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"Second generation of planted hardwood forests in the EU"

The walnut plantations (*Juglans* spp.) in Italy and Spain: main factors affecting growth

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Abstract - Walnut tree species (*Juglans* spp.) are commonly used for high-quality wood production in plantation forestry. In this paper, the most relevant walnut plantations in Italy and Spain have been reviewed and analysed under a geographic and technician management point of view. Between 2016 and 2019 a total of 96 plantations (15 - 25 years old) were visited distributed in the North-western part of the Mediterranean basin. A statistical analysis (linear model no interaction and PCA) was then performed to evaluate the relative importance of some environmental and management variables for walnut trees in analysed plantations. Results highlighted a variable situation with many different adopted planting schemes across the regions as well as a not standardised spatial layout and management type (thinning). Lower densities and smaller trees were adopted in Italy with about 200 trees ha^{-1} versus 330 trees ha^{-1} in Spain. In addition to the age of the plantation as one of the most influencing parameters also the plantation density and the average crown diameter were highly statistically significant. Overall, the interesting potentiality of walnut for timber production with active management in suitable areas was detected as the focal point for a successful timber production from walnut trees.

Keywords - planted forests, agroforestry, timber, wood quality, H2020 Woodnat project.

Introduction

Forest plantations have globally increased during recent decades in response to the growing demand for timber, pulp, energy and other goods (Ares and Brauer 2005, Evans 2009, Cambria and Pierangeli 2012, FRA 2015). Around 7% of global forest area is currently covered by planted forests (291·10^6 ha) and fulfil almost 65% of the global demand of timber products representing a consistent reduction of the human pressure over the natural forests (Evans 2009, EFIATLANTIC 2013). About 50% of planted forests are currently owned by public bodies while approximately 33% belongs to small landowners (Carle 2013). At European level planted forests are the 8% of the whole forested area (83·10^6 ha) and showing an annual increment of +1.11% between 1990 and 2015 (FRA 2015). To this respect, the European Commission Regulation 2080/92 played a key role with approximately 1,000,000 ha of afforestation distributed in small lands between 1992 and 1999 in the 15 countries of the European Union (IFD 2001).

Walnut species (*Juglans* spp.) are among of the most popular and widely-used forest tree species in tree farming activities, characterized by marketable nuts and high timber quality. Walnut forest plantations oriented for timber production have been often established during the last decades all over the world (Mohni et al. 2009). The Persian (or European) walnut (*J. regia* L.), Black (or American) walnut (*J. nigra* L., *J. major* (Torr.) A. Heller, and *J. hindsii* (Jeps.) Jeps. ex R.E. Sm.) probably are the most used walnut trees in both pure or mixed stands (Nichols et al. 2006, Clark et al. 2008). However also several hybrids have been specifically developed for timber production, e.g. Mj-209xRa and Ng-23xRa (Aletà et al. 2003 , Aletà 2004, Victory et al. 2004, Mohni et al. 2009, Clark and Hemery 2010, Coello et al. 2013, Bernard et al. 2018). Despite the relevance that walnut timber has historically had within the forest sector, just a small proportion of the forested area in Europe is currently characterised by the presence of such valuable tree species. The species is also not usually included in the forestry statistics in the EU due to its relative (spatial and numerical) scarcity, owing to a complicate, time-consuming and biased estimation. According to Spiecker et al.

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(2009) around 2.4% of the planted forests associated to the ECR 2080/92 (i.e. 24,000 ha) corresponded to *Juglans* spp. stands, mainly established in abandoned agricultural lands and located in the Southern Europe and around the Mediterranean basin (i.e. Northern Italy, Southern France, Spain). The use of *Juglans* spp. trees has been relatively different according to the environmental variability they were planted. Most of the walnut planted forests belonging to small scale forest owners and the EU Regulation 2080/92 has been determinant for their expansion, relatively wide planted forests were established by medium size enterprises with more than 100 ha each.

Among all the European countries, Italy, Spain and France currently are the most active in cultivation of *Juglans* spp. trees. Concerning Italy, approximately 100,000 ha were afforested within the framework of the ECR 2080/92 between 1992 and 1999 with 70% realised with valuable or semi-valuable broadleaves such as *Juglans* spp., *Prunus avium*, *Fraxinus* spp. and *Populus* spp. (IFD 2001). Romano and Cesaro (2016) estimated that more than 200,000 ha were afforested with valuable broadleaves in former agricultural lands between 1994 and 2013; however just around 25% of the considered surfaces included walnut species. In France, walnut plantations represent 6% of the afforested area within the framework of EC 2080/92 (Spiecker et al. 2009). Hence, considering that 45,147 ha were planted between 1992 and 1999 within this program (IFD 2001), walnut trees were used in more than 2,700 ha, mainly as unique tree species in pure stands. In Spain most walnut plantations were established in large areas (100-600 ha each), mainly by private companies. For instance, 600 ha were planted by Foresta Capital S.L., around 300 by Bosques Naturales S.A. and 120 ha by Valor Forestal S.A. In addition to these major companies, many other relatively big (approx. more than 5 ha but less than 100 ha) private plantations were censed with different business models which started after the big companies (García-Martín et al. 2011).

The objective of this paper is to summarize and evaluate the most relevant walnut plantations (pure or mixed) in Italy and Spain and to evaluate the effect of a wide range of variables at plantation level and single-tree level on tree diameter growth. Overall 96 First Generation Planted Forests (FGPF) between 15 and 25 years-old were visited between 2016 and 2019 and analysed to derive indication on management type, productivity and issues related to the cultivation of this tree.

Materials and Methods

Tree-level and stand level data

To make an evaluation of walnut's FGPF, different areas where walnut is traditionally cultivated were sampled across Italy and Spain. Overall, 79 plots were established in Italy and mainly for European walnut plantations, realized in small and medium farms located in four Regions: Piedmont, Lombardy (North Italy), Tuscany (Central-West Italy) and Marche (Central-East Italy). Plantations have been selected below 600 m above the sea to avoid failed stands, very likely in the analysed environments. Concerning Spain, only 17 hybrid walnut were considered (*Juglans x intermedia* Carr.). The sampling mainly included actively managed stands owned by an important forest enterprise (Bosques Naturales) and geographically distributed in the regions of Galicia (North West Spain), Girona (North East Spain), Toledo, Cuenca and Cáceres (Central Spain). Intensive management included the application of irrigation, fertilization, weeding and thinning trials was manly applied in Spain only. According to Buresti Lattes and Mori classification (2007, 2008) different plantation types have been retrieved in Italy (pure, mixed, polycyclic, etc.) and mainly European walnut plantations have been detected. Conversely, only 17 pure walnut plantations have been sampled in Spain.

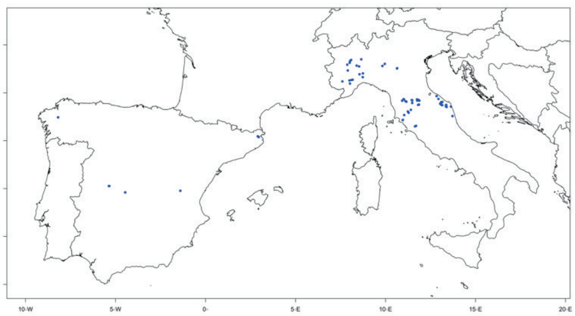

Figure 1 - Spatial distribution across Italy and Spain of the 96 sampled stands.

A sample made by 30 walnut trees was measured and included within a representative plot of the stand, averaging the measurements to calculate unbiased estimates. The main parameters surveyed for each tree were: diameter at breast height (DBH), total height, crown insertion, diameter at 2.6 m, stem diameter at crown insertion, crown diameter, stem quality classes, sanitary conditions (general, leaf, stem, root damages). The plantation age was determined interviewing the owners, reading documentation or by means of coring trees in the proximity of collar. Stem quality was also evaluated attributing a stem quality class to the first logs up to 2.6 m and according to stem quality classification already existing at European level for other species such as *Quercus* spp. and *Fraxinus* spp. (EN standards, Nosenzo et al. 2012). Stem ovality was also considered and estimated measuring orthogonal DBH values.

The phytosanitary conditions of walnut stands represented the most time-consuming effort. In accordance with a qualitative damage scale, 4 single-tree levels were considered: 0: healthy tree; 1: slight damage to the crown and/or the stem; 2: damaged collar and/or stem necroses; 3: whole tree decline with slow or stopped growth, overshadowed tree. Single trees were observed and evaluated according to this scale along random transects in each stand. A synthetic rating was then assigned to the whole stand considering the most frequent damage class among the observed trees. The damage classes roughly mirror a criterion aimed to emphasize main differences in damage: class 1 was associated with mainly quantitative damage, consisting in a lower height and diametric increment; class 2 included trees with mainly qualitative damage, since stem necroses induce discolorations and alterations of the underlying wood; class 3 often involved the loss of entire trees, combining quality and quantity damage. More in detail, during the monitoring the major walnut adversities were recorded with respect to the tissues affected. All the recorded adversities were previously reported for years in several surveys (Belisario 1996, Fernández-Moya et al. 2019). The damage class frequencies were calculated and statistically processed in the (χ2).

Concerning biomass and quantitative data, timber volume was calculated by using the mean diameter at various stem section ($S_{1.3}$, $S_{2.6}$, S_{crown_ins}, S_{hd10}) and using the total height for the final portion. Other parameters such as mean annual increment (MAI) and mortality were calculated from raw data. For all the plantations, a characterization of site quality classes of walnut using DBH and age, has been realized according to Cisneros et al. (2008).

Statistical analysis

Among all the descriptive numeric data (i.e. Latitude/Longitude of the trial, number of trees per hectare, average diameter, height, volume, etc.), 20 variables were used to derive insights on the structure of the surveyed plots. In addition to a Principal Component Analysis (PCA) a correlation matrix was built, using the Spearman correlation method in order to include non-linear relationships. To avoid biases in PCA calculation due to different units between the different variables, a correlation matrix was used in place of the classical covariance matrix.

Afterwards the mean annual diametric increment (MAI_{dbh}) was selected as target variable in a modelling procedure, aimed at evaluating whose environmental/management parameters were detectable as the most relevant drivers for walnut growth, within the surveyed plots. A multivariate linear model (LM) was built, with no interaction between terms in order to generate a robust and simple but informative output:

$$MAI_{dbh} = i + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + \beta_3 \cdot x_3 + \cdots \beta_n \cdot x_n + \varepsilon$$

Once the model was fitted, a stepwise procedure (backward direction) was implemented, to remove not useful parameters and to maximize the concentration of explained variance into few non-correlated variables. Then the relative importance of each predictor (x_1, x_2, x_3…x_n) was tested, decomposing the proportion of deviance explained by each. Finally, the derived coefficients (β_1, β_2, β_3… β_n) were used as indicator in order to understand whether the significant coefficients were directly (positive) or inversely (negative) influencing MAI_{dbh} values. All the statistical analyses were compiled in R language (R core Team 2019)

Results

The investigated plantations

Small scale plantations were dominant in the database for a mean surface 2.7±2.4 ha and a total surface of 210.1 ha (Tab. 1). Only 12 of them (15%) were more than 5 ha wide, covering a total of 89 ha (42%) while only 2 of them (3%) were more than 10 ha (10%). This situation is somehow different when considering the consistent amount of medium size (5-100 ha) planted forests in Spain. Regarding the used species, almost all the Italian plantations were characterized by European walnut trees (75 plantations), while three were established with black walnut and one mixed European walnut and hybrid walnut. Concerning Spain only the hybrid walnut was used. Then different plantation types have been adopted in Italy with pure (mono-specific) and mixed (multi-specific) plantations with nurse trees including N-fixing (trees and shrubs). Medium-size and big pure plantations were sampled in Spain (mean surface 11.0±9.1 hectares with a total surface of 186.9 hectares).

Italian plantations showed an average age around 20 years with the pure and pure-with-nurse-trees plantations slightly older than the mixed plantations. The younger and more recent type were the polycyclic plantations with 13.8 years in average. Overall, younger sites were visited in Spain for an average age around 14.5 years.

Table 1 - Number surface and age of the sampled plots per walnut (*Juglans* spp.) plantation types in Italy and Spain.

Italy (IT) and Spain (SP) stand type	Sampled stands	Mean surface ha ± SD.	Total surface ha	Mean age yrs ± SD
Italy	79	2.66 ± 2.4	210.07	20.0 ± 4.7
IT mixed	20	2.94 ± 2.7	58.77	18.0 ± 2.4
IT mixed with nurse trees	13	3.29 ± 2.3	42.83	18.7 ± 3.5
IT polyclyclic	5	3.33 ± 2.4	16.63	13.8 ± 4.0
IT pure	34	2.22 ± 2.3	75.44	22.1 ± 4.9
IT pure with nurse trees	7	2.34 ± 2.4	16.4	22.6 ± 4.2
Spain	17	11.00 ± 9.1	186.95	14.5 ± 3.1
Pure	17	11.00 ± 9.1	186.95	14.5 ± 3.1

Mensurational parameters

Walnut planting densities were very variable across Italy and according to the different layout and management types (thinning in particular). Lower densities were adopted in Italy than in Spain with about 200 trees ha^{-1}. An average spacing between 5 and 6 metres was adopted in the pure plantations while wider distances (from 8 to 10 metres) were used in the mixed and polycyclic ones. Conversely in Spain, densities were generally higher than Italy and around 330 trees ha^{-1} with distances of 5-6 meters everywhere. Smaller DBH values were detected in Spanish sampled plantations than Italians, with mean value of 17.3 cm against 19.5 cm for Italy whose value came from data ranging between 17.2 cm in mixed plantation and 21.3 cm in pure and polycyclic plantation (Tab. 2). The volume per hectare of walnut trees was, on average, around 20.2 m^3 ha^{-1} in Italy, highly variable again among the plantation types. However higher values were found in some pure plantations: for example, in Piedmont, a volume up to 104 m^3 ha^{-1} has been estimated in a pure 23 years old plantation. In Spain walnut volumes reached 29.6 m^3 ha^{-1} on average and up to 56.6 m^3 ha^{-1} in a pure plantation in Gerona (17 years-old, 6 m spacing). The average marketable timber volume per tree in Italy was 0.118 m^3 with superior volume in younger polycyclic plantation and around 0.144 m^3 while, in Spain, single-tree volume reach and average value of 0.09 m^3 (±0.037) in pure plantation with similar age. The relationship between the average DBH values and age is shown in Figure 2 and compared to the site quality curve for walnut plotted using the methodology applied by Cisneros et al. (2008). According to our data 19 plots were referred to class I, 47 were close to class II and 30 allocated in class III. Concerning growth trends, an average MAI_{dbh} value of 1.0 cm yr^{-1} was observed for Italy with difference among planting types. The best MAI_{dbh} have been observed in polycyclic plantation with value of 1.6 cm. yr^{-1} and with a maximum of 1.9 cm yr^{-1} in a polycyclic plantation in Lombardy (10 years-old) where walnut trees have been planted with a rectangular layout admixed with poplar trees and Short Rotation Systems (SRC). In Spain a MAI_{dbh} of 1.22 cm yr^{-1} was measured on average with e maximum of 1.65 cm yr^{-1} in a plantation near a Coruña (Boimorto/Arzúa).

Overall, poor stem quality was detected in Italy. Only 30.2% of the logs is included in the first two stem classes suitable for industrial transformation (Tab. 3). The best wood quality in Italy have been observed in the polycyclic plantation with 67% of trees belonging to the A and B classes, while the worst stem quality was for pure plantations, with only 7%. In Spain the use of selected material (i.e. hybrid *Juglans with walnut*) and the choice of appropriate sites and management, brought to superior results than Italy with 78% of tree suitable for the industrial transformation.

Table 2 - Number of trees, DBH, volume and MAI per country and per plantation types for the sampled walnut plantations.

Italy (IT) and Spain (SP) stand type	Walnut n trees ha^{-1}		Walnut DBH cm		Walnut vol. m^3 ha^{-1}		Tree volume m^3		DBH MAI cm	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
IT mixed	179.9	124.4	17.2	5.9	13.4	11.9	0.091	0.068	1.0	0.3
IT mixed with nurse trees	138.9	66.2	18.2	7.2	12.7	11.7	0.105	0.081	1.0	0.4
IT polycyclic	93.4	33.5	21.3	7.1	14.7	15.3	0.144	0.113	1.6	0.4
IT pure	221.6	78.5	21.1	5.8	26.4	19.7	0.136	0.098	1.0	0.3
IT pure with nurse trees	260.4	76.6	19.2	5.9	27.2	23.5	0.109	0.074	0.9	0.3
Average Italy	192.8	97.4	19.5	6.3	20.2	17.8	0.118	0.088	1.0	0.4
SP pure hybrid walnut	328.6	26.0	17.3	2.5	29.6	12.3	0.090	0.037	1.22	0.2
Average Spain	328.6	26.0	17.3	2.5	29.6	12.3	0.090	0.037	1.22	0.2

Table 3 -Stem quality classes per plantation types in Italy and Spain.

Italy (IT) and Spain (SP) stand type	Stem quality classes				
	A %	B %	C %	D %	A+B%
IT mixed	8.3	22.2	32.0	27.0	30.5
IT mixed with nurse trees	11.3	18.5	24.1	38.2	29.7
IT polycyclic	28.7	38.7	23.3	7.3	67.3
IT pure	6.7	21.0	35.4	29.7	27.6
IT pure with nurse trees	0.5	15.2	31.0	48.1	15.7
Average Italy	8.7	21.5	31.5	30.6	30.2
SP pure hybrid walnut	35.9	42.4	16.9	1.6	78.3
Average Spain	35.9	42.4	16.9	1.6	78.3

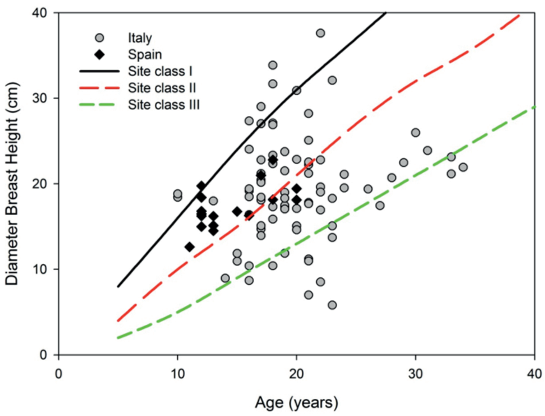

Figure 2 - Characterization of site quality of walnut (*Juglans* sp.) of the Woodnat database from Italy and Spain, according to the site classes defined by Cisneros at al. (2008).

Phytosanitary conditions

The results of surveys for damage class in Italy and Spain did not show significant differences as such. Although the walnut Italian pure stands appeared more damaged than the others plantation types and with respect to Spanish pure stands (Tab. 4). The samples were too heterogeneous to give a significant chi-square value (χ^2 = 17.42, p = 0.0577). Instead, grouping class 0 and 1 with no or slight damage and class 2 and 3 with marked damage, the chi-square test become significant (χ^2 = 11.88, p = 0.0431), owing mainly to a marked deviation of the observed frequencies of Italian pure stands from the expected ones. As regards the observed pests and diseases in Italian stands, the most incident was anthracnose by *Ophiognomonia leptostyla* on leaves and apical branches, followed by the bacterial shallow bark canker by *Brenneria nigrifluens* on the trunk. The feared *Geosmithia morbida*, pathogenic agent of the Thousand cankers disease recently reported in Italy, was never recorded in the analysed plots, whereas the bacterial blight by *Xanthomonas arboricola* pv. *juglandis*, the downy leaf spot by *Pseudomicrostroma juglandis* and the pustule canker by *Juglanconis juglandina* were seldom observed. Among non-specific pests, the goat moth (*Cossus cossus*) and the leopard moth (*Zeuzera pyrina*) were rarely recorded on trunks, and the fall webworm (*Hyphantria cunea*) on leaves as well; among specific pests, only aphids (*Panaphis juglandis* and *Chromaphis juglandicola*) were recorded with low or no incidence. Frost cracks or mechanical damage were sometimes observed in confined conditions.

Statistical structure of the investigated variables and influence on MAI_{dbh}

The results of the correlation analysis and a graphical plot of PCA are summarized in Figure 3 and Table 5. Overall many variables were highly inter-correlated showing a statistically significant (p.value ≤ 0.05) correlation value with correlation

Table 4 - Number of Italian and Spanish stands included in damage classes (see text for their definition).

Italy (IT) and Spain (SP) stand type	Damage class				Total
	0	1	2	3	
IT mixed	45%	50%	5%		20
IT mixed with nurse trees	15%	77%	8%		13
IT polycyclic	40%	60%			5
IT pure	26%	41%	26%	7%	34
IT pure with nurse trees	28%	44%	28%		7
SP pure	47%	47%	6%		17
Total	33%	50%	15%	2%	96

Table 5 - Spearman correlation values (lower the diagonal) and p.values (upper the diagonal) between the 20 parameters included in the PCA. Above the diagonal p.values have been coded according to the following rules: '***' ≤ 0.001; 0.001 < '**' ≤ 0.01; 0.01 < '*' ≤ 0.05; n.s.> 0.05. Variables are: Latitude [1], Longitude [2], Number of trees per hectare [3], Number of walnuts per hectare [4], Average DBH of walnut trees [5], Ovality of the stem [6], Total height of walnut trees [7], Crown depth of walunt trees [8], Average diameter at 2.6 m [9], Length of the pruned stem [10], Quality of trees [11], Average crown diameter [12], Timber volume [13], Volume of the first marketable log [14], Sanitary condition [15], Failure percentage [16], Total volume per hectare [17], Mean annual volume increment [18], Age [19], Mean annual increment of DBH [20].

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]	[18]	[19]	[20]
[1]	1	n.s.	n.s.	***	n.s.	n.s.	n.s.	**	n.s.	n.s.	***	**	n.s.	n.s.	***	**	**	***	***	***
[2]	0.04	1	*	***	**	n.s.	n.s.	n.s.	**	**	*	**	**	***	*	*	n.s.	n.s.	n.s.	n.s.
[3]	-0.02	-0.25	1	*	***	n.s.	n.s.	n.s.	***	***	n.s.	***	***	***	n.s.	n.s.	*	n.s.	*	*
[4]	-0.44	-0.41	0.25	1	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	***	n.s.	n.s.	n.s.	*	***	***	n.s.	n.s.
[5]	0.08	0.30	-0.42	-0.17	1	n.s.	***	***	***	***	**	***	***	***	n.s.	n.s.	***	***	*	***
[6]	-0.12	0.13	-0.11	0.03	-0.12	1	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*
[7]	-0.02	0.19	-0.20	-0.19	0.80	-0.12	1	***	***	***	***	***	***	***	n.s.	n.s.	***	***	n.s.	***
[8]	-0.28	-0.03	-0.08	0.04	0.44	0.03	0.60	1	***	**	***	*	***	***	n.s.	n.s.	***	***	n.s.	***
[9]	0.07	0.28	-0.43	-0.19	0.94	-0.10	0.76	0.47	1	***	***	***	***	***	n.s.	n.s.	***	***	*	***
[10]	0.12	0.29	-0.47	-0.16	0.97	-0.10	0.71	0.29	0.93	1	**	***	***	***	n.s.	n.s.	***	***	**	***
[11]	-0.38	-0.22	-0.12	0.09	0.32	-0.07	0.42	0.53	0.37	0.27	1	**	***	***	*	***	***	***	***	***
[12]	0.30	0.32	-0.52	-0.44	0.78	-0.14	0.58	0.25	0.76	0.79	0.31	1	***	***	n.s.	n.s.	***	**	n.s.	***
[13]	-0.02	0.27	-0.36	-0.13	0.94	-0.07	0.82	0.67	0.92	0.87	0.44	0.71	1	***	n.s.	n.s.	***	***	*	***
[14]	0.04	0.34	-0.35	-0.16	0.97	-0.14	0.78	0.46	0.93	0.92	0.33	0.74	0.94	1	n.s.	n.s.	***	***	**	***
[15]	0.48	-0.25	0.05	0.08	0.04	-0.11	0.04	-0.06	0.06	0.08	-0.23	0.06	0.03	0.01	1	n.s.	n.s.	n.s.	***	**
[16]	0.31	0.25	0.06	-0.20	-0.02	0.05	-0.13	-0.16	-0.06	-0.02	-0.37	0.04	-0.07	-0.04	0.07	1	*	**	n.s.	n.s.
[17]	-0.31	-0.07	-0.21	0.51	0.67	-0.10	0.57	0.55	0.65	0.64	0.47	0.33	0.73	0.66	0.06	-0.22	1	***	n.s.	***
[18]	-0.47	-0.09	-0.16	0.53	0.58	-0.13	0.53	0.55	0.56	0.54	0.57	0.27	0.65	0.57	-0.05	-0.27	0.95	1	n.s.	***
[19]	0.41	0.10	-0.22	0.01	0.26	0.15	0.12	-0.02	0.25	0.28	-0.38	0.16	0.23	0.27	0.41	0.16	0.16	-0.10	1	***
[20]	-0.38	0.18	-0.22	-0.07	0.60	-0.24	0.55	0.36	0.56	0.55	0.60	0.52	0.58	0.57	-0.29	-0.20	0.47	0.63	-0.53	1

coefficients ranging between -0.21 and 0.93. Most of the silvicultural parameters (e.g. volume of the first marketable log and average diameter at breast height of walnut trees) were highly correlated and as shown by the PCA with overlapping red arrows. Overall, the most influencing and isolated drivers were the latitude, the number of walnuts per hectare, the quality of trees and the mean annual volume increment. A wide group of 7 highly correlated variable was then recognised. Those were the average DBH of walnut trees, the total height of walnut trees, the average diameter at 2.6 m, the length of the pruned stem, the average crown diameter, the timber volume and the volume of the first marketable log. Finally, low importance was given to the number of trees per hectare, the stem ovality, the phytosanitary condition and the mortality.

Concerning the statistical model, the main result was that after the stepwise procedure all climatic variables were removed by. Then 91.6% of the total variance was obtained with 11 variables (Tab. 6). The age of the plantation was the most influencing parameters, explaining 25.17% of the variance of the model with a negative effect. The crown diameter was highly significant as well, but with a positive effect on MAI_{dbh}. Other significant parameters were the longitude (negative) and the latitude (positive) of the site explaining environmental and climat-

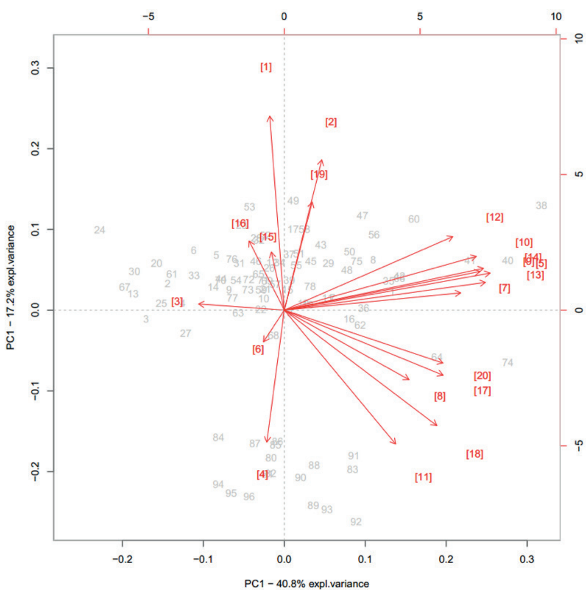

Figure 3 - PCA plot of the surveyed plantations. The length of each red arrow expresses the importance of each measured variable. While uncorrelated variables are expressed by orthogonal arrows, opposite or overlapped arrows describes correlation values of -1 and 1 respectively. Variables are: Latitude [1], Longitude [2], Number of trees per hectare [3], Number of walnuts per hectare [4], Average DBH of walnut trees [5], Ovality of the stem [6], Total height of walnut trees [7], Crown depth of walunt trees [8], Average diameter at 2.6 m [9], Length of the pruned stem [10], Quality of trees [11], Average crown diameter [12], Timber volume [13], Volume of the first marketable log [14], Sanitary condition [15], Failure percentage [16], Total volume per hectare [17], Mean annual volume increment [18], Age [19], Mean annual increment of DBH [20].

Table 6 - Deviance analysis of the statistical model where the current DBH increment has been modelled (R2: 0.916). Asterisks have been added to p.values according to the following rules: '***' ≤ 0.001; 0.001 < '**' ≤ 0.01; 0.01 < '*' ≤ 0.05; n.s.> 0.05.

Predictor	Sum of Squares	Prop. of variance	DF	F value	Pr(>F)		Effect
Age	1.0412	25.17%	1	70.5136	3.75E-12	***	(-)
Crown diameter	0.7080	17.11%	1	47.9526	1.82E-09	***	(+)
Longitude	0.0890	2.15%	1	6.0285	0.0166	*	(-)
Latitude	0.1663	4.02%	1	11.2603	0.0012	**	(+)
Trees per ha	0.1608	3.89%	1	10.8893	0.0015	**	(-)
Quality	0.1523	3.68%	1	10.3167	0.0020	**	(+)
Soil texture	0.3201	7.74%	10	2.1676	0.0302	*	none
Soil Depth	0.1752	4.23%	2	5.9316	0.0042	**	50-100 cm less than others
Morphology	0.1240	3.00%	3	2.798	0.0465	*	Wide valley better than others
Plantation type	0.1330	3.21%	4	2.2519	0.0723	.	Pure with nurse trees better than others
DBH ovality	0.0487	1.18%	1	3.2969	0.0737	.	(-)
Residuals	1.0188	24.63%	69				

ic factors and highly related to the walnut species used in the plantation (i.e. mainly the hybrid versus the European). Then the soil texture and soil depth were statistically significant too but with low differences within them. Indeed, while no evidences were derived for the texture of the soil, only the middle class of soil depth (i.e. between 50 cm and 100 cm) was acknowledged as a negative factor for growth when compared to deeper soil. Concerning the planting site, the morphology was the last statistically significant predictor with the plantations established in wide valleys showing higher MAI_{dbh} values than the others. Even if not statistically significant, also the plantation type and the ovality of the stem were included in the LM by the stepwise procedure. In this case a slight within-variable difference was observed for the plantation type with the pure with nurse trees plantations showing some positive influence on the target variable. A high leverage value was associated to just few observations, and overall the Shapiro test p value was 0.186 acknowledging a normal distribution of regression residuals.

Discussion

The analysis of the main mensurational parameters highlighted different results between countries, walnut species and plantation types. The best performances were obtained in Spain where the hybrid walnut species was mainly used. As expected, age, crown size and total number of trees per hectare were among the most relevant drivers, explaining 25.0%, 17.1% and 3.9% of the whole variance.

MAI_{dbh} was negatively correlated with the plantation age and stem densities. The lack of a regular/correct management and thinning, due to low price of small assortment and unfavourable market conditions, have negatively affected the growth performance of the main part of plantations. The statistical model also confirmed the importance of both geographical and management parameters on growth trends (Balandier et al. 2000, Paris et al. 2005). Even if simple, the performed LM was able to respect the general assumptions of statistical modelling, with the additional advantage of being informative without any data management or statistical transformation, generating unbiased estimates of coefficients (Marchi 2019).

The analysis of FGPF has pointed out the two different choices in the two countries: although with pure plantations predominant in Italy, mixed plantations have had a remarkable development too showing interesting results often superior to walnut monoculture under the wood quality. It is well known that the use of different species/genotypes increases the resilience of the plantation reducing the risk of pest and disease damages; unfortunately, the wood produced by these nurse trees, with the first thinning, often found strong difficulty in the placing on the market. As ancillary result, the recent developed of polycyclic plantation have achieved further progress in the design of mixed plantations allowing to realize innovative plantation more profitable under the economic and environmental point of view. Inter-specific and intra-specific competition can cause a strong reduction of DBH growth on walnut trees (Mohni et al. 2009, Fernández-Moya et al. 2019) and early thinning are necessary to maintain a stable diametric growth. Then latitude and longitude demonstrated that the plots at higher latitudes showed superior MAI_{dbh} in comparison to the plots situated in the South and Mediterranean areas of the two Countries. Among these the northern regions of Spain (Galicia) and Italy (Piedmont and Lombardy) were better than central Italy (i.e. Tuscany) and Catalugna. These results probably agree with the walnut requirement in rainfall with an optimum at 700 mm of total annual precipitation with more than 125 mm during the vegetative period (May-September) which characterise almost all the sampled plots This mainly occurs in Oceanic or Continental areas rather than in strictly Mediterranean area (Gonin et al. 2014, Mohni et al 2009, Fernández-Moya et al. 2019). Concerning longitude, this parameter is more connected to the species used for planting than to ecological features. While hybrid walnut has been planted in all the Spanish sampled plantations and in one plantation in Lombardy, the European walnut was used in almost all the other areas. Indeed, the hybrid walnut is acknowledged to be able to overcome the European one in term of growth (Mohni et al. 2009, Fernández-Moya et al. 2019). This is also reflected by our survey and in some experimental plantations included in this investigation (Pelleri et al. 2013). Spanish pure plantations using first hybrid walnut derived by seed and then clones have permitted to obtain interesting results in term of wood production and stem quality. For wood production several hybrids have been obtained during the last 100 years. Among them, the progeny of the mating between *J. major* var. 209 x *J. regia* (Mj209xRa) seems to be the most suitable for the European conditions. This seed progeny is characterized by its high vigour, a remarkable apical dominance and an outstanding growth (Aletà et al. 2003, Clark and Hemery 2010). The use of suitable clones permits to reduce heterogeneity inside the plantation in term of growth and stems quality (Urbán-Martínez et al. 2018, Licea-Moreno 2016). For specific site conditions the selection of suitable walnut clones permit to obtain a superior DBH homogeneity as showed in Figure 4 and where a comparison between Italian (pure or mixed plantation) and Spanish pure plantation is reported.

Concerning soil and environmental characteristics, the soil depth, texture and morphology were detected as important and statistically significant factors influencing walnut MAI_{dbh}. Soil depth explained 4.3% of variance while 8.4% was associated to soil texture. Results confirmed the requirement of fertile and deep soils (≥ 80-100 cm) characterized by a loamy texture. According to literature, the tolerance of clay would be lower in relation to higher amount of rainfall (Oliver et al. 2008, Mohni et al. 2009, Fernández-Moya et al. 2019) which probably occurred in analysed stands close to high mountain chains. Regarding morphology walnut trees prefers wide valley and plain areas not interested by frequent late frost. In our surveys, best results have been found in wide valley where frost is less likely to occur. In the same way the plantation types are often acknowledged as interesting parameter. Many experimentations in Italy demonstrated the use of nurse trees (especially N-fixing trees and shrubs) to reduce the management costs (pruning in particular) in comparison with walnut monoculture. Then higher increment rates, due to the intercropping with Nitrogen fixing nurse trees were shown on poor soil (Bianchetto et al. 2013, Marron and Epron 2019, Loewe-Muñoz et al. 2019). The recent developed of polycyclic plantation stimulated progresses in the design of mixed plantation more profitable under the economic and environmental point of view (Buresti Lattes and Mori 2016, Buresti Lattes et al. 2017, Pra et al. 2019).

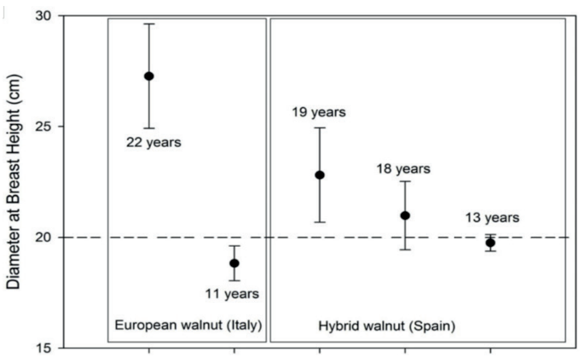

Figure 4 - Difference on mean DBH ± standard deviation homogeneity among different plantations in Italy and Spain.

The stand density was a further indicator of site management, given its dependence to thinning and/or planting densities. As expected, this factor was positively correlated with number of walnut trees and negatively correlated with walnut MAI_{dbh}, DBH, crown diameter, and timber volume. Medium and high-density plantation not managed in suitable way caused a decrease of DBH growth and of wood quality (Carle 2013). A low stocking density of 70-120 final crop trees per hectare have been most widely adopted in many countries, but not always actively managed (Mohni et al. 2009). In fact, these final densities are obtained in late postponing or avoiding the precommercial thinning in order to permit an easier placement of the assortments into the market but reducing the growth and the quality of the final crop trees. Stem quality explained 3.7% of variance which was also positively correlated with average crown diameter, and with all volume factors (timber volume, volume of first log, total volume per hectare). The quality of trees was influencing MAI_{dbh} with and increased growth rate was where more A class trees were observed for a more valuable marketable volume (Nozenzo et al. 2012). This was also connected to crown diameter, with MAI_{dbh}, positively associated to a good development of walnut due to a suitable management system application. Finally, the Spanish pure stands resulted more healthy than Italian pure stands; however, the former are composed by hybrid walnut genotypes and the latter by European walnut. This fundamental genetic difference may have importance in connection with the respective site pedoclimatic conditions (Pollegioni et al. 2009). In addition, the provenance of Italian material was often unknown and heterogeneous.

Conclusions

This survey has pointed out the interesting potentiality of walnut for timber production; both European walnut and hybrid walnut are able to obtain interesting growth rate in diameter some time superior to 1.5 cm yr. This growth rhythms will permit to obtain suitable assortments for industrial transformation (>40 cm) in 25-30 years. On the other hand, the results of the survey conducted stressed the importance of favourable site conditions (deep soils, loamy texture, morphology, etc.) as well as the need to apply correct planting designs and correct management systems. The failure of many Italian plantations realised under the support of the EU 2080/92 regulation can be attributed to the lack of knowledge at national level. Financial funding was often the main aim of farmers, especially in marginal areas and converting part of their farms to wood production.

Pure walnut plantations have often obtained interesting results due to the use of hybrid walnut, the selection of clones suitable for different environmental situations and adoption of suitable management system. This type of pure plantation, in Mediterranean area, needs high intensity management characterized by watering, repeated weed control per year, pruning of all the trees and often precommercial thinning. Pure plantations are often one of the best options in favourable site conditions and, under certain aspects, the use of only one specie is simpler to manage in comparison to mixed plantation and, generally, make it possible to produce a greater timber quantity of a specific valuable tree species. Mixed plantations have had a remarkable development in Italy showing interesting results, often superior to walnut monoculture under the wood quality, and sometime in growth, in not suitable site condition. It is well known that the use of different species/genotypes increases the resilience of the plantation reducing the risk of pest and disease damages; unfortunately, the retrieved timber from the first thinning is not easily placed in the market. For these reasons the polycyclic plantations, where walnut is intercropped with poplar clones or SRC, have been developed solving the problem of precommercial thinnings with the earlier production of valuable assortments (poplar for plywood and SRC for biomass production) requested from the industry.

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