Article

Quantification Model of Residual Biomass in Citrus Uprooting

Isabel López-Cortés [1], Borja Velázquez Martí [2,*], Javier Estornell [3], John Eloy Franco Rodríguez [4], Jesús Martí-Gavilá [3] and Domingo Salazar Hernández [1]

[1] Departamento de Producción Vegetal, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain; islocor@upv.es (I.L.-C.); dsalazar@upv.es (D.S.H.)
[2] Departamento de Ingeniería Rural y Agroalimentaria Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain
[3] Departamento de Ingeniería Cartográfica, Geodesia y Fotogrametría, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain; jaescre@cgf.upv.es (J.E.); jemarga@upv.es (J.M.-G.)
[4] Facultad de Educación Técnica para el Desarrollo, Universidad Católica de Santiago de Guayaquil, Av. Carlos Julio de Arosemena km 1,5, Guayaquil 090615, Ecuador; john.franco@cu.ucsg.edu.ec
* Correspondence: borvemar@dmta.upv.es

Abstract: In this paper, the aerial biomass of citrus plantations in Spain was evaluated using destructive methods. Before cutting down the trees, their geometric variables were measured: trunk diameter at 10 cm from the ground (D_t), trunk perimeter at 10 cm from the ground (P_m), mean crown diameter (D_c), canopy height (H_c), and maximum crown height (H_{max}). After geometric characterization of the tree, it was felled. This was performed with a chainsaw about 10 cm above the ground. After cutting down, trees with and without leaves were weighed, and biomass variables such as moisture, calorific value, elemental composition, and proximate analysis were measured. The predictive models obtained showed an r^2 of 0.78. According to our analysis, in plantations in Spain, where the average plantation pattern is 4×4 m, the amount of carbon stored in a plot is 15 t of C per hectare. If leaves and wood are counted, the energy density in citrus plots can be estimated at 900 MJ/tree. However, if only wood is included in the calculation, the accumulated energy per tree is 750.3 MJ/tree, which represents 5.6×10^5 MJ/ha.

Keywords: bioenergy; renewable energy; biomass; crop residues

1. Introduction

A high number of fruit tree plots are periodically uprooted due to different reasons: renewal of trees after the end of their productive life, change of cultivation, land abandonment, and change of land use.

The residual biomass from this uprooting can represent a significant resource that can be used as raw material in industry or as biofuels. The objective of this research has been to develop simple biomass quantification models that allow the evaluation of the profitability of the resources in order to make business decisions for their utilization.

Biomass quantification methods in forest trees based on dendrometric variables have been fully studied in the 20th century and constitute a mature science [1]. However, these methods have not been fully adapted to fruit trees. Some approaches were proposed by Velazquez et al. [2].

There are few references to studies on the biomass contained in fruit trees. However, their valuation and characterization are very important because it allows their analysis as a carbon sink [3,4], energy resource, and to relate them to costs and application rates for different products such as water, pesticides, or fertilizers [5,6].

Many biomass quantification studies have been conducted at national, regional, and local levels. Nevertheless, the lack of allometric methods for the determination of biomass in fruit trees in a non-destructive way makes these studies very estimative and sometimes

inaccurate. The same is true for life cycle and carbon footprint analyses. These analyses require tools to predict the biomass contained in the whole tree [7].

The development of models for quantifying the biomass of the aerial part of agricultural trees with remote sensing techniques also makes it necessary to develop terrestrial quantification techniques, which act as a reference. These terrestrial variables, in the case of biomass, must be able to be measured non-destructively [8–10].

For this reason, this research has been carried out, in which destructive methods have been applied in order to develop non-destructive biomass measurement methods. In this research, 37 citrus trees were measured geometrically and subsequently were cut and weighed in order to develop biomass estimation equations from easily measurable variables from the ground. This allows for subsequent measurement techniques by remote sensing.

2. Materials and Methods

2.1. Study Area and Sample Election

This study was conducted in the Valencia Community (Spain), on the Mediterranean coast of the Iberian Peninsula. This area is characterized by a significant extension of plots dedicated to citrus cultivation. It does not have very cold winters due to the thermal regulating effect of the sea, with average minimum temperatures of 4 °C. The summers are long, quite dry, and hot, with maximum temperatures of around 32 °C. Precipitation is concentrated in spring and autumn, with a risk of cold drops in the latter season. The average annual rainfall is 800 mm [11–13].

In 2020, the most important fruit-tree crops occupying the largest area in the Valencia Community were citrus (157,012 ha), olive (93,953 ha), almond (93,441 ha), and vineyard (64,079 ha) [14].

For the analysis of the biomass contained in citrus trees, 37 trees were randomly selected in the municipalities of Oliva and Gandía. The trees studied were of the ortanique variety. This is a tree of the citrus family, hybrids of mandarin (*Citrus reticulata*) and orange (*Citrus* × *sinensis*) [15].

2.2. Measurement of Variables

Before cutting the trees, their geometric variables were measured: trunk diameter at 10 cm from the ground (D_t), trunk perimeter at 10 cm from the ground (P_m), mean crown diameter (D_c), canopy height (H_c), and maximum crown height (H_{max}). The number of main branches was counted, and their diameter was also measured. In addition, the distance from the lowest branches to the ground was measured. This parameter was called skirting height (H_{falda}).

After the geometric characterization of the tree, it was felled. This was performed with a chainsaw at about 10 cm from the ground. After felling, the trees were chopped up, and the residues of each tree were deposited on pallets. These were weighed using an industrial scale. The area of the residual stump on the ground was also measured (Figure 1).

Figure 1. Measuring, cutting down, and weighing process of tress.

To determine the fraction of leaf biomass and the fraction of woody biomass that make up the residues of the trees that were cut down, eight trees were sampled, initially

measuring their weight with leaves and later their weight without leaves. The percentage of woody biomass (% B_l) was calculated by Equation (1), and the percentage of leaf biomass (% B_f) by Equation (2), where m_t is the biomass of the aerial part of the whole tree, m_l is the biomass of the tree without leaves.

$$\% \ B_l = \frac{m_l}{m_t} 100\% \tag{1}$$

$$\% \ B_f = 100\% - \% \ woody \ biomass \tag{2}$$

The UNE EN 14774-3 standard was applied to determine the moisture content of the woody biomass and leaf biomass. A total of 15 wood samples and 15 leaf samples were taken when the trees were cut down, applying Equation (3), where ω is the percentage of moisture on a wet basis, m_h is the weight of the initial sample, and m_s is the weight of the sample after drying in an oven at 105 °C for 4 h. Wood samples had dimensions of less than 5 cm in all directions. Wet leaf samples were at least 250 g.

$$\omega = \frac{m_h - m_s}{m_h} 100\% \tag{3}$$

After weighing the tree, the dry weight of its woody biomass was calculated using Equation (4), where m is the mass of the sample, and ω_l is the percentage of moisture in the woody fraction.

$$dry \ woody \ biomass = m \cdot \frac{\% \ B_l}{100\%} \cdot \frac{(100\% - \omega_l)}{100\%} \tag{4}$$

The dry weight of woody biomass was related to the variables related to tree geometry: trunk diameter at 10 cm from the ground (D_t), trunk perimeter at 10 cm from the ground (P_m), mean crown diameter (D_c), crown canopy height (H_c), maximum crown height (H_{max}), and the sum of the diameters of the main branches.

Values from 20 samples were used to obtain predictive models of tree biomass. Subsequently, the models were validated with values from 17 different samples.

2.3. Biomass Characterization

For biomass characterization, branches with diameters in 6 ranges (0–1, 1–2, 2–3, 3–4, 4–5, and >5 cm) were selected. Five samples were taken from each diameter class for a total of 30 samples. Sample preparation followed the principles defined in the UNE-EN 14780 standard: "Solid biofuels. Sample preparation". The main purpose of sample preparation is to reduce a sample to one or more test portions, generally smaller than the original one, without modifying its composition during each preparation stage. For this purpose, a mechanical saw and a stainless-steel hammer mill equipped with a 3 mm sieve were used.

Subsequently, the leaves were separated from each branch. These leaves were crushed with the hammer crusher and stored in airtight jars with identification labels. As the nominal particle size was less than 3 mm, the minimum mass to be retained was between 50 and 100 g.

The calorific value was obtained using a LECO® AC500 model isoperibol calorimeter, following the UNE-EN 14918 standard.

For the determination of C, H and N content, the UNE-EN ISO 16948 standard was followed. The apparatus used was the LECO® TruSpec CHN elemental analyzer. To determine the S and Cl content, the complementary module of the TruSpec CHN elemental analyzer was used to measure sulfur, in this case, following the UNE-EN 16994 standard.

For the proximate analysis of the biomass, standard muffle tests were performed according to the EN 14775: 2009 standard for ash content and EN 15148: 2009 standard for volatile matter content.

3. Results and Discussion

3.1. Analysis of Tree Geometry

Table 1 shows the statistical summary for each of the geometric variables of the trees measured. Of particular interest here is the standardized skewness and standardized kurtosis, which can be used to determine whether the sample comes from a normal distribution. Values in these statistics that fall outside the range −2 to +2 would indicate significant deviations from normality, which would tend to invalidate many of the statistical procedures usually applied to these data. In this case, none of the variables show values of standardized skewness and standardized kurtosis outside the expected range. Therefore, it is concluded that they follow a normal distribution.

Table 1. Dendrometric variables studied.

	Trunk Diameter at 10 cm (cm)	Mean Crown Diameter (m)	H Max (m)	H Canopy (m)	Perimeter (m)	Stump Area (cm^2)
Count	37	37	37	37	37	37
Average	20.77	3.52	3.28	2.97	0.86	324.59
Standard Deviation	5.50	0.73	0.43	0.40	0.30	171.04
Coefficient of Variation	26.52%	20.68%	13.00%	13.44%	35.11%	52.69%
Minimum	10.75	1.91	2.35	2.21	0.34	79.09
Maximum	31.25	5.22	4.28	3.98	1.6	816.61
Range	20.5	3.31	1.93	1.77	1.26	737.51
Standardized Skewness	0.55	−0.039	0.12	0.89	0.96	1.66
Standardized Kurtosis	−0.91	−0.17	−0.37	−0.360	−0.47	1.65

Figure 2 shows the distribution and classification of the trees according to the number of main branches, which could influence the existing aerial biomass, mainly in the crown. It can be observed that 49% of the trees evaluated have 3 main branches, 22% have 2 main branches; another 24% have 4 branches; and only 5% have 5 main branches. We believe that these frequencies of the crown structure are generally repeated in citrus trees in the study area.
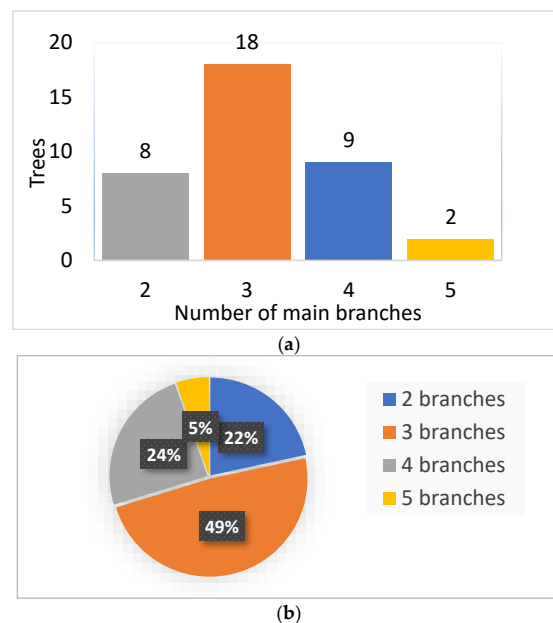

(a)

(b)

Figure 2. Frequency of trees with different numbers of main branches. (**a**) Absolute frequency; (**b**) Relative frequency.

Table 2 shows the statistical description of the woody and foliar fractions, as well as their moisture content. It can be observed that the percentage of foliar biomass in wet conditions is 13.72% of the total in the mixture, with an average moisture content of 54.15%.

Table 2. Woody and foliar fraction and humidity.

	% Leaf Biomass	% Total Woody Biomass	% Woody Biomass in Trunk	% Woody Biomass in Branches	% Moisture in Leaf Biomass	% Moisture in Woody Biomass
Average	13.72	86.88	46.03	40.87	54.15	43.23
Standard Deviation	8.59	8.58	7.89	6.97	14.21	12.23
Minimum	9.29	78.93	43.01	33.83	41.12	37.23
Maximum	21.07	91.70	45.10	48.70	70.25	56.25

Table 3 shows the statistical description of woody, leaf, and total biomass in the evaluated trees. It can be observed that the average wet mass of the aerial part of the tree after cutting is 113.19 kg. However, there are samples of more than 200 kg. This is especially important if the biomass is to be transported to a processing plant without pre-drying. The average dry woody biomass obtained per tree is 50.92 kg, which presents an indication of the available energy resource if destined for use as solid biofuel.

Table 3. Statistical description of woody and foliar biomass weighted wet and dried.

	Total Wet Weight (kg)	Dry Woody Weight (kg)	Dry Leaf Weight (kg)	Total Dry Weight (kg)
Count	37	37	37	37
Average	113.19	42.51	8.41	50.92
Standard Deviation	19.25	11.79	2.25	9.14
Minimum	41.55	34.18	5.10	16.27
Maximum	232.02	97.98	16.47	115.45
Range	190.47	63.8	11.37	99.18
Standardized Bias	1.85	0.94	1.55	−0.85
Standardized kurtosis	−0.89	1.84	0.69	−1.49

To verify if the number of main branches in the tree influences the diameter of the branches or the aerial woody biomass of the tree, two analyses of variance were carried out, shown in Table 4. "a", "b" and "ab" show the similarity or significant difference between the groups. It is observed that there are no significant differences in the diameter of the branches in trees with different numbers of main branches. However, it is observed that although there is a greater number of branches, and the aerial biomass of the tree increases, there are only significant differences between trees with 2 or 3 main branches and those with 5.

Table 4. Analysis of variance to analyze the influence of the number of branches. "a", "b" and "ab" show the similarity or significant difference between the groups.

Main Branches	Branch Diameters (cm) Average ± Standard Deviation	Sum of Diameters (cm) Average ± Standard Deviation	Dry Woody Biomass (kg) Average ± Standard Deviation
2	9.41 ± 2.40 [a]	18.82 ± 4.81 [a]	38.36 ± 8.06 [a]
3	8.66 ± 1.98 [a]	25.99 ± 5.94 [b]	39.75 ± 7.18 [a]
4	8.50 ± 2.10 [a]	34.01 ± 8.41 [c]	44.20 ± 10.24 [ab]
5	7.21 ± 4.11 [a]	36.05 ± 20.57 [bc]	46.40 ± 5.59 [b]
All main branches	8.71 ± 2.16	26.93 ± 8.99	42.51 ± 19.25

3.2. Woody Biomass Forecasting Models

To evaluate the relationship between geometric variables and dry woody and leaf biomass, Pearson's correlation coefficient was calculated among all measured variables. Table 5 shows the correlations between each pair of variables. These correlation coefficients range from −1 to +1 and measure the strength of the linear relationship between the variables. Variables with a significant linear *p*-value relationship with a confidence level greater than 95.0% are indicated with an asterisk. It can be seen that the geometric variables have very strong linear relationships with each other. Note that the only variable that does not maintain a significant relationship with aerial mass is the canopy height.

Table 5. Correlation matrix of the measured variables.

	D_t	D_c	H_{max}	H_c	P_m	A_t	Skirting Height (m)	Wet Weight	Dry Woody Weight
D_t		0.77 *	0.73 *	0.75 *	0.86 *	0.8130	0.16	0.80 *	0.80 *
D_c	0.77 *		0.59	0.76 *	0.75 *	0.8087	0.34	0.78 *	0.78 *
H_{max}	0.73 *	0.56 *		0.90 *	0.58 *	0.5854	0.14	0.68 *	0.68 *
H_c	0.75 *	0.76 *	0.90 *		0.63 *	0.6876	0.33	0.75 *	0.75 *
P_m	0.86 *	0.75 *	0.58 *	0.63 *		0.94 *	0.03	0.82 *	0.82 *
A_t	0.81 *	0.81 *	0.58 *	0.69 *	0.94 *		0.14	0.84 *	0.84 *
Skirting height (m)	0.16	0.34	0.14	0.33	0.03 *	0.14		0.18	0.17
Wet weight	0.80 *	0.78 *	0.68 *	0.75 *	0.82 *	0.84 *	0.18		1.00 *
Dry woody weight	0.80 *	0.78 *	0.68 *	0.75 *	0.82 *	0.84 *	0.18	1.00 *	

"*" show the significant correlation between the variables.

Table 6 compares different predictive models of dry woody biomass based on their coefficient of determination r^2, adjusted coefficient of determination r_{aj}^2, mean absolute error (MAE), mean square error (MSE), Akaike information criterion (AIC), and Bayesian information criteria (BIC).

Table 6. Models with Larger Adjusted r-Squared.

MSE	r-Squared	Adjusted r-Squared	Cp	AIC	BIC	Included Variables
43.6231	78.793	75.006	5.05394	4.10092	4.32539	ABCDE
44.2004	78.5123	74.6752	5.41199	4.12359	4.25827	ABCDF
42.912	78.3936	75.4134	3.56341	4.03066	4.21023	ABCD
45.1772	78.0375	74.1156	6.01777	4.1247	4.25938	ABCEF
43.6486	78.0227	74.9914	4.03655	4.05327	4.27773	ABCE
45.3056	77.9751	74.042	6.09737	4.12853	4.39789	BCDEF
44.4788	77.6047	74.5157	4.56979	4.07029	4.29475	BCDE
45.0064	77.3391	74.2134	4.9087	4.09567	4.23035	ABCF
43.685	77.246	74.9706	3.02748	4.0123	4.19187	ABC
45.3545	77.1638	74.014	5.13227	4.10863	4.33309	BCEF
47.2962	77.0073	72.9015	7.33191	4.16353	4.43289	ACDEF
44.3648	76.8919	74.5811	3.47918	4.02774	4.20731	BCE
44.4945	76.8243	74.5068	3.56537	4.03827	4.17295	ACE
45.7047	76.194	73.8133	4.36956	4.0575	4.23707	ACF
46.3409	75.8626	73.4488	4.79228	4.08913	4.31359	ACD
44.937	75.8136	74.2532	2.85473	3.98173	4.11641	AC
47.5507	74.4069	72.7557	4.64935	4.07132	4.25089	CE
50.3599	72.8949	71.1461	6.57824	4.14168	4.41103	AD
51.7861	72.1272	70.329	7.55748	4.16536	4.25515	BC
51.8433	72.0965	70.2962	7.59677	4.16637	4.43573	CF
57.2665	68.1833	67.189	10.5889	4.20937	4.47873	A
67.7208	62.3749	61.1991	17.9986	4.33304	4.42283	C
78.7133	56.2676	54.901	25.7897	4.48346	4.57324	E
79.5205	55.8191	54.4385	26.3619	4.49366	4.58345	D
86.1396	52.1417	50.6461	31.0533	4.57362	4.6634	B

The adjusted r-squared statistic (r_{aj}^2) measures the proportion of the variability of dry woody weight that is explained by the model where the influence of the number of variables used has been removed. The AIC value based on the residual mean square error with a penalty that increases with the number of coefficients in the model is also used. The goal is to select a model with the minimum residual error and as few coefficients as possible. The best model is the one that minimizes the AIC and MSE.

Up to five models are shown for each subset of between one and five variables. The variables are shown as A = mean trunk diameter, B = mean crown diameter, C = maximum height, D = canopy height, E = trunk circumference at 10 cm, and F = the sum of main branch diameters.

Note that the simplest model with the best r^2 takes the mean diameter of the trunk at 10 cm from the ground as the explanatory variable. Its r^2, at 0.68. We have used this variable for testing in polynomial models and detected that with a third-degree polynomial model, the r_{aj}^2 improves significantly at 0.72, and the r^2 at 0.75.

These models are beneficial because they use only one variable, and it is easier to measure in order to predict the biomass from Earth. However, if predictions are to be made from satellite or drone spectral images, the most convenient variable is crown diameter, but this variable is the worst explainer of dry woody biomass when used linearly. In addition, when polynomial models are tested, the model evaluation statistics do not improve. Table 7 compares different polynomial models based on their coefficient of determination r^2, adjusted coefficient of determination r_{aj}^2, MAE, root mean square (RMS), AIC, and BIC. For this reason, the use of two variables—crown diameter and tree height—is recommended for biomass analysis using Lidar or multispectral images. A linear combination of these variables gives an r^2 of 0.72, but if quadratic models are used, this statistic improves to 0.78.

Table 7. Predictive models of citrus dry woody biomass.

Models	r^2	$r_{aj}{}^2$	MAE	RMS	AIC	BIC
dry woody weight = $-52.21 + 16.22 \cdot D_t - 1.25 \cdot D_t^2 + 0.05 \cdot D_t^3 - 0.000712 \cdot D_t^4$	74.98	71.53	5.51	7.05	4.1217	4.2592
dry woody weight = $53.03 - 6.64 \cdot D_t + 0.53 \cdot D_t^2 - 0.01 \cdot D_t^3$	74.73	72.20	5.522	6.96	4.1247	4.2518
dry woody weight = $-25.91 + 5.81 \cdot D_t - 0.089 \cdot D_t^2$	72.98	71.23	5.656	7.08	4.1247	4.2525
dry woody weight = $-5.41 + 54.86 \cdot D_c - 35.48 \cdot D_c^2 + 11.01 \cdot D_c^3 - 1.13 \cdot D_c^4$	53.94	47.58	9.56	7.05	4.1471	4.2598
dry woody weight = $105.16 - 92.02 \cdot D_c + 35.43 \cdot D_c^2 - 3.78 \cdot D_c^3$	53.87	49.26	7.09	9.40	4.1241	4.1593
dry woody weight = $-17.26 + 27.12 \cdot D_c - 1.88 \cdot D_c^2$	52.61	49.55	7.48	9.38	4.1142	4.2594
dry woody weight = $-1.64 + 6.73 \cdot D_c + 2.87 \cdot H_{max}^2$	78.37	75.72	6.80	5.14	4.0243	4.2391

All the models in Table 7 have been validated.

3.3. Biomass Characterization

Table 8 shows the most important statistical values of the biomass properties of citrus trees from an energy perspective. These values allow us to balance energy, emissions, and carbon sequestration. The values are consistent with those obtained by other authors on similar types of wood, such as Velázquez et al. [16].

Table 8. Characterization of citrus dry woody biomass.

Species	Media	Standard Deviation	Asymmetry Coefficient	Kurtosis Coefficient	Maximum	Minimum
PC (kJ/kg)	17,653.35	230.03	−0.23	−1.044	18,108.26	15,781.85
C%	40.974	2.359	0.192	−0.706	42.800	33.600
H%	7.179	0.291	−1.284	−0.485	7.590	6.540
N%	0.430	0.143	1.383	0.474	0.800	0.222
S%	0.031	0.013	1.100	−0.031	0.063	0.015
Cl%	0.061	0.054	1.802	−0.898	0.166	0.006
Ashes%	2.31	0.13	1.100	−0.031	3.63	0.45
Volatiles%	86.51	0.54	1.702	−0.928	92.66	74.06

Table 9 shows that the higher calorific value (PC, in kJ/kg) correlates well with the percentage of carbon. This is in agreement with what was reported by Callejón Ferre et al. [17].

Table 9. Ratio of calorific value to carbon percentage.

	r^2	$r_{aj}{}^2$	MAE	RMS
PC= 1171.68 + 414.53·C	87.17	85.17	94.3692	72.549

3.4. Discussion

Two of the few existing works focused on the development of predictive models of biomass in citrus trees are Velazquez et al. [18] and Sahoo et al. [6]. The models we present in this paper have better accuracies than those reported by these authors. The models presented by Velazquez et al. [18] had lower coefficients of determination. The reason may be due to the fact that in this work, tree biomass had been measured by non-destructive methods. Velázquez et al. [18] present a system of biomass quantification by measuring the diameters and lengths of branches in different strata. This method is very laborious and can present difficulties, especially in the determination of biomass in the final layers, where the branches are small. However, in our work, the biomass values of the trees were

obtained by the cutting of the trees and subsequent weighing. This system, for scientific purposes, significantly reduces the dispersion of the obtained results.

Sahoo et al. [6] presented the relationships of tree height (*H*) and diameter at breast height (1.3 m) (*D*) with aerial biomass (*Y*). The methods used were algorithmic:

$$\ln Y = \ln(\alpha) + \beta \cdot \ln(D)$$

$$\ln Y = \ln(\alpha) + \beta \cdot \ln(H)$$

$$\ln Y = \ln(\alpha) + \beta \cdot \ln(HD)$$

The r^2 values were between 0.61 and 0.78. These results are very similar to those obtained in our study, but the models have a drawback. The trees grown in Spain have very small trunks, making it impossible to measure their diameter at a height of 1.3 m.

Using these models, Sahoo et al. [6] indicated that the total and accumulated biomass carbon in the soil could be estimated at 7.69 and 100.2 t C/ha, respectively, in plantations in India. These values were referenced to planting densities of between 1460 and 3210 trees/ha, with an average of 2360 trees/ha in India.

According to our analysis, in plantations in the Valencia Community (Spain), where the average plantation pattern is 4×4 m, that is, the number of trees per hectare is significantly lower. The amount of biomass contained in one hectare is estimated at 31.82 t/ha. The amount of carbon stored in a plot is 13 t of C per hectare. As can be observed, this value is significantly higher than that reported by Sahoo et al. [6] for the aerial part, although the density of trees in Spain is lower.

The energy density in citrus can be estimated at 900 MJ/tree if leaves and wood are counted. However, if only wood is included in the calculation, the accumulated energy per tree is 750.3 MJ/tree, which represents 5.6×10^5 MJ/ha.

4. Conclusions

The models developed in the present study can be applied to the estimation of stand biomass, energy, and carbon at local and regional scales in citrus orchards. However, the biomass models must first be validated before they are applied in new areas. Nevertheless, the results of the present study represent a tool with enormous potential for the accurate estimation of biomass production and carbon storage in orange orchards with more advanced remote sensing-based technologies, such as Lidar and multispectral imaging.

In addition, these tools can also be used to estimate production inputs such as water, fertilizers, or pesticides.

We suggest future studies to develop baseline data on the potential carbon credits that could be generated from these sweet-orange orchards and fruit species in all parts of the world, allowing for more precise policies to help mitigate carbon emission targets under the Kyoto Protocol (Section 3.4).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All the data are available in the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kuyah, S.; Dietz, J.; Muthuri, C.; Jamnadass, R.; Mwangi, P.; Coe, R.; Neufeldt, H. Allometric Equations for Estimating Biomass in Agricultural Landscapes: I. Aboveground Biomass. *Agric. Ecosyst. Environ.* **2012**, *158*, 216–224. [CrossRef]
2. Velázquez-Martí, B.; Fernández-González, E.; López-Cortés, I.; Callejón-Ferre, A.J. Prediction and Evaluation of Biomass Obtained from Citrus Trees Pruning. *J. Food Agric. Environ.* **2013**, *11*, 1485–1494.
3. Iglesias, D.J.; Quiñones, A.; Font, A.; Martínez-Alcántara, B.; Forner-Giner, M.Á.; Legaz, F.; Primo-Millo, E. Carbon Balance of Citrus Plantations in Eastern Spain. *Agric. Ecosyst. Environ.* **2013**, *171*, 103–111. [CrossRef]
4. Yasin, G.; Farrakh Nawaz, M.; Zubair, M.; Qadir, I.; Saleem, A.R.; Ijaz, M.; Gul, S.; Amjad Bashir, M.; Rehim, A.; Rahman, S.U.; et al. Assessing the Contribution of Citrus Orchards in Climate Change Mitigation through Carbon Sequestration in Sargodha District, Pakistan. *Sustainability* **2021**, *13*, 12412. [CrossRef]
5. Huang, T.-B.; Darnell, R.L.; Koch, K.E. Water and Carbon Budgets of Developing Citrus Fruit. *J. Am. Soc. Hortic. Sci. Jashs* **1992**, *117*, 287–293. [CrossRef]
6. Sahoo, U.K.; Nath, A.J.; Lalnunpuii, K. Biomass Estimation Models, Biomass Storage and Ecosystem Carbon Stock in Sweet Orange Orchards: Implications for Land Use Management. *Acta Ecol. Sin.* **2021**, *41*, 57–63. [CrossRef]
7. Bwalya, J.M. Estimation of Net Carbon Sequestration Potential of Citrus under Different Management Systems Using the Life Cycle Approach. Ph.D. Thesis, University of Zambia, Lusaka, Zambia, 2012.
8. Krooks, A.; Kaasalainen, S.; Kankare, V.; Joensuu, M.; Raumonen, P.; Kaasalainen, M. Predicting Tree Structure from Tree Height Using Terrestrial Laser Scanning and Quantitative Structure Models. *Silva Fenn.* **2014**, *48*, 1125. [CrossRef]
9. Colaço, A.F.; Molin, J.P.; Rosell-Polo, J.R.; Escolà, A. Application of Light Detection and Ranging and Ultrasonic Sensors to High-Throughput Phenotyping and Precision Horticulture: Current Status and Challenges. *Hortic. Res.* **2018**, *5*, 35. [CrossRef] [PubMed]
10. Jiang, M.; Nakano, S. Application of Image Analysis for Algal Biomass Quantification: A Low-Cost and Non-Destructive Method Based on HSI Color Space. *J. Appl. Phycol.* **2021**, *33*, 3709–3717. [CrossRef]
11. Cañada, J.; Pinazo, J.M.; Boscá, J. V Analysis of Weather Data Measured in Valencia during the Years 1989, 1990, 1991 and 1992. *Renew. Energy* **1997**, *11*, 211–222. [CrossRef]
12. Vicente-Serrano, S.M.; González-Hidalgo, J.C.; de Luis, M.; Raventós, J. Drought Patterns in the Mediterranean Area: The Valencia Region (Eastern Spain). *Clim. Res.* **2004**, *26*, 5–15. [CrossRef]
13. Gomez, I.; Estrela, M.J.; Caselles, V. Verification of the RAMS-Based Operational Weather Forecast System in the Valencia Region: A Seasonal Comparison. *Nat. Hazards* **2015**, *75*, 1941–1958. [CrossRef]
14. Generalitat Valenciana Superficies y Producciones de La Comunitat Valenciana (Principales Cultivos). Available online: https://agroambient.gva.es/es/estadistiques-agricoles (accessed on 27 June 2022).
15. Gregoriou, C.; Economides, C.V. Tree Growth, Yield, and Fruit Quality of Ortanique Tangor on Eleven Rootstocks in Cyprus. *J. Am. Soc. Hortic. Sci. Jashs* **1993**, *118*, 335–338. [CrossRef]
16. Velázquez-Martí, B.; Fernández-González, E.; López-Cortés, I.; Salazar-Hernández, D.M. Quantification of the Residual Biomass Obtained from Pruning of Trees in Mediterranean Almond Groves. *Renew. Energy* **2011**, *36*, 621–626. [CrossRef]
17. Callejón-Ferre, A.J.; Velázquez-Martí, B.; López-Martínez, J.A.; Manzano-Agugliaro, F. Greenhouse Crop Residues: Energy Potential and Models for the Prediction of Their Higher Heating Value. *Renew. Sustain. Energy Rev.* **2011**, *15*, 3208–3217. [CrossRef]
18. Velázquez-Martí, B.; Estornell, J.; López-Cortés, I.; Martí-Gavilá, J. Calculation of Biomass Volume of Citrus Trees from an Adapted Dendrometry. *Biosyst. Eng.* **2012**, *112*, 285–292. [CrossRef]