Annals of Silvicultural Research
44 (1), 2020: 24-29

https://journals-crea.4science.it/index.php/asr

Research paper

Special Issue: HORIZON 2020 GA 728086 WOODnat
"Second generation of planted hardwood forests in the EU"

Estimation of crown competition factor for hybrid walnut (*Juglans x intermedia*) Mj209xRa planted forests in Spain

Jesús Fernández-Moya[1*], Ignacio Urbán-Martínez[1]

Received 14/06/2019 - Accepted 20/12/2019 - Published online 07/02/2020

Abstract - Many walnut (*Juglans* spp.) planted forests oriented for timber production have been established during the last decades. These plantations usually have a relatively low initial density (250-400 trees ha^{-1}) and 1 or 2 thinnings are needed for valuable timber production (75-150 trees ha^{-1} for final harvesting). Hence, forest managers need to design when to perform the thinnings and how to do it. Analyzing the trees crown area is a very helpful and easy-to-use tool to evaluate the competence between trees and design the thinnings. The present study proposes two statistical models to estimate Crown Diameter (CD) and Crown Competence Factor (CCF) as a function of Diameter at Breast Height (DBH) for hybrid walnut (*Juglans x intermedia*) Mj209xRa planted forests, within a DBH range between 5 cm (min) and 33 cm (max). CD and DBH were measured in 702 trees at the Bosques Naturales SA walnut planted forests in Cuenca, Girona and A Coruña (Spain). The CCF model is a tool to evaluate the Crown Competition Factor as a function of measured DBH in a plantation, and, accordingly, decide if a thinning should be done or not yet and design it.

Keywords - crown diameter, crown competition factor, *Juglans* spp., planted forests, thinning, walnut.

Introduction

Walnut trees are species of the genus *Juglans* spp., traditionally characterized by their highly-valued nuts and timber. Considering the high timber value and the shortage of the species, many walnut forest plantations oriented for timber production have been established during the last decades (Mohni et al. 2009). These plantations have been established with the common species of Persian or European walnut (*J. regia* L.) and Black or American walnut (*J. nigra* L., *J. major* (Torr.) A. Heller, *J. hindsii* (Jeps.) Jeps. ex R.E. Sm.) but also with several hybrids which have been specifically developed for timber production, e.g.: Mj209xRa and Ng23xRa (Aletà 2004, Victory et al. 2004, Mohni et al. 2009, Clark and Hemery 2010, Coello et al. 2013).

Walnut planted forests have been usually established with a relatively low density (around 250-400 trees ha^{-1}) and 1 or 2 thinnings are needed for valuable timber production and around 75-150 trees ha^{-1} are harvested at the end of the rotation period (Cisneros et al. 2008, Mohni et al. 2009, Coello et al. 2013, Fernández-Moya et al. 2019). Thinning is regarded as a key silvicultural activity when managing planted forests oriented to the production of high-value timber, aiming to reduce stands density and produce large-diameter trees. To this respect, forest managers must deal with several main questions when designing a thinning: *(i)* It is necessary to apply thinning?; *(ii)* How many times would the forest be thinned along the rotation period?; *(iii)* When the thinning should be done?; *(iv)* How many trees should be removed?; and *(v)* Which particular trees should be removed? (West 2006, Kerr and Haufe 2011).

Walnut does not readily react to canopy opening if it is grown in dense plantations where excessive lateral competition and reduction in a crown's functionality is already evident (Clark 1967, Hemery et al. 2005, Marchino and Ravagni 2007). In such situations, the trees demonstrate small diameter growth for many years after thinning. Therefore, thinning must be undertaken before lateral competition influences diameter growth, with the aim of maintaining trees with crowns free from competition and able to grow with large and constant diameter increments. However, estimating when this lateral competition starts to influence tree growth is difficult to manage in the practice and, consequently, some silvicultural tools need to be designed in order to estimate when to perform the thinnings based on easy-to-measure parameters.

The method of crown competition factor (CCF) is proposed as a method for thinning design (Krajicek et al. 1961, USDA 1981, Schlesinger 1988 a, b, Mohni et al. 2009). This factor is an objective method to evaluate the optimal stocking density and to plan thinning regimes. According to this method, when CCF reach a certain value (100-110%), the stand

1 Bosques Naturales SA , Alcobendas (Madrid) – Spain

*Corresponding author: jesusfernandez@bosquesnaturales.com

http://dx.doi.org/10.12899/asr-1931

Table 1 - Location, climate and soil attributes in the studied hybrid walnut (*Juglans x intermedia*) Mj209xRa planted forests of Bosques Naturales SA in Girona, Cuenca and A Coruña (Spain). Location data is shown in geographic coordinates. Climate data was obtained from https://sig.mapama.gob.es/geoportal/, except summer precipitation that was obtained from www.worldclim.org. Soil attributes data represents the mean and the confidence interval (95% probability) from the soil samples taken at each site.

	Attributes	Girona	Cuenca	A Coruña
Location	Latitude	42.1878	39.9148	42.9805
	Longitude	2.8943	-1.4078	-8.1944
	Altitude (m a.s.l.)	125	1030	440
Climate	Papadakis classification	Continental Mediterranean	Temperate Mediterranean	Temperate Mediterranean
	Mean annual rainfall (mm)	700	500	1400
	Duration of dry period (months)	3	3-4	2
	Summer precipitation (mm)	119	79	162
	Mean annual temperature (ºC)	14	12	12
Soil	Number of soil samples	15	7	16
	pH	8.4 (8.2 / 8.5)	8.6 (8.5 / 8.7)	5.5 (5.8 / 5.2)
	Electrical conductivity (mmhos/cm)	0.16 (0.12 / 0.19)	0.11 (0.09 / 0.13)	0.09 (0.1 / 0.08)
	Organic matter (%)	1.2 (1.1 / 1.3)	0.6 (0.4 / 0.8)	7.8 (9.1 / 6.5)
	C/N ratio	6.3 (5.7 / 6.9)	6.5 (4.7 / 8.3)	9.3 (11.8 / 6.9)
	Sand (%)	37 (31 / 44)	64 (56 / 72)	46 (43 / 50)
	Silt (%)	45 (34 / 55)	30 (20 / 41)	11 (2 / 19)
	Clay (%)	18 (8 / 28)	6 (0 / 11)	43 (32 / 53)
	Carbonates (%)	25 (18 / 33)	12 (10 / 14)	
	Active CaCO3 (%)	18 (9 / 27)	5 (4 / 7)	
	CIC (meq/100g)	18.2 (15.7 / 20.8)	16.5 (11.7 / 21.3)	14.8 (21.6 / 7.9)
	K (meq/100g)	0.35 (0.30 / 0.40)	0.46 (0.35 / 0.57)	0.65 (0.98 / 0.31)
	Ca (meq/100g)	22.1 (19.4 / 24.9)	16.2 (12.1 / 20.3)	2.3 (3.1 / 1.5)
	Mg (meq/100g)	0.9 (0.7 / 1.0)	0.8 (0.5 / 1.1)	0.4 (0.5 / 0.3)
	Na (meq/100g)	0.3 (0.1 / 0.5)	0.2 (0.1 / 0.3)	0.2 (0.3 / 0.2)
	P (mg/kg)	73 (0 / 152)	18 (10 / 26)	53 (82 / 23)
	Fe (mg/kg)	10 (7 / 12)	8 (5 / 11)	96 (132 / 60)
	Cu (mg/kg)	2 (1 / 3)	1 (1 / 2)	2 (2 / 1)
	Mn (mg/kg)	17 (12 / 22)	5 (3 / 6)	46 (65 / 27)
	Zn (mg/kg)	1.0 (0.7 / 1.3)	0.5 (0.3 / 0.7)	1.0 (0.7 / 1.3)

should be thinned. This CCF is a relatively easy to use method with the following steps: *(i)* estimate a mean Diameter at Breast Height (DBH) for each stand or plantation; *(ii)* calculate the crown diameter or the crown area based on a statistical model; *(iii)* calculate the proportion of crown area by surface [divide the crown area (in m^2) of each tree by 10,000 (m^2 ha^{-1})]; *(iv)* estimate the total CCF by multiply the proportion of crown area calculated above by the tree density (trees ha^{-1}); and *(v)* analyze the results. If CCF is higher than a certain value (100-110%) a thinning should be designed to reduce the crown competence (USDA 1981). Several authors have published 110% as a CCF limit value for walnut (USDA 1981, Mohni et al. 2009) while Schlesinger (1988 a, b) refers to 100%.

In addition, the CCF model allow forest managers to design the initial layout of a plantation and/or estimate when the thinning is going to be needed. Hence, using the models to perform projections of the trees DBH under different scenarios, we might establish an initial density adequate for the specific conditions. The difference in the mean DBH of the trees to be thinned is especially relevant when considering the market potential interest, making a difference between thinning as a management investment if DBH is low and "commercial thinning" as an intermediate income when DBH is big enough. However, market prices and interests are very variable and fluctuates a lot depending on final-consumer demands. Indeed, during recent years the market demand has been lower than expected and these "commercial thinnings" that were regarded as an intermediate small income by many forest managers had turned into investments needed in order to achieve in the future the objectives fixed for the final harvest at the end of the rotation period. Hence, the expected market price is a key issue regarding the

initial establishment of a planted forests as the idea of a thinning regarded as an income or as an investment would directly influence the decision about the initial tree density planted at establishment.

To estimate crown area, several statistical models have been proposed to estimate walnut crown diameter (CD) as a function of DBH in order to evaluate tree competence for different walnut species: *Juglans regia* L. (Hemery 2000, Hemery et al. 2005, Montero and Cisneros 2006) and *Juglans nigra* L. (USDA 1981, Bechtold 2003). However, there are no published statistical models to estimate CD and/or CCF for hybrid walnut (*Juglans x intermedia*) Mj209xRa to our knowledge. This paper aims to made public the statistical models used for that purpose by the Spanish company Bosques Naturales SA.

Material and Methods

Study area and data collection

The study was conducted in the Bosques Naturales SA company hybrid walnut (*Juglans x intermedia*) Mj209xRa planted forests in various locations in Spain, described in Table 1. Girona and Cuenca sites have calcareous soils relatively similar (Table 1), even though soils in the planted forest in Cuenca are generally deeper while soils in Girona are shallow at some sites, with toxicity due to excess of active lime. Soils is A Coruña are generally more acidic with a deep 40 cm layer rich in organic matter (umbric horizon).

The management of the planted forests is relatively similar in the different locations. Plantation density at establishment is 333 trees ha^{-1} (5 x 6 m spacing). Weeding is done by using herbicides combined with mechanical methods and tillage between plantation rows during the first years (3-5 years) and with mechanical methods and tillage accompanied by sheep grazing in older plantations. Pruning is done according to tree height up to a total clean bole of 4 m (5 m in A Coruña). Fertirrigation is used in Cuenca and Girona according to each site needs and in A Coruña, where irrigation is usually unnecessary, regular fertilization is done complemented with liming (1000 kg ha^{-1} each 2 years). More details of the management of the plantations can be read in Fernández-Moya et al. (2019).

Crown diameter (CD) and Diameter at Breast Height (DBH) were measured in 808 trees (675 in Girona, 27 in Cuenca and 106 in A Coruña). Mean DBH of the measured trees was 20 cm with a range between 5 cm (minimum) and 33 cm (maximum). For CD estimation, two crown diameters (i.e. four radii) were measured, the direction of the first diameter was selected at random, and the second was at right angles to it (Hemery et al. 2005). Measures were taken during the vegetative period (with leaves) between July and September, using measuring tape. The criterion to establish the crown perimeter projection on the ground was a visual estimation.

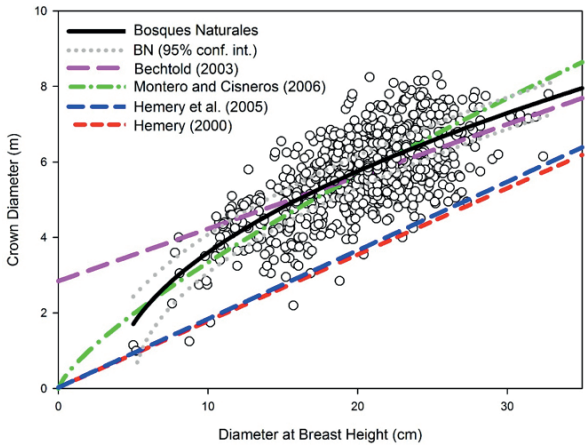

Figure 1 - Comparison between different regression models for estimating Crown Diameter as a function of Diameter at Breast Height in walnut (*Juglans* spp.) planted forests. Bosques Naturales refer to the model detailed in the present paper (Table 2, Figure 1) for hybrid walnut (*Juglans x intermedia*) Mj209xRa in Spain and BN (95% conf. int.) refers to the confidence intervals (95%) of this model. Bechtold (2003) is fitted for black walnut (*J. nigra L.*) in USA. Montero and Cisneros (2006) is fitted for common walnut (*J. regia L.*) in Spain and Hemery (2000) and Hemery et al. (2005) are also fitted for common walnut in England.

Estimation of Crown Competition Factor

Crown Competition factor (CCF) (Krajicek et al. 1961) is calculated as the per cent ratio between Maximum Crown Area (MCA) – calculated based on crown diameter measurement – and the surface (A) of land occupied by trees:

$$CCF = \Sigma\,(MCAi)/A \times 100 \quad (1)$$

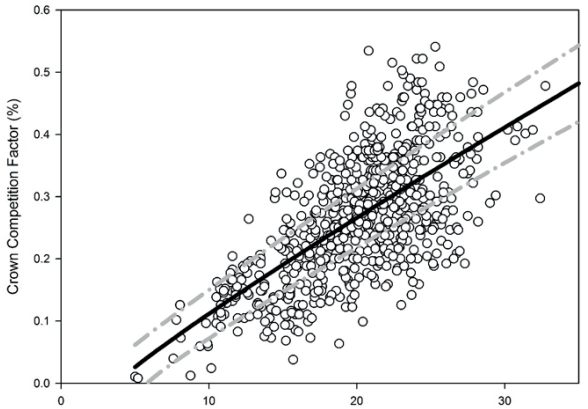

Figure 2 - Regression model for estimating Crown Competition Factor as a function of Diameter at Breast Height in hybrid walnut (*Juglans x intermedia*) Mj209xRa planted forests of Bosques Naturales SA in Girona, Cuenca and A Coruña (Spain). DBH range between 5 cm (minimum) and 33 cm (maximum). See Table 3 for details about the model parameters. Grey lines represent confidence intervals (95%).

Table 2 - Model parameters of the regression for the estimation of Crown Diameter (CD, [m]) as a function of Diameter at Breast Height (DBH, [cm]) in hybrid walnut (*Juglans x intermedia*) Mj209xRa planted forests of Bosques Naturales SA in Girona, Cuenca and A Coruña (Spain). DBH range between 5 cm (minimum) and 33 cm (maximum). Model structure: $CD = (b_0 + b_1 \cdot DBH)(1/\lambda)$, where λ=2.

Parameter	Estimate	Standard Error	p-value
b_0	-7.13535	1.2076	< 0.0001
b_1	2.012019	0.0628	< 0.0001

Table 3 - Model parameters of the regression for the estimation of Crown Competition Factor (CCF) as a function of Diameter at Breast Height (DBH) in hybrid walnut (*Juglans x intermedia*) Mj209xRa planted forests of Bosques Naturales SA in Girona, Cuenca and A Coruña (Spain). DBH range between 5 cm (minimum) and 33 cm (maximum). Model structure: $CCF = (b_0 + b_1 \cdot DBH)(1/\lambda)$, where λ=1.1.

Parameter	Estimate	Standard Error	p-value
b_0	-0.0536611	0.0117863	< 0.0001
b_1	0.0143371	0.0005768	< 0.0001

Hence, CCF of the forest stand can be regarded as the sum of each tree individual CCF which is the measure used in the present paper to be modeled as a function of individual trees DBH.

Statistical analysis

All the statistical analyses were performed using R (R Core Team 2018). Different model types were tested to fit the regression between either individual trees CD and CCF with DBH, within the general framework of the Generalized Linear Models (GLM), choosing the best fitting one based on the Akaike Information Criterion (AIC). The gamma and the gaussian family were compared. Different link functions were also tested: power links with lambda between -2 and 2, with 0.1 intervals. Finally, the possible random effect of the three sites (Girona, A Coruña and Cuenca) was analyzed compared the GLM with an analogous Generalized Linear Mixed Model (GLMM). Model efficiency (EF) was calculated as a pseudo-R^2 measurement, as:

$$EF\ (\%) = \text{model deviance} \cdot 100 / \text{null deviance} \quad (2)$$

Definition of planted forests

The term "planted forests" has been used along this document according to the FAO definition: "A planted forest is defined as a forest that at maturity is predominantly composed of trees established through planting and/or deliberate seeding. Planted forest includes but is not limited to plantation forest" (see http://www.fao.org/forestry/plantedforests/67504/en/).

Results and Discussion

Estimation of Crown diameter and Crown Competition Factor

A GLM with gaussian family and power link function (lambda=2) and no random effect resulted as the best model for estimating individual tree Crown Diameter (CD) as a function of DBH (Tab. 2, Fig. 1), with an efficiency of 52.6% within a DBH range between 5 cm (minimum) and 33 cm (maximum). Within the core DBH range of the model (10-30 cm) this model is relatively similar to the ones fitted for *Juglans nigra* L. (Bechtold 2003) and *Juglans regia* L. (Montero and Cisneros 2006), but a little different from those fitted for *Juglans regia* L. by Hemery (2000) and Hemery et al. (2005) (Fig. 1). A more detailed review of the model proposed by Hemery (2000) shows that this model also underestimate the original data within the DBH range between 10-30 cm, considering that the model is fitted for a DBH range up to more than 90 cm. This might be explained because it uses a simple regression model (straight line) and initial values for the ratio between crown diameter and stem diameter reduces as stem diameter increases, dropping by about 60% from 10 to 70 cm DBH (Hemery et al. 2005).

A GLM with gaussian family and power link function (lambda=1.1) and no random effect resulted as the best model for estimating individual tree Crown Competition Factor (CCF) as a function of DBH (Tab. 2, Fig. 2), with an efficiency of 57.7%. The proposed model is very similar to the one published by USDA (1981) for *J. nigra* L. within the DBH range between 10-20 cm but the differences outside this range are noticeable. Hence, the individual tree CCF for a black walnut of DBH of 10, 15 and 20 cm are 0.12, 0.20 and 0.31%, respectively, while the values for these DBH are 0.11, 0.19 and 0.27%, respectively, for the hybrid walnut (Fig. 2). However, a tree CCF of 0.59% is proposed by USDA (1981) for a black walnut with 30 cm DBH while the proposed model for hybrid walnut estimates 0.41% for that tree (Fig. 2).

Application of the methodology for the design of thinnings

Some recommendations have been published as general rules for thinnings schedules in walnut

planted forests. Cisneros et al. (2008), in a scheme with initial plant densities lower than 400 trees ha^{-1}, propose the first thinning corresponding with a mean DBH higher than 20 cm, and a DBH higher than 35 cm where initial plant densities are lower than 200 trees ha^{-1}. Coello et al. (2013) proposed a first thinning when the trees would have a DBH of 20 cm, in a scheme with an initial walnut density of 185 trees ha^{-1}.

A more detailed approach such as CCF can be used to design thinnings for a specific plantation (Krajicek et al. 1961, USDA 1981, Mohni et al. 2009). Hemery et al (2005) summarizes how the crown diameter and the ratio between crown and stem diameters can be used in forest management, mainly to estimate optimal stand density at various stages in the stand's development and design thinnings. Besides these uses of the crown diameter data, Krajicek et al. (1961) proposed the CCF method for the thinning design based on crown area measurements, which is explained in detail for *J. nigra* L. in USA by the USDA (1981) and proposed to be used in Europe by Mohni et al. (2009). There have been some experiences with the application of the CCF in walnut planted forests in Italy, where thinnings of 30-35% of the number of trees are proposed for reducing the CCF from 110% to 70% (Frattegiani and Mercurio 1991, Mercurio and Minotta 2000)

The proposed CCF model (Tab. 3, Fig. 2) would help to design a specific thinning scheme for a hybrid walnut planted forest. This model is a tool to estimate individual tree CCF as a function of measured DBH. The CCF of a stand is calculated as the sum of the individual tree CCF or multiply the individual CCF from the average DBH by the stand's density. Hence, if the stand's CCF would be higher than 100 - 110%, it should be thinned (USDA 1981, Schlesinger 1988 a, b, Mohni et al. 2009).

As an example about the application of this methodology, for a planted forest with 333 trees ha^{-1} (5x6 m wide layout – very common in the current plantations in Spain), a mean CCF of 0.33% per each tree would be needed to reach a CCF of 110%, which corresponds with a mean DBH of 24 cm (21-28 cm [95% Confidence Interval]). Similarly, to reach a CCF of 100% in the same planted forests, a mean CCF of 0.30% per each tree would be needed, which corresponds with a mean DBH of 22.4 cm (19.4-26 cm [95% Confidence Interval]) (Fig. 2). Taken into account that walnut is considered as species with a poor response to late thinnings, when excessive lateral competition and reduction in a crown's functionality is already evident (Marchino and Ravagni 2007); this difference about the use of a CCF limit value of 100 (proposed by Schlesinger 1988 a, b) or 110 (proposed by USDA 1981, Mohni et al. 2009) might be relevant regarding the trees' response to the thinning. To this respect, more research is needed in order to what is the best CCF limit value for the thinning design in walnut planted forests.

Conclusion

The proposed models are easy to use tools to estimate individual trees Crown Diameter and Crown Competition Factor as a function of Diameter at Breast Height in hybrid walnut (*Juglans x intermedia*) Mj209xRa planted forests. These models are helpful for the thinning design for a specific plantation and for the planification of the initial layout of a new plantation, to estimate the tree size that the trees would have in the scheduled thinnings, depending on the stand's density.

Acknowledgements

The present study makes public some management equations developed by the company Bosques Naturales SA. The authors – employees of that company – would like to acknowledge the effort of their co-workers in the field work needed to develop these equations. This publication of this study is done under the framework of the European H2020 Woodnat project (www.woodnat.eu).

References

Aletà N. 2004 - *Current Research in Spain on Walnut for Wood Production*. In: Proceedings of the 6th Walnut Council research symposium Michler et al. (Eds.), Black walnut in a new century. Lafayette; U.S. Department of Agriculture, Forest Service, North Central Research Station. 188 p.

Bechtold W.A. 2003 - *Crown-Diameter Prediction Models for 87 Species of Stand-Grown in the Eastern United States*. Southern Journal of Applied Forestry 27 (4): 269-278.

Cisneros O., Montero G., Aletà N. 2008 - *Selvicultura de* Juglans regia *L.* In: "Compendio de Selvicultura Aplicada en España" (Eds. Serrada R, Montero G, Reque JA). INIA-Fundación Conde del Valle de Salazar, Madrid.

Clark F.B. 1967 - *Pole-Sized Black Walnut Respond Quickly to Crown Release*. Journal of Forestry 65 (6): 406–408.

Clark J., Hemery G. 2010 - *Walnut hybrids in the UK: fast growing quality hardwoods*. Quarterly Journal of Forestry 104: 43-46.

Coello J., Becquey J., Gonin P., Ortisset J.P., Desombre V., Baiges T., Piqué M. 2013 - *Guía de ecología y selvicultura de especies productoras de madera de calidad*. Generalidad de Cataluña - Centro de la Propiedad Forestal.

Fernández-Moya J., Urbán-Martínez I., Pelleri F., Castro G., Bergante S., Giorcelli A., Gennaro M., Licea-Moreno R.J., Santacruz Pérez D., Gutiérrez-Tejón E., Homar-Sánchez C., Bidini C., Chiarabaglio P.M., Manetti M.C., Plutino M., Sansone D. 2019 - *Silvicultural guide to managing walnut plantations for timber production*. ISBN 978-84-09-12163-2.76 p.

Frattegiani M., Mercurio R. 1991 - *Il fattore di competizione*

*delle chiome (CCF) nella gestione delle piantagioni da legno di noce comune (*Juglans regia *L.)*. Monti e Boschi 5: 59-61.

Hemery G.E. 2000 - Juglans regia *L.: genetic variation and provenance performance.* PhD Thesis. Department of Plant Sciences, University of Oxford.

Hemery G.E., Savill P., Pryor S.N. 2005 - *Applications of the crown diameter-stem diameter relationship for different species of broadleaved trees.* Forest Ecology and Management 215 (1–3): 285–294.

Kerr G., Haufe J. 2011 - *Thinning Practice: A Silvicultural Guide.* UK Forestry Commission. [www.forestry.gov.uk/pdf/Silviculture_Thinning_Guide_v1_Jan2011.pdf/$file/Silviculture_Thinning_Guide_v1_Jan2011.pdf]

Krajicek J.E., Brinkman K.A., Gingrich S.F. 1961 - *Crown Competition – A measure of Density.* Forest Science 7 (1): 35-42.

Marchino L., Ravagni S. 2007 - *Effetti del diradamento in impianti puri di noce: prime osservazioni.* Sherwood - Foreste e alberi oggi 139: 40-41.

Mercurio R., Minotta G. 2000 - *Arboricoltura de legno*. Ed. CLUEB. Bologna, Italy. 203 p.

Mohni C., Pelleri F., Hemery G.E. 2009 - *The modern silviculture of* Juglans regia *L.: A literature review.* Die Bodenkultur 60 (3): 21-34.

Montero G., Cisneros O. 2006 - *Informe sobre el desarrollo del proyecto AGL2003-09347-C02-01, "Selvicultura de plantaciones de frondosas autóctonas productoras de madera de calidad en Castilla y León".* Private working document.

R Core Team 2018 - *R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing.* Vienna, Austria. [www.R-project.org]

Schlesinger R.C. 1988 (a) - *First Thinning.* In: Burde EL (ed) Walnut Notes. USDA, Forest Service, North Central Forest Experiment Station.

Schlesinger R.C. 1988 (b) - *Second Thinning.* In: Burde EL (ed) Walnut Notes. USDA, Forest Service, North Central Forest Experiment Station.

USDA 1981 - *Quick reference for thinning black walnut.* USDA Forest Service, Minnesota

Victory E.R., Woeste K.E., Rhodes O.E. 2004 - *History of Black Walnut Genetics Research in North America.* In: Proceedings of the 6th Walnut Council Research Symposium "Black Walnut in a New Century".

West P.W. 2006 - *Growing Plantation Forests.* Springer, Germany.