the factor "aim of pruning" in orange with a confidence level of 95%.

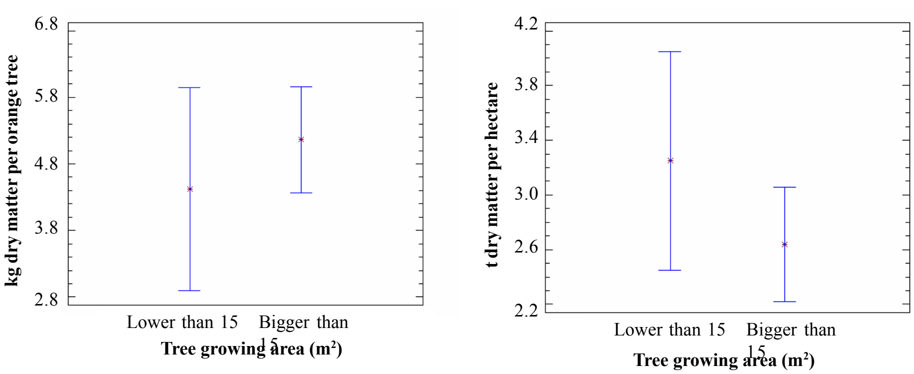

Figure 5. LDS intervals for the factor "tree growing area" in orange with a confidence level of 95%.

Mandarin trees: Tables 5 and 6 show the results obtained in the multiple contrast of the amount of residual biomass from pruning. As it can be seen, the studied varieties can be classified in two groups according to the kg of biomass obtained per tree, and three groups according to tons of biomass obtained per hectare.

According to pruned biomass per tree, there are two distinct groups of production. Clemenules, Clemenvilla and Owall form the first group of classification, which generates the biggest average, 9.6 kg per tree and 6.9 tons per hectare, while the second group includes the other varieties of mandarins, which have a lower amount of pruned biomass, with average 3.8 kg per tree and 2.9 tons per hectare.

According to pruned biomass obtained per hectare, the mandarin varieties could be classified into three groups. The group with the biggest amount would include Clemenvilla and Oroval. The group with the lowest amount of residual biomass could include Nova, Mioro. Fortune, Okitsu, Marisol, and Clemenpons. A group of transition, with intermediate residue production would be Clemenules, Primosol, Oronules, Ortanique, Orogrande and Marisol.

Fig, 6 shows the least significant Ddifference intervals (LSD) that analyze the influence of tree growing area. When this area is lower than 15 m^2, the amount of biomass generated per tree is lower than those grown in upper area. Nevertheless, smaller growing area generated higher amount of biomass per hectare because more trees exist. Plots with more than 15 m^2 per tree produce 3 t residual biomass per hectare. Plots with less than 15 m^2 per hectare reach 4.5 t ha^{-1}.

Several regression models were developed to predict the dry biomass obtained per orange and mandarin trees in pruning operations (Bot and Bmt) from variables that influence the available amount, explicative or independent variables. Regression models were also calculated that relate the residual biomass obtained per hectare (Boh and Bmh) with these variables. Initial testing, for simplicity, was by a linear model. Subsequently, to improve the coefficient of determination (r^2) non-linear relations formed by the squares or products of the independent variables were analysed. The results are shown in Table 7. The characteristic parameters of the regression models calculated are in Table 8. In the following list, only the statistically significant variables in the

Table 5. Homogeneous groups mandarin kg per tree.

	Variety	kg dried wood tree^{-1}	Sigma LSD	Homogeneus groups		
Mandarin pruning	Nova	2.150	1.045	X		
	Clemenpons	2.863	1.169	X	X	
	Mioro	2.880	1.169	X	X	
	Okitsu	2.948	0.739	X	X	
	Fortune	3.191	1.045	X	X	
	Primosol	3.375	1.169	X	X	
	Oronules	3.395	0.826	X	X	
	Ortanique	3.901	0.826	X	X	
	Orogrande	4.648	0.675		X	
	Marisol	4.889	0.675		X	
	Clemenules	7.823	0.551			X
	Clemenvilla	9.540	0.826			X
	Owal	9.727	1.169			X

Table 6. Homogeneous groups mandarin tons per hectare.

	Variety	t dried wood biomass ha^{-1}	Sigma LSD	Homogeneus groups				
Mandarin pruning	Nova	1.170	0.743	X				
	Mioro	1.600	0.830	X	X			
	Fortune	1.773	0.743	X	X			
	Okitsu	2.052	0.525	X	X			
	Marisol	2.847	0.479	X	X	X		
	Clemenpons	3.272	0.830	X	X	X	X	
	Clemenules	3.554	0.391		X	X	X	
	Primosol	3.858	0.830			X	X	
	Oronules	3.881	0.587		X	X	X	
	Ortanique	4.053	0.587			X	X	
	Orogrande	4.398	0.479				X	
	Owal	6.530	0.830					X
	Clemenvilla	7.292	0.587					X

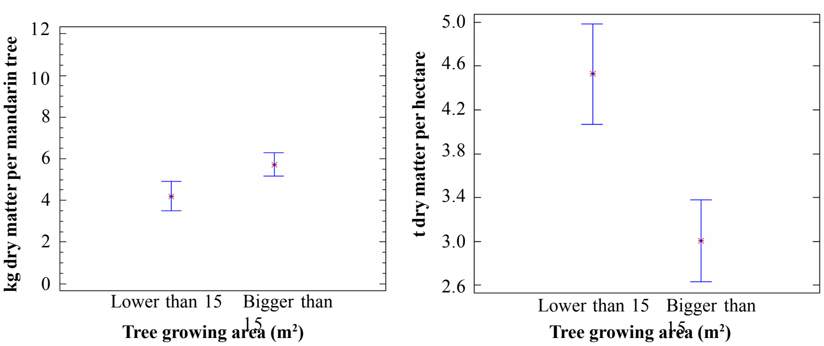

Figure 6. LSD intervals for the factor "Tree growing area" in mandarin with a confidence level of 95%.

present analysis are named.

Quantitative variable:

(1) Height of tree (h). It indicates the height of the tree in m.

(2) Height from the soil to main branches bifurcation (Height of the crown) (hc)

(3) Diameter of the stem (dt) measured in m.

(4) Diameter of the crown (dc). Indicates the average of the diameters perpendicularly measured in m.

(5) Size of plantation (m). Represents the area occupied by each tree in the plot in m^2.

(6) Fruit production (p). The quantity of fruit in tons obtained per hectare.

Given that the p-value in the ANOVA tables is smaller than 0.01, there is a statistically significant relationship among the variables of the models, with a 99% level of confidence. The r^2 of the linear models to predict the available residual orange wood biomass from pruning is situated around 0.55. In the orange trees, linear models to predict the available biomass per hectare r^2 is 0.58. When quadratic models are studied, these values increase to 0.69 and 0.65, respectively. This indicates that the quadratic models explain approximately 65% of the changeability in the quantity of dry biomass obtained. We think that in natural systems, where a lot of uncontrolled factors exist, this value is acceptable. Introducing the quadratic components in the regression models can be seen to substantially decrease average absolute errors and dispersion. Average absolute errors are 0.712 kg tree^{-1} and 0.812 t ha^{-1} in quadratic models. These values represent the average error for the prediction obtained by using the quadratic equations calculated, Bot and Boh, respectively. The standard deviation indicates the prediction error dispersion, which is 1.123 kg tree^{-1} and 2.013 t ha^{-1}, respectively.

In mandarin case, r^2 of linear models is around 0.50. The quadratic models increase r^2 to 0.66 and 0.67. The application of this model gives give it a relative error decreased from 1.781 kg tree^{-1} to 1.608 t ha^{-1}. Table 8 shows the equations, quadratic and linear, obtained for the cultivation of orange and mandarin.

The evolutions of moisture content during the drying processes are show in Figs 7 and 8. It can be noted that the initial moisture content of the material after cutting was about 38% in wet basis in both drying process in orange wood, and 45% on mandarin wood. When both materials were dried in open air, the minimum moisture content was about 16% and 21%, respectively, in our conditions. The Gross Heating Power of the samples was mean 17.4 MJ kg^{-1} and 0.12 MJ kg^{-1} standard deviation.

A comparison of the densities between the different varieties of orange and mandarin groups was studied. They did not present significant differences in density. The average density of the samples is of 1.002 g cm^{-3} (Figs 9 and 10).

To assess the practical relevance of the obtained data, the amount of residual biomass from orange and mandarin trees pruning of Comunidad Valenciana (Spain) was extrapolated. The area cultivated with orange trees is about 78,189 ha in this region. The average of orange trees in the plantations is about 554 trees ha^{-1}. Considering 6.2 kg dried wood residues per orange tree coming from pruning, 468 million MJ can be obtained per year. On the other hand, the area cultivated with mandarin trees is about 82,918 ha in the same region. The average of mandarin trees in the plantations is about 540 trees ha^{-1}. Considering 5.1 kg dried wood residues per mandarin coming from pruning, 397 million MJ can be obtained per year. So, according to this study, the amount of energy that could be utilized from biomass pruning of citrus in the Comunidad Valenciana amounts to 865 million MJ.

Regression models were analyzed to predict the percentage of

Table 7. Characterization of models to predict the biomass obtained from the pruning of the citrus trees.

			R^2	Average absolute error	Standard dev. error	P-value
Orange	B_{ot} (kg tree^{-1})	Linear model	0.55	1.674	1.875	<0.01
		Quadratic model	0.69	0.712	1.123	<0.01
	B_{oh} (t ha^{-1})	Linear model	0.58	0.855	3.187	<0.01
		Quadratic model	0.65	0.812	2.013	<0.01
Mandarin	B_{mt} (kg tree^{-1})	Linear model	0.50	0.561	0.730	<0.01
		Quadratic model	0.66	1.355	0.015	<0.01
	B_{mh} (t ha^{-1})	Linear model	0.51	1.290	2.600	<0.01
		Quadratic model	0.67	2.586	3.256	<0.01

Table 8. Equations for the prediction of biomass obtained by the orange pruning.

Orange	Linear model	B_{ot} $(kg\ tree^{-1}) = -8.393 + 0.167 \cdot m + 1.038 \cdot dc + 2.645 \cdot h$
	Quadratic model	B_{ot} $(kg\ tree^{-1}) = -0.042 + 0.031 \cdot m \cdot e - 0.136 \cdot e \cdot dc - 0.002 \cdot p^2 + 0.078 \cdot p \cdot dc$
	Linear model	B_{oh} $(t\ ha^{-1}) = -3.438 + 1.047 \cdot h + 0.559 \cdot dc + 0.205 \cdot dt - 0.103 \cdot e$
	Quadratic model	B_{oh} $(t\ ha^{-1}) = -0.579 - 0.071 \cdot e \cdot dc + 0.007 \cdot p \cdot dc + 0.085 \cdot dt \cdot dc + 0.006 \cdot m \cdot e$
Mandarins	Linear model	B^{mt} $(kg\ tree^{-1}) = -8.727 + 1.359 \cdot dc + 0.078 \cdot e + 0.049 \cdot hc + 2.225 \cdot h$
	Quadratic model	B_{mt} $(kg\ tree^{-1}) = 10.629 - 4.109 \cdot dc + 0.384 \cdot e - 6.393 \cdot h + 2.233 \cdot dc \cdot hc - 0.012 \cdot e^2$
	Linear model	B_{mh} $(t\ ha^{-1}) = -1.117 + 1.871 \cdot h + 0.840 \cdot dc + 0.052 \cdot e - 0.281 \cdot m$
	Quadratic model	B_{mh} $(t\ ha^{-1}) = 4.043 + 1.279 \cdot h + 0.318 \cdot e - 0.951 \cdot 0 + 0.151 \cdot dc^2 - 0.006 \cdot e^2 + 0.022 \cdot m^2$

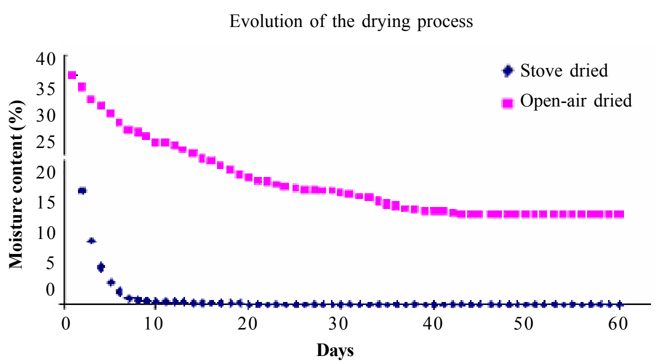

Figure 7. Evolution of the drying process in orange wood.

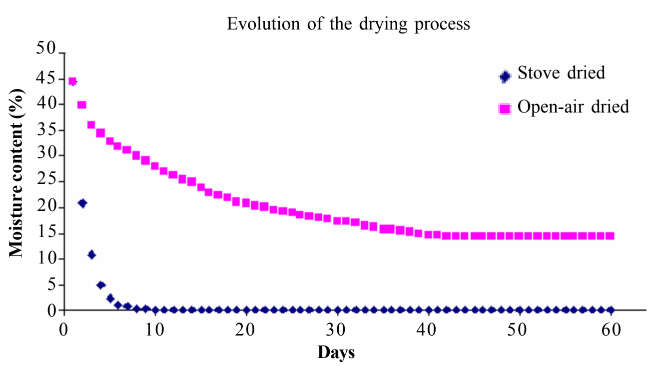

Figure 8. Evolution of the drying process in mandarin wood.

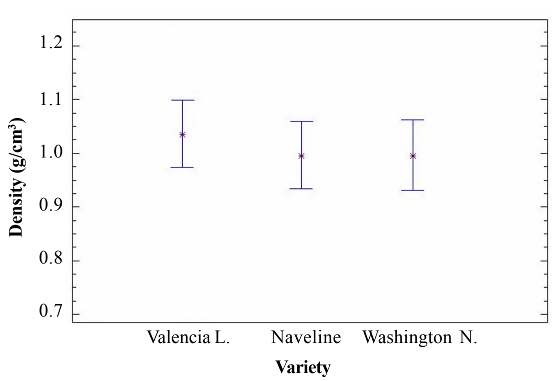

Figure 9. LSD intervals for wood density in orange trees with a confidence level of 95%.

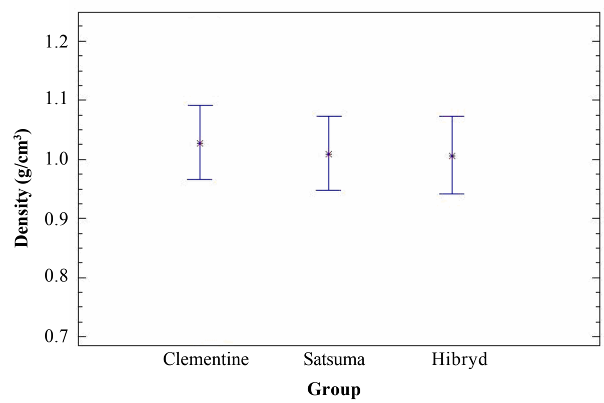

Figure 10. LSD intervals for wood density in mandarin groups with a confidence level of 95%.

bark according to pruned branch diameter. The exponential model points the best coefficient of correlation, although linear model is also acceptable. Both equations are shown in Tables 9 and 10, where % Bark is the percentage of bark in a section; Dcc is the diameter of the branch with bark (mm).

In both cases, the importance of % bark in branch resides in the inability of this material when the % bark exceeds a certain value, which precludes their use for the wood industry.

Conclusions

In this work the amount of residual biomass obtained from oranges and mandarins pruning has been quantified. The aim of this work was to evaluate the amount of residual biomass obtained from citrus. In orange, this amount is influenced by the variety and aim of the pruning. The trials show that the amount of pruned biomass can be considered similar in the varieties Navelina and Washington Navel, giving an average 4.73 kg per tree and 2.68 tons per hectare. The dispersion of these values is relatively high because a lot of uncontrolled conditions exist. The Valencia Late produces about 48% more than the other evaluated varieties. The amount of residual biomass per tree obtained in formation pruning is about 49% lower than the trees in full production. In mandarin this available amount of pruned biomass is very similar than orange trees, but this is more influenced by the tree growing area. When

Table 9. Equations for the prediction of percentage of bark in orange trees.

Type of equation	Equation	Coefficient of regression
Linear	$\% Bark = -0.976 \cdot \phi c.c + 37.846$	$r^2 = 0.773$
Exponential	$\% Bark = 45.279 \cdot e^{-0.5\phi cc}$	$r^2 = 0.808$

Table 10. Equations for the prediction of percentage of bark in mandarin trees.

Type of equation	Equation	Coefficient of regression
Linear	$\% Bark = -1.019 \cdot \phi c.c + 42.725$	$r^2 = 0.701$
Exponential	$\% Bark = 47.554 \cdot e^{-0.03\phi cc}$	$r^2 = 0.788$

this area is lower than 15 m^2, the amount of biomass generated per tree is lower than those grown in upper area. Nevertheless, smaller growing area generated higher amount of residual biomass per hectare because more trees exist.

Regresion equations have been modeled to predict the available biomass per tree and per hectare from dendrometic characteristics of the trees. The coefficients of determination have been acceptable. The information offered by these equations is of vital importance to estimate the amount of biomass that is generated in a given area, and for implementing GIS maps. In addition, logistic algorithms can be applied.

The drying process of pruned materials has been depicted. The average initial moisture content of the pruned mateials is 38 % in orange wood and 45% in mandarin wood.

The different studied varieties do not present significant differences in their dried density, about 1 g cm^{-3}. The gross heating power of dry matter proceeding from the orange tree is 17.4 MJ. Models of prediction were obtained to estimate the % of bark, having acceptable coefficient of determination.

Acknowledgements

The techniques shown in this paper were developed by the project AGL2007-62328 funded by the Ministry of Education and Science of Spain, and FEDER funds

References

[1]Guardiola, L., Monerri, C. and Agusti, M. 2008. The inhibitory effect of gibberellic acid on flowering in Citrus. Physiol. Plantarum **55**:136-42.

[2]Sartori, I., Koller, O., Theisen, S., de Souza, P., Bender, R. and Marodin, G. 2007. Pruning effect, hand thinning and use of growth regulators on 'Montenegrina' mandarin oranges (*Citrus deliciosa* Tenore). Rev. Bras. Frutic. **29**:5-10.

[3]Nesbitt, M. L., Ebel, R. C. and Dozier, W. A. 2008. Production practices for satsuma mandarins in the southeastern United States. HortScience **43**:290-292.

[4]Velázquez-Martí, B., Fernández-González, E., López-Cortes, I. and Salazar-Hernández, D. M. 2010. Quantification of the residual biomass obtained from pruning of trees in Mediterranean almond groves. Renew. Energ. **36**:621-626.

[5]Velázquez-Martí, B., Fernández-González, E., López-Cortes, I. and Salazar-Hernández, D. M. 2011a. Quantification of the residual biomass obtained from pruning of trees in Mediterranean olive groves. Biomass Bioener. **35**:3208-3217.

[6]Velázquez-Martí, B., Fernández-González, E., López-Cortes, I. and Salazar-Hernández, D. M. 2011b. Quantification of the residual biomass obtained from pruning of vineyards in Mediterranean area. Biomass Bioener. **35**:3453-3464.

[7]Velázquez-Martí, B. and Annevelink, E. 2009. GIS application to define biomass collection points as sources for linear programming of delivery networks. T. ASABE **52**:225-236.

[8]Annevelink, E. and de Mol, R.M. 2007. Biomass logistics. Workshop IEA Bioenergy Task32, 15th European Biomass Conference, Berlin, Germany.

[9]Diekema, W. H., De Mol, R. M., Annevelink, E. and Elbersen, H. W. 2005. Combining goals in the logistics bio-energy chains. 14th Euroean Biomass Conference, Paris, France, pp. 495-498.

[10]Cremer, T. and Velázquez-Martí, B. 2007. Evaluation of two harvesting systems for the supply chips in Norway spruce forest affected by bark beetles. Croat. J. For. Eng. **28**:145-155.

[11]Velázquez-Martí, B., Fernandez-Gonzalez, E., Estornell, J. and Ruiz, L. A. 2010. Dendrometric and dasometric analysis of the bushy biomass in Mediterranean forests. Forest Ecol. Manag. **259**:875-882.

[12]Askew, M. F. and Holmes, C. A. 2002. The potential for biomass and energy crops in agriculture in Europe, in land use, policy and rural economy terms (Reprinted from Aspects in Applied Biology **65**:365-374, 2001). Int. Sugar J. **104**:482.

[13]Di Blasi, C., Tanzi, V. and Lanzetta, M. 1997. A study on the production of agricultural residues in Italy. Biomass Bioener. **12**:321-333.

[14]Koopmans, A. and Koppejan, J. 1998. Agricultural and forest residues generation, utilization and availability. FAO. AEEMTRC/ASSN-NRSE Conference "Renewable Energy for project Developers, Users, Suppliers & Bankers, 22-26 May 1998, Bangkok, FAO. on line: http://wgbis.ces.iisc.ernet.in/energy/HC270799/RWEDP/acrobat/p_residues.pdf

[15]Spinelli, R. and Picchi, G. 2010. Industrial harvesting of olive tree pruning residue for energy biomass. Bioresource Technol. **101**:730-735.

[16]Spinelli, R., Magagnotti, N. and Nati, C. 2010. Harvesting vineyard pruning residues for energy use. Biosyst. Eng. **105**:316-322.

[17]CAPA 2009. Anuario estadístico agrario de la Comunidad Valenciana. Generalitat Valenciana, Valencia, Spain, 529 p. (in Spanish).

[18]Leyva, D. 1984. Ciencia y Técnica en la agricultura. Cítricos y otros frutales **7**:87-95 (in Spanish).

[19]Ferrer, E. 2006. Estudios Sobre la incorporación de los restos de poda de cítricos en diferentes municipios de la provincia de Valencia. Levante agrícola **379**:24-28 (in Spanish).