The modern silviculture of *Juglans regia* L.: A literature review

C. Mohni, F. Pelleri and G.E. Hemery

Moderner Waldbau mit der Walnuss (*Juglans regia* L.): Eine Literaturübersicht

1 Site requirements

1.1 Temperature

Juglans regia requires warmth during the growing season, with at least 6 months of an average temperature > 10 °C (BECQUEY, 1997). *Juglans regia* is sensitive to winter and late spring frosts, with the former being especially damaging for common walnut because the species often exhibits early initiation of vegetative activity (flushing) (BERNETTI, 1995). The timing of spring flushing can vary greatly between provenances, as demonstrated by various authors (FADY et al., 2003), therefore provenance choice could affect propensity to frost damage (HEMERY et al., 2005b). In The Netherlands cold-tolerant cultivars have been developed in the north of the country (OOSTERBAAN et al., 2006). With good quality plant material it still remains important to avoid cold sites or areas where cold air can accumulate (BECQUEY, 1997), even within an overall good site (e.g. valley bottoms or hollows). Young shoots and flowers are easily damaged by spring frosts of –1 °C in Britain where these frequently cause failure of the nut crop (SAVILL, 1991). Late spring frosts affect both leaf and flower buds; whilst early frosts in autumn can affect shoots not yet lignified ŞOFLETEA and CURTU, 2007).

1.2 Water

For optimum growth, *Juglans regia* requires 700–800 mm of rainfall annually, which ideally is well-distributed throughout the year (BECQUEY, 1997; BERGOUGNOUX and

Zusammenfassung

Der Walnussbaum (*Juglans regia* L.) wird in vielen Ländern Europas kultiviert. Schnelles Wachstum, hoher Holzwert sowie seine Flexibilität gegenüber erwarteten klimatischen Veränderungen sind Qualitäten, die ihn auch in Zukunft als Edellaubholz auszeichnen. In einigen europäischen Länder, insbesondere Frankreich und Italien, wurden viele Jahre in Waldbau- und Genetikforschung investiert, um Erkenntnisse über das „Artenpotential" zu gewinnen. Heute sind viele europäische Länder am Walnussbaum interessiert, und Forschungsergebnisse sind in vielen Sprachen publiziert. Dieser Artikel fasst die wichtigsten in französisch, italienisch, deutsch und englische erschienen Artikel zusammen und gibt einen Überblick über die neuesten Empfehlungen für den Waldbau mit Walnuss.

Schlagworte: Walnussbaum, Waldbau, Pflanzung, Wertastung, Durchforstung.

Summary

Common walnut (*Juglans regia* L.) is cultivated across much of Europe. There are many qualities that favour it as a valuable broadleaved tree for the future including its rapid growth, the high value of its timber and its plasticity in respect to projected climate change. Some countries in Europe, particularly France and Italy, have invested many years of silvicultural and genetic research in developing the species' potential. Today, most European countries are interested in common walnut, and research findings have been published in many languages. This paper summarises the most important of these, published in French, Italian, German and English, and provides an overview of the latest recommendations for best practise in walnut silviculture.

Key words: Common walnut, silviculture, plantation, pruning, thinning.

GROSPIERRE, 1981). *Juglans regia* can tolerate a period of drought although rainfall must ideally never fall below 100–150 mm during the growing period (GIANNINI and MERCURIO, 1997).

1.3 Soil

Juglans regia requires deep and rich soils (BARY-LENGER et al., 1988; JACAMON, 1987), and to grow well, the species must be planted in soils deeper than 80–100 cm (BECQUEY, 1997; GIANNINI and MERCURIO, 1997). The best soils for *J. regia* cultivation are loams (clay >25 %, silt 30–50 % and sand 30–50 %) (GIANNINI and MERCURIO, 1997). Ideally, clay soil content should be less than 35 %, and accordingly, the more rainfall, the less the amount of clay that can be tolerated (GIANNINI and MERCURIO, 1997). In central Italy the best basal area increment for the species have been found in soils with a clay content ranging between 15 and 25 % (FRATTEGGIANI et al., 1996). *Juglans regia* dislikes flooded, shallow soils, and soils with free calcium (BOUDRU, 1989).

The ideal soil pH value ranges between 6.5 and 7.5 (BECQUEY, 1997; ŞOFLETEA and CURTU, 2007) or according to other authors between 6 and 7.5 (GIANNINI and MERCURIO, 1997). To avoid chlorosis, BECQUEY (1997) advises against planting *Juglans regia* on surface soils with a high pH (8.0–8.5). Sites that should be avoided are light sandy soils and heavy soils (KLEMP, 1979), shallow soils over chalk, peaty soils and water-logged sites (SAVILL, 1991).Walnut requires well-aerated soils, ideally up to 1.0 m in depth (BERNETTI, 1995).

Some species that indicate favourable site conditions for *Juglans regia* include: *Sambucus nigra* L., *Corylus avellana* L., *Rubus spp., Fraxinus excelsior* L., *Ulmus campestris* L., *Acer pseudoplatanus* L., *Arum maculatum* L., *Mercurialis perennis* L., *Ficaria verna* Huds., *Allium ursinum* L., *Urtica dioica* L. Unfavourable site conditions are characterised by *Juncus conglomeratus* L., *Pteridium aquilinum* (L.) Kuhn and *Molinea caerulea* (L.) Moench (BECQUEY, 1997).

2 Root system

Young *Juglans regia* trees have a deep root system with a substantial taproot. In the first year of growth, the taproot can grow 50 to 80 cm (BOUDRU, 1989), and up to 3–5 m in following years, according to soil qualities (BECQUEY, 1997; BERNETTI, 1995). Generally, the taproot disappears gradually as the tree ages (BECQUEY, 1997). Lateral roots develop rapidly, producing a very large and shallow root system (BECQUEY, 1997; BERNETTI, 1995) which can reach lengths of up to 12–14 m (STĂNESCU et al., 1997). For this reason, *J. regia* demonstrates strong intra-specific competition (BERNETTI, 1995). Root system research of walnut species by SALBITANO et al. (2001) indicated differences among *Juglans regia*, *Juglans nigra* L. and their hybrids *Juglans major* Heller × *J. regia*. Walnut hybrids have a more complex root system in comparison to both common walnut and black walnut. In a mixed plantation with Italian alder, *J. regia* root systems were found to develop less in depth but to have greater radial growth in comparison with those in a pure plantation (SALBITANO et al., 2001).

Several ecological and anthropogenic factors can influence the physiological operation and the health of the root system, and thus also influence the growth and health of the tree. Careful handling of *Juglans regia* roots is recommended during planting in order to avoid wounds, which can increase susceptibility to pathogen attacks (EHRING, 2005; LÜTHY, 2005; MASSON, 2005). *Amillaria mellea* s. l. (Vahl) Kumm is particularly dangerous when roots are damaged, whilst *A. mellea* attacks are particularly observed in forest stands (MASSON, 2005).

Soil temperature can influence the growth of *Juglans regia*. Chilling of the root system to 2 °C has been found to result in a rapid and long-lasting decrease of net photosynthesis within 24 hours, which remained depressed for up to 12 days (LYR, 1996). LYR (1996) also observed an important influence of soil temperature on the transpiration and respiration of the tree that demonstrated a strong and rapid relationship between root activity and leaf processes.

The roots of *Juglans regia* are also very sensitive to changes in water regime. According to BELLONI and MAPELLI (2001), flooding and drought both have negative effects on physiological parameters of growth. The authors found that epinastic leaves appeared in conjunction with a reduction of leaf gas exchange, where stress was found to block xylem water transport. Furthermore, stem radial growth was halted and small stem shrinkage was evident. When the stresses were removed it was found that stem diameter growth reinitiated much faster in trees subjected to drought stress than in those trees subjected to root hypoxia (BELLONI and MAPELLI, 2001).

3 Light management

Juglans regia is a light-demanding species, demonstrating strong positive phototropism, at both young and adult stages (BARY-LENGER et al., 1988; JACAMON, 1987). Only in seedling form and in nitrogen-rich soil it is shade-tolerant (BERNETTI, 1995). However, some authors have noted a higher (but still low) shade tolerance at a young stage compared to an adult stage (e.g. EHRING, 2005; WINTER, 1982; WINTER and GÜRTH, 1990). *Juglans regia* reacts sensitively to light availability (BECQUEY, 1997; EHRING, 2005; WINTER, 1982). Young trees can tolerate a short period of shade but if it persists, crown deformation and undesirable stem form may result (WINTER, 1982). As the tree matures it requires full light conditions (ŞOFLETEA and CURTU, 2007). This positive phototropism is very pronounced at all ages, therefore the light environment for *J. regia* must be managed very carefully to avoid crooked stem growth, leading to the development of tension wood or other stem deformations (MASSON, 2005). Also, protection from wind is important in promoting good growth form (CRAVE, 1990). However, it is important to manage any side shelter with care, considering the great sensitivity to light levels of the species (BECQUEY, 1997).

The presence of companion or nurse plants can have a positive effect on butt log quality, including finer branches, better log form, and better height growth (BECQUEY, 2006; CAMPBELL and DAWSON, 1989; DELANNOY, 2003; EHRING, 2005; SCHÜTT et al., 1994). In fact, when companion plants overshadow walnut, it tends to grow more in height and with a straighter trunk, with walnut growth response directly related to the architecture of the companion plant (CLARK et al., 2008). The density and the species of the interplanted trees also influence the butt log quality as well as diameter and height growth (GRAESCHIKE and GÜRTH, 1993; PEDLAR et al., 2006; SCHULZE-BIERBACH, 1991). Other benefits of companion planting are discussed further below.

4 Stand density

4.1 Branch development

Crown shape in *Juglans regia* is strongly influenced by the density of stems and the species mixture of a plantation. In pure walnut plantations with low density and without artificial pruning, *J. regia* tends to produce forks and large branches. Crown shape and branching habit in dense mixed plantations contrast greatly to those in pure plantations (GIANNINI and MERCURIO, 1997). TANI et al. (2006) analysed the effects of companion species on growth, stem form, branching, and crown shape of *J. regia* grown in pure and mixed plantations with Italian alder (*Alnus cordata* (Loisel.) Desf.) and other companion species (*Robinia pseudacacia* L., *Corylus avellana* L., *Elaeagnus umbellata* Thunb.). The nutritional effects of enrichment in nitrogen (N) were assessed by measuring nitrogen concentration in the soil and in the walnut's leaves. Also the quality of radiation under the canopy of these different plantations types were analysed measuring red/far red ratio. TANI et al. (2006), observed that in mixed plantations, *J. regia* grew faster (both in height and in diameter) and there was a positive effect on stem form and crown shape, especially with Italian alder, compared to those in pure plantation conditions. Indeed, *J. regia* trees grown in mixed plantations with Italian alder had straighter stems, with crowns characterised by fewer competing branches with a lower insertion angle at the stem, which developed a different crown shape (narrower and lengthened). Moreover, nitrogen-fixing companion trees increased the amount of N in the soil favouring its translocation in the walnut's leaves. No significant differences were found in the quality of light (red/far red ratio) except in a mixed plantation with hazel. Among the nitrogen-fixing trees, *Robinia pseudacacia* has been found to be a very competitive species that may reduce the diameter growth of *J. regia*, especially in plantations at high stocking density (1100 n ha^{-1}) (TANI et al., 2006). CLARK et al. (2008) found that branch diameter was greatly reduced on young trees (6 years), and fewer competing stems were present, when accompanied by the shrub *Elaeagnus umbellata*, compared to those grown in open conditions.

Other authors (SALBITANO and BAGNARA, 2004) have observed similar architectural effects on crown development amongst walnut trees grown in pure and in mixed plantations with Italian alder, using the same spacing (3 × 3 m) but in different mixtures. SALBATINO and BAGNARA (2004) analysed a sample of trees (from 4 to 10) within each mixture type (pure walnut plantation and mixed plantation with *Alnus cordata* included at 50 %; 75 % and 80 %). For each walnut, measurements were made of total height; height of crown insertion; height of each terminal bud of branch, branch terminal bud distance from main axes and azimuthal angle. Different architectural shapes and also significant differences in the complexity of branching were identified. Walnuts in the mixed plantation were taller, had longer crowns, and branches with a higher insertion angle and that were fewer in number. *Juglans regia* grown with 50 % *Alnus cordata* demonstrated the best form, whilst an increase in the proportion of *A. cordata* demonstrated a progressive reduction of crown width.

At a young stage *Juglans regia* has a conic crown with clear apical dominance but later, if it is in free growth, the main stem forms large branches and a globular crown (Giannini and Mercurio, 1997). *Juglans regia* requires light and a large space, reaching a maximum crown diameter of 8–10 m (Bernetti, 1995). Wide crown dimensions (12–15 m) have been observed in Italy near Florence (Buresti, *pers. comm.*) and in The Netherlands (Oosterbaan and van den Berg, 1998).

The crown diameter-stem diameter relationship (D/d) has been studied for *Juglans regia* in fully occupied stands with no crown overlap (Hemery et al., 2005a). This relationship indicated that with a stem diameter of 60 cm dbh, a crown diameter of 13.6 m and a stocking density of 68 trees per hectare could be predicted (Table 1). In plantation conditions, the D/d ratio varies between 16 and 18 (Boudru, 1989). In The Netherlands it was found that trees with a dbh of 40–50 cm had crown diameters ranging between 11 and 13 m (Oosterbaan and van den Berg, 1998).

Table 1: Stand density and basal area for walnut (*Juglans regia*) stands based on 100 % canopy closure and square planting dbh (diameter at breast height), cd (crown diameter), z (crown/stem diameter) (from Hemery et al., 2005a)

Tabelle 1: Bestandesdichte und Grundfläche für Walnussbestände (*Juglans regia* L.) basierend auf 100 % Kronenschluss und Pflanzen im Vierechsverband BHD (Durchmesser auf Brusthöhe), cd (Kronendurchmesser), z (Krone/Stammdurchmesser) (nach Hemery et al., 2005a)

dbh (m)	*cd* (m)	*z* *K/d* ratio	*N* trees/ha	Basal area (G m^2 ha^{-1})
0.10	4.47	44.70	500	3.9
0.15	5.35	35.67	349	6.2
0.20	6.23	31.15	258	8.1
0.25	7.11	28.44	1198	9.7
0.30	7.99	26.63	157	11.1
0.35	8.87	25.34	127	12.2
0.40	9.75	24.38	105	13.2
0.45	10.63	23.62	88	14.1
0.50	11.51	23.02	75	14.8
0.55	12.39	22.53	65	15.5
0.60	13.27	22.12	57	16.1
0.65	14.15	21.77	50	16.6
0.70	15.03	21.47	44	17.0

4.2 Growth

In plantation conditions, for single *Juglans regia* trees no more than 70 years old, diameter increments of approximately 1 cm per year have been observed (Becquey, 1997; Bernetti, 1995; Boudru, 1989; Hubert, 1979). Diameter increments of about 2 cm have been observed in optimum conditions in the north of Italy (Bertolotto et al., 1994; Buresti and Mori, 2003a; Ravagni, 2001), in the south of Italy (Di Vaio and Minotta, 2005), and in France (Becquey, 1997) within young low-density plantations situated on flood plains with deep soils rich in nutrients and well-fed with water. According to Colpacci (1971) diameter growth is dependent on site characteristics: under the favourable conditions of Sibiflel-Hunedoara (in central Romania), at 60–70 years of age, walnuts can reach 80–90 cm in diameter, whereas walnuts of the same age but grown at upper elevations and on less fertile soils reach a maximum of 50–60 cm in diameter.

Şofletea and Curtu (2007) observed fast early height growth; with trees attaining 30–50 cm in the first year of growth. Stump sprouts can grow up to 3 m in height in the first year. Grown without competition, at 8 years old, trees can be 8 m tall and 20 cm in diameter. Negulescu and Săvulescu (1965) observed height growth between 70 and 100 cm per year after 8 years.

5 Maximum age and size

Juglans regia can live for 150–200 years and can reach 25–30 m in height and 1.5–2.0 m in diameter (Gellini and Grossoni, 1997), whilst increased longevity (300–400 years) has been reported in natural stands (Hemery and Popov, 1998).

6 Growth models

There is relatively little published data on the growth of *Juglans regia* but there are many publications about the growth of *Juglans nigra* in the USA (e.g. Ares and Brauer, 2004; Bohanek and Groninger, 2005; Pedlar et al., 2006; Riebeling, 1991).

A volume table for pure *Juglans regia* plantations between 16–26 years old was developed in Italy (Bordin et al., 1996; Bordin et al., 1997), from data arising from the analysis of 1800 trees sampled across twenty four plantations. Merchantable volumes for trees up to 35 cm (dbh) were forecast (Table 2) using the following equations with one or two independent variables: $v = b_0+b_1d+b_2d^2$ and $v = b_0+b_1d+b_2d^2+b_3h^{ins}$, where v is the volume, b_0, b_1, b_2 are coefficients, d is dbh and h^{ins} is height of crown insertion . Production forecasts indicated 35–60 $m^3\ ha^{-1}$ at the age of 26 years and diameters between 20.7–26.5 cm.

Di Vaio and Minotta (2005) developed a production table for pure *Juglans regia* plantations in the Campania region of Italy. This table is valid for plantations between 7–27 years old and estimated yields are consistent with those of Bordin et al. (1996).

Table 2: Mean expected value of merchantable tree volume, confidence intervals and mean tree height dbh classes (from Bordin et al., 1997)

Tabelle 2: Durchschnittlich geschätzter Wert des verkäuflichen Holzvolumens, Vertrauensintervalle und durchschnittliche Baumhöhe, BHD-Klassen (nach Bordin et al., 1997)

Dbh (cm)	Volume (dm^3)	Confidence intervals (dm^3)	Height (m)	Crown insertion (m)
5	6.1	±0.1	4.6	2.7
10	27.5	±0.2	7.1	3.0
15	65.2	±0.6	9.3	3.8
20	119.0	±1.3	11.2	3.9
25	189.0	±2.3	12.8	3.6
30	275.2	±3.6	14.1	–
35	377.5	±5.3	15.2	–

7 Silvicultural interventions

7.1 Formative shaping

Walnuts do not have a strong central axis, their growing habit being sympodial, and formative pruning is normally required to ensure a single and straight stem of 1.5–3.0 m (Evans, 1984). In *Juglans regia* the terminal shoot sometimes shows reduced growth so it can be overtaken by one or two lateral shoots. In this case the defective terminal shoot should be substituted with the most vertical and tall lateral shoot (Hubert, 1979; Hubert and Courraud, 1998).

Bulfin and Radford (1999a) studied the effect of early and annual formative shaping on newly planted broadleaves (including *Juglans regia*) on stem quality, height and diameter growth. In the experiment, early formative shaping was defined as: "w*ork carried out to maintain a single, straight stemmed and apically dominant leading shoot on the broadleaf*". The authors state that formative shaping had a slight positive effect on *J. regia* quality in the first two growing seasons after planting. This effect increased in the two following years. The form of *J. regia* in the unshaped treatment was distinctly globular and bush-like but it was also noted that: "*the straightening response, which was clearly evident among the shaped ash (Fraxinus excelsior* L.*) and sycamore (Acer pseudoplatanus* L.)*, was not so apparent in walnut (J. regia)*". The authors suggest that this could be explained by the unsuitability of the experimental site (frost and exposure) for *J. regia*. In the second part of this work Bulfin and Radford (1999b) found a significant positive effect of early formative shaping on the height growth of *F. excelsior*, *Castanea sativa* Mill. and *A. pseudoplatanus*, but it had no significant effect on *J. regia* and the other studied species. There was a significant negative effect from formative shaping on the diameter growth of *F. excelsior, C. sativa*, *A. pseudoplatanus* and *J. regia.*

Becquey (1997) recommended that formative shaping of *Juglans regia* should be initiated from the second growing season when trees reach 1 m in height and demonstrate annual height increment of approximately 25 cm. Productive pruning should be started later, after 3–4 growing seasons, when trees are 2 m in height or when the diameter of branches reach approximately 3 cm at the basis of the crown.

7.2 Pruning

Pruning is a very important silvicultural operation for *Juglans regia*, as it is desirable to obtain a stem of at least 2.5 m without defects. It is possible to define three types of formative pruning: "flagpole pruning" (termed "astone" pruning in Italy , and "élagage en queue du billard" in France) is the typical pruning method adopted in the South of Italy and in France for the production of wood and nuts (Becquey, 1997; Falconi et al., 1996), "progressive pruning" used in France (Becquey, 1997; Hubert and Courraud, 1998) and a new type, "reiterative pruning", tested in Italy (Buresti and Mori, 2003b; Buresti et al., 2001b). These three types of pruning were defined by Bidini et al. (2004) and are described in more detail in Table 3 and Figure 1.

According to an investigation described by Becquey (1997), pruning that is conducted too early and too brutally can have the following consequences: a lack of stem rigidity (cylindrical trunk rather than conical), an explosion in

Table 3: Three methods of pruning used for *Juglans regia:* definitions, advantages and disadvantages (BIDINI et al., 2004)
Tabelle 3: Drei Wertastungs-Methoden für *Juglans regia* und ihre Vor- und Nachteile (BIDINI et al., 2004)

Pruning method	Advantages	Disadvantages
Flagpole pruning This technique is the most widely adopted for *Juglans regia* in Italy. It is practical only with optimal site conditions where it is possible to obtain an annual height increment of at least 100–150 cm. Use of this pruning method provides effective control of tree architecture. It consists of systematic and repeated removal of all shoots along the stem. Only the apical shoot it is not controlled and grows freely. It is necessary to repeat this process every year until the trunk reaches 2.5–3.0 m in height. When this pruning method is adopted, more operations are necessary during the same growing season to control new shoots. In general, the pruning period extends from April to July.	Pruning produces rapid stem elongation and defects are absent from the central stem.	The stress due to this technique, that favours stem elongation rather than diameter growth, produces instable trees that need additional support.
Progressive pruning In this type of pruning trees initially grow without any intervention. Later, at least after two years, pruning is carried out to control and modify tree architecture. During *formative cutting (shaping)* only branches that are prone to become dominant or competitive with the apical shoot must be cut or controlled. The *progressive pruning* method focuses on increasing the crown height minimizing the stress on a tree in order to reach a minimum of 2.5 m of clean stem. This goal must be obtained progressively before stem diameter reaches 10 cm by removing all branches. Using this technique, larger knots and anomalous colours in the wood are avoided. Progressive pruning can be implemented in winter or spring but to favour rapid healing, vigorous branches (c. 3 cm) should to be cut in winter.	With this method of pruning it is not necessary to provide additional support because trees are generally stable. This technique is more suitable for medium and low fertility conditions.	This pruning technique requires a highly skilled workforce. In contrast with the other pruning methods, wood quality is lower due to the presence of knots and defects.
Reiterative pruning This pruning method is carried out in green (June–July) With this technique it is possible to stimulate trees to produce a particular crown structure that will be reiterate every year until a free stem 2.5 m long is produced. The typical crown structure consist in : • apical shoot without lateral branches; • intermediate stem of two or more years (according to pruning intensity) with many small branches able to develop freely and to produce a large photosynthetic surface; • basal stem without branches. In relation to site conditions it is possible to distinguish three intensity levels: **Low intensity**: used in non-optimal site conditions, trees have to demonstrate height increments at least 50–70 cm. **Medium intensity**: used in medium-good site conditions, trees have to demonstrate height increments at least 70–100 cm. **High intensity**: good site conditions, trees have to show height increments at least 100–150 cm.	The trunk presents few defects in the central cylinder. Its dimension depends on pruning intensity.	Using high intensity pruning, trees are stressed and instable, similarly to flagpole pruning, and additional support is required.

the production of epicormics, a hypertrophy of the pruning wounds (continual elimination of the epicormics which develop on the wounds of pruning), and a general reduction in growth. BECQUEY (1997) states that this type of pruning could initially encourage height growth but only for a few years, thereafter as a consequence, growth would slow down considerably, accompanied by a general weakening of the tree. On the contrary, if a good proportion between crown length and the length of the pruned stem is maintained (respectively ⅔ and ⅓ of the total tree length, and for isolated trees ½ and ½), pruning will permit the development of a clean trunk without epicormic growth (BECQUEY, 1997). EHRING (2005) advises pruning that does not exceed 50 to 60 % of the total tree length. According to HUBERT and COURRAUD (1998), the target pruning height is 4 m for isolated trees and 6 m for stand trees. On isolated trees grown on less favourable sites, the pruning height could be as little as 2.5 m but this should be considered the minimum. Generally in plantations the target height should be between 2.5–4.0 m. The stem diameter should not exceed 10

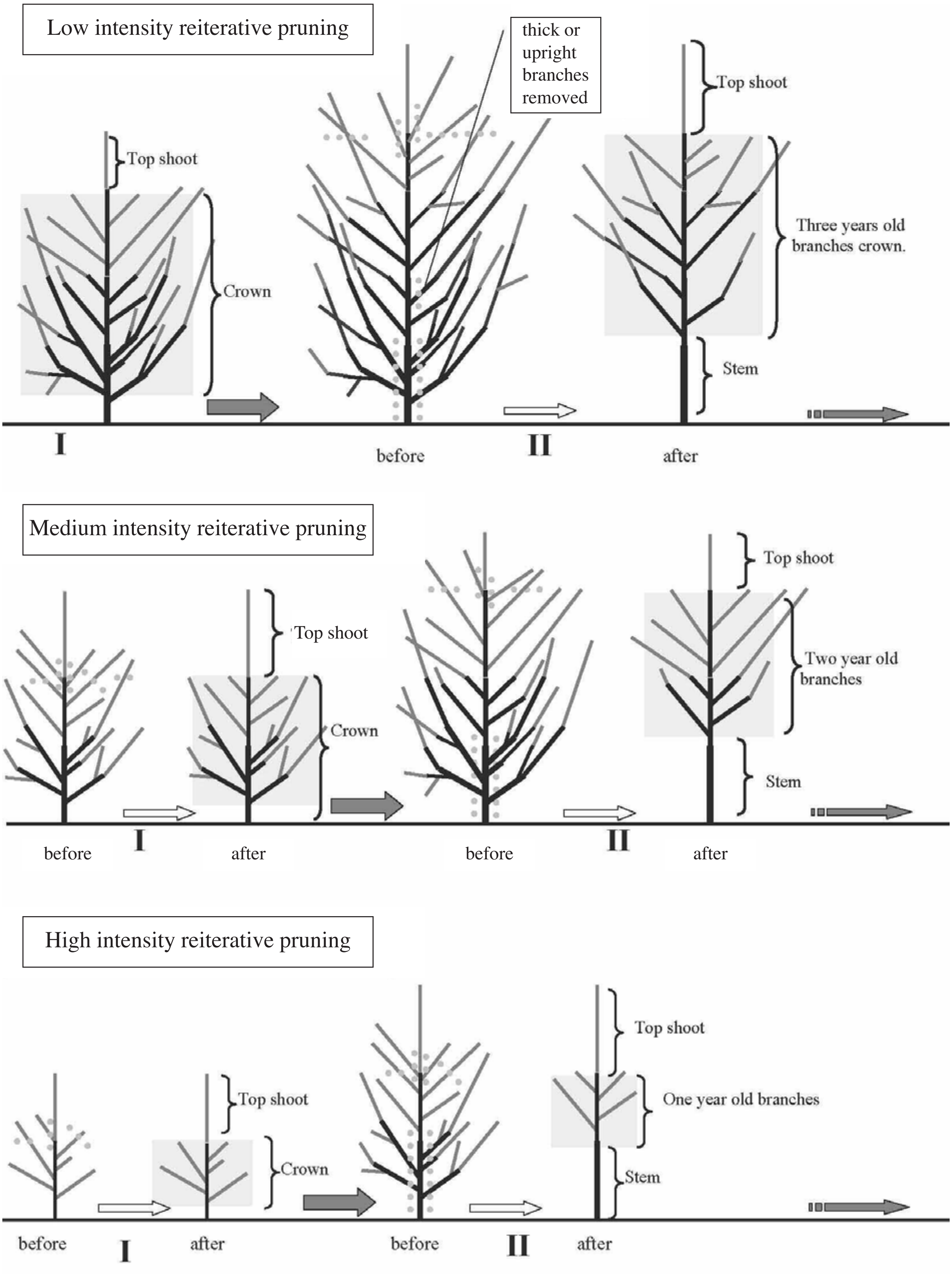

Figure 1: Different intensity levels of reiterative pruning (adapted from BIDINI et al., 2004)
Abbildung 1: Verschiedene Stärken bei wiederholtem Wertasten (BIDINI et al., 2004, verändert)

cm at the height of the lowest pruned branches (HUBERT and COURRAUD, 1998).

EHRING and METZLER (2005) studied the effect of variation in the timing of pruning on development of epicormics, radial growth, callous margin, discoloration of wood, and fungi or bacterium susceptibility in a *Juglans regia* plantation (2 × 2 m) in Germany. They concluded that *J. regia* could be pruned at anytime during the year. However, the best time to prune to avoid development of epicormics, was June and August; although diameter growth was reduced (20 % less radial growth compared to the unpruned tree of the study) for three to four years after pruning in June and August. The best wound occlusion results were achieved after pruning in June, the worst after pruning in August (when radial growth had ceased). The study demonstrated that it is inadvisable to prune in November due to the development of a high number of epicormics and the detection of pathogenic fungi. No fungi or bacterium were found after pruning during the other seasons. February was found to be a good time to prune with regard to diameter growth, callous margin, wood discoloration, pathogenic attacks and epicormic development. According to the conditions in any winter, pruning at the end of the winter (February) may cause wound bleeding, although bleeding was absent after pruning in February in this study. The authors specify that even if there was bleeding it did not cause any damage to the tree. Table 4 summarises the effects of the different pruning seasons.

BRUNETTI and NOCETTI (2007) studied the effects of pruning techniques, different pruning tools and time of pruning on the presence and extent of wood discoloration. The preliminary results indicated that shears are the best tools and winter is the best season. Pruning in summer produced negative effects on wood quality (72 % of sample showed wood discoloration). The presence and extent of wood discoloration depended mainly on branch dimension, indicating that a maximum branch diameter of 3 cm was desirable. To obtain a clean trunk without epicormics and other defects, BECQUEY (1997) and EHRING (2005) advised limiting any pruning to small-diameter branches (less than 3–4 cm in diameter). According to CUTTER et al, (2004) it is also important to prune at an early age.

7.3 Thinning

Building on work carried out in the USA on *Juglans nigra* (KURTZ et al., 1984; SCHLESINGER, 1976), crown competition factor (CCF) was assessed in Italy in the management of *Juglans regia* plantations (FRATTEGGIANI and MERCURIO, 1991). CCF is the per cent ratio between Maximum Crown Area (MCA) and the surface (A) of land occupied by trees: $CCF = \Sigma (MCA_i)/A \times 100$. This factor is an objective method to evaluate the optimal stocking density and to plan thinning regimes. In Italy, CCF has been applied in plantations with different stand density (from 4.0 × 4.5 to 7.0 × 7.0) and has shown good potential of application for *J. regia* plantations. When CCF has reached 110 %, the stand must be thinned reducing the factor to 70 %. Independently from the initial spacing, this aim is achieved by thinning approximately 38 % of trees.

Recent research has identified a slow reaction of walnut trees after a late thinning (MARCHINO and RAVAGNI, 2007). *Juglans regia* 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. In such situations, the tree demonstrates 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.

Table 4: Pruning season and their effects (EHRING and METZLER, 2005)
Tabelle 4: Zeitpunkte der Wertastung und ihre Effekte (EHRING and METZLER, 2005)

Pruning season	Epicormics 0 = negligible development - = moderate developement — = the highest development	Radial growth 0 = no reduction — = the highest reduction - = the least	Callous margin + = the best 0 = medium	Discoloration + = very little 0 = normal	Fungi infection + = no infection - = infection
June	0	—	+	0	+
August	0	—	-	0	+
November	—	0	0	0	-
February	-	0	0	+	+

8 Cultivation systems

8.1 Pure plantations

Prior to the 1990s in Italy the majority of walnut's timber came from multipurpose walnut plantations (nut and wood production). Specialised walnut plantations for wood production are relatively recent and were established under CEE Reg. 2080/92. (Di Vaio and Minotta, 2005). Early pure *Juglans regia* plantations were designed with a stocking density of 400–300 trees per hectare (Giannini and Mercurio, 1997). At this density the plantation required several thinnings, and the spread of *Armillaria mellea* s. l. (Vahl) Kumm, a dangerous fungal disease of *J. regia*, was favoured. More recently, a stocking density of 200–150 trees per hectare has been adopted. At this stocking density, it has been found difficult to maintain a constant diameter increment until a commercial dimension (40 cm) is attained (Buresti et al., 2006). Currently, pure plantations with a low stocking density of 120–70 trees per hectare have been most widely adopted in Italy (Becquey, 1997; Buresti Lattes and Mori, 2006) even though mixed plantations appear to be the best silvicultural option.

8.2 Mixed plantations with companion trees

Many research programmes indicate that the cultivation of *Juglans regia* in mixed plantations can support good diameter and height growth, and reduce the number and diameter of branches (Becquey and Vidal, 2006; Buresti, 1995; Buresti et al., 2001a; Buresti and Fratteggiani, 1995; Clark et al., 2008; Gavaland et al., 2006; Ravagni and Buresti, 2003; Tani et al., 2006).

Research testing the growth of *Juglans regia* in dense plantations with companion trees has often demonstrated greater height and diameter growth (Becquey and Vidal, 2006; Buresti and De Meo, 2000), compared to *J. regia* in pure stands at low density. In Italy, Buresti and De Meo (2000) report that *J. regia* grown in dense mixed plantations (204 *J. regia* trees in mixture with a total of 816 stems per hectare) with *Alnus cordata* and *Elaeagnus umbellata*, at the age of 12 years old, have shown superior height (60 %) and superior diameter (70 %) in comparison to pure plantations (only 204 stems per hectare). These results could be attributed to a combination of effects, including stand densities and increase of N from N-fixing trees. Contrasting results have been obtained in similar plantations (Contu and Mercurio, 2005), where growth in diameter and height of *J. regia* in a pure plantation and in a mixed plantation with *Prunus avium* L. was greater in comparison with the growth of *J. regia* in a mixed plantation with *A. cordata*.

More recently in plantation conditions, *Juglans regia* is often mixed with different species without any negative effects. Indeed, mixed planting schemes are recommended for walnut in Italy. Problems can arise when the distance between plants, of different or of the same species, lead to interspecific and intraspecific negative competition. In these situations, *J. regia* can exhibit poor growth with very competitive species (for example, *Robinia pseudacacia* or *Fraxinus angustifolia* Vahl.). However, by choosing the right species and with prompt silvicultural interventions (e.g. thinning or pollarding) problems can be overcome or avoided altogether (Buresti, *pers. comm.*).

Becquey and Vidal (2006) summarized the results of several French experiments of mixed stand plantations with hybrid walnut *(Juglans nigra × Juglans regia)* combined with various tree and shrub companion species. They noted that the trees within mixed plantations with hybrid walnut have a stronger and longer effect on the shape and the growth of the walnut than companion shrub species. Alder (*Alnus spp.*), birch (*Betula spp.*) and black locust (*Robinia pseudacacia*) seemed to be the most suitable tree species and it is recommended they should be planted at the distance of 4–5 m from hybrid walnut. Poplar (*Populus spp)* can be planted in association with hybrid walnut, but at a wider spacing (9–10 m). Similar observations have been made in Italy (Buresti Lattes and Mori, 2003). European elder (*Sambucus nigra*), hazel (*Corylus avellana*), autumn olive (*Elaeagnus umbellata)* are the most appropriate shrubs; and these should be planted near walnut at the distance of 1–2 m. These shrubs rapidly cover the soil and reduce weed competition. However, they can restrict forest operations by making access more difficult, especially at the time of the last pruning and first thinning operations (Becquey and Vidal, 2006).

Mixed plantations have been projected to obtain intermediate income, before the plantation reaches economic maturity (Buresti et al., 2006). In particular, successful economic results have been obtained in mixed plantations of *Juglans regia*, *Populus hybrid I214*, *Alnus cordata* and some nurse shrubs tested in the Padana valley in Italy (Buresti et al., 2001a). Seven or eight years following establishment the poplar was mature (dbh > 30 cm) and was felled to obtain roundwood; while the remaining species, including *J. regia,* would be cut when they are about 20 years old (Buresti Lattes, *pers. comm.*). With adequate planning in these *multi-objective* (round wood and biomass) and *poly-cycle* plantations (use of different rotations: biomass 2–4 years, poplar roundwood 8–10 years and walnut roundwood 20–25 years) it is possible to obtain quality round wood (poplar and walnut) together with wood for energy

(Buresti Lattes et al., 2007). The linear distribution of the poplar and a distance of 7 m between poplar and walnut was sufficient to sustain regular growth in the walnut and to avoid any damage on walnut during poplar exploitation.

Similar mixed plantations of hybrid walnut *(Juglans nigra × Juglans regia)* and poplar (*Populus hibrid I214*) without companion trees have been realised in France; the results from two mixed plantations, with a spacing of 7 and 8 m between the trees, were reported after eight years by Vidal and Becquey (2008). In these plantations walnut demonstrated superior growth, both in diameter and height, in comparison to pure plantations where a distance of 8 × 8 m or of 7 × 14 m was adopted.

8.3 Agro-forestry systems

Recently, several agro-forestry systems have been established using walnut in agricultural land intercropped with cereal production and fodder plants (Oosterbaan, 2004; Oosterbaan, 2005; Oosterbaan et al., 2006; Paris and Olimpieri, 1993; Paris et al., 1995; Paris et al., 2005; Pisanelli et al., 2006). In France, Chifflot et al. (2006) demonstrated the positive effect of intercropping hybrid walnut (*Juglans nigra × J. regia*) with non-irrigated cereals on the diameter growth and the leaf biomass production of the walnut trees. The beneficial effect on tree growth was accounted for in terms of enhanced nitrogen nutrition. In the USA, several researchers have studied agro-forestry or silvo-pastoral systems with *J. nigra* (Delate et al., 2005; Lehmkuhler et al., 1999) to develop, for example, sustainable agricultural methods or increase farm income.

8.4 Combined nut and wood production

Traditionally walnut has been planted as single tree crops or in linear plantations to produce nuts and wood. Later, specialised plantations for nut production were adopted, using grafted varieties developed for nut production. Pure and mixed plantations using hazel (*Corylus avellana*) have been adopted, especially in the south of Italy (Minotta, 1990; Minotta, 1992). It is possible to obtain a stem of 2 m in height that can be marketed for timber in both combined nut-timber plantations and in nut orchards. This subject is covered in detail by Becquey (1997).

9 Conclusions

In this paper we have drawn together a wealth of up-to-date knowledge on the silviculture of walnut. Clear guidelines exist for site selection, including optimal temperatures and soil conditions. Light management was revealed as a key issue for successful walnut culture, with *Juglans regia* being strongly phototrophic. In combination with good stand design (e.g. stand density), the development of good quality walnut is possible, thereby minimising the need for intervention. Where intervention is required in the form of pruning, we reviewed three different pruning techniques adopted across Europe.

We highlighted that relatively little work has been conducted on modelling growth for *Juglans regia*. A growth model for young plantations is now available and studies of the crown diameter: stem diameter relationship for walnut can be used to predict thinning regimes.

It is evident that mixed plantations are now widely recommended for walnut culture. In practise however, anecdotal evidence suggests that forest managers in some countries have been slow to adopt new techniques, preferring traditional (wide spacing and pure plantations) methods. With the predicted impacts of climate change in mind, mixed plantations may be a highly practical option for forest owners, due to their additional resilience to environmental change. Mixed plantations may provide insurance for forest owners, in that diversity may provide a range of products for alternative markets, together with a resource capable of withstanding climate change.

Interest in land-use diversification, together with the projected change in climate, may provide an opportunity for walnut culture to increase in importance in new areas of Europe, as the climate space shifts north and east. Opportunities for including walnut in agro-forestry schemes and in combined nut and timber cultural schemes, provides additional options for land owners. The relatively short rotation of the species may help meeting any future needs for high quality and sustainably produced hardwoods.

10 Acknowledgments

Valeriu-Norocel Nicolescu and Anne Oosterbaan for their help in search of literature.

Support from COST Action E42. Claudio Bidini for assistance in preparing the Figure 1.

11 References

AA.VV (2005) RaFT (2005): Rapporto sullo stato delle foreste della Toscana. ARSIA – in Sherwood no. 124 supplement no. 2, 52–60.

ARES, A. and D. BRAUER (2004): Growth and nut production of black walnut in relation to site, tree type and stand conditions in south-central United States. Agroforestry systems 63, 83–90.

BARY-LENGER, A., R. EVRARD and P. GATHY (1988): La forêt. Editions du Perron, Liège.

BECQUEY, J. (1997): Les noyers à bois. Institut pour le Développement Forestier (IDF), Paris.

BECQUEY, J. (2006): Des billes de noyer plus longues avec l'accompagnement ligneux. Forêt-entreprise 170 (5), 45–50.

BECQUEY, J. and C. VIDAL (2006): Quels accompagnements ligneux choisir pour les plantations de noyer? Forêt-entreprise 170, 35–38.

BELLONI, V. and S. MAPELLI (2001): *Effects of drought or flooding stresses on photosynthesis xylem flux and stem radial growth.* In: Proceedings of the Fourth International Walnut Symposium. (ISHS), A.H. (ed. E. Germain), 327–333.

BERGOUGNOUX, F. and P. GROSPIERRE (1981): Le noyer. Invuflec, Paris.

BERNETTI, G. (1995): *Selvicoltura speciale.* UTET Torino.

BERTOLOTTO, C., A. PISANELLI and F. CANNATA (1994): La coltivazione del noce da legno nelle aree interne: indagine conoscitiva nell'Italia centrale e meridionale. *Linea ecologica* 2, 53–58.

BIDINI, C., E. BURESTI LATTES, P. MORI, and V. ROSSI (2004): La potatura delle principali specie impiegate in arboricoltura. In: *Conduzione e valutazione degli impianti di arboricoltura da legno* (BURESTI LATTES, E. and P. MORI, Eds.), Edizioni Arsia, 38–60.

BOHANEK, J.R. and J.W. GRONINGER (2005): Productivity of European black alder (*Alnus glutinosa*) interplanted with black walnut (*Juglans nigra*) in Illinois, U.S.A. Agroforestry systems 64, 99–106.

BORDIN, C., M. FRATTEGGIANI, R. MERCURIO and G. TABACCHI (1997): Indagine sulla produzione legnosa in piantagioni di noce comune dell'Italia centrale. Ann. Ist. Sper. Selv 25–26, 413–428.

BORDIN, C., M., F., MERCURIO, R. and G. TABACCHI (1996): Valutazione sulla produzione legnosa in piantagioni di noce comune. Modelli di previsione e indici di competizione. Monti e boschi 47 (3), 54–60.

BOUDRU, M. (1989): Forêt et sylviculture: sylviculture appliquée. Les Presses Agronomiques de Gembloux, Gembloux.

BRUNETTI, M. and M. NOCETTI (2007): Effetti della potatura sulla qualità del legno. Sherwood Foreste ed alberi oggi 139, 32–33.

BULFIN, M. and T. RADFORD (1999a): Effect of early formative shaping on newly planted broadleaves, part 1, Quality. Irish Forestry 55 (2), 35–51.

BULFIN, M. and T. RADFORD (1999b): Effect of early formative shaping on newly planted broadleaves, part 2. Height and diameter growth. Irish Forestry 55 (2), 52–61.

BURESTI, E. (1995): Walnut trees in mixed stands with shrubs and trees. In: European development of walnut trees for wood and fruit production as an alternative and extensive system to agricultural crops. Développement de la culture extensive des noyers à bois et à fruits en Europe. Période du 01/07/94 au 31/12/94. Commission des Communautés Européennes, Bruxelles (BEL); Direction générale de l'Agriculture (Jay-Allemand, C., ed.), Paris, France, 72–81.

BURESTI, E., C. BIDINI and P. MORI (2001a): Una nuova tecnica per il noce: la potatura replicativa. Sherwood Foreste 66, 11–17.

BURESTI, E. and I. DE MEO (2000): L'impiego delle consociazioni nelle piantagioni di arboricoltura da legno: primi risultati di un impianto di noce comune (*Juglans regia* L.). Ann. Ist. Sper. Selv. 29, 57–66.

BURESTI, E. and M. FRATTEGGIANI (1995): Impianti misti in arboricultura da legno. Sherwood Foreste ed Alberi Oggi 3, 11–17.

BURESTI, E. and P. MORI (2003a): Progettazione e realizzazione di impianti di arboricoltura da legno. ARSIA (Agenzia Regionale per lo Sviluppo Agricolo-forestale della Toscana), Firenze.

BURESTI, E. and P. MORI (2003b): Vigore delle piante ed intensità della potatura replicativa. Sherwood Foreste ed alberi oggi 88, 11–17.

BURESTI, E., P. MORI, F. PELLERI and S. RAVAGNI (2006):

Enseignements de 30 années de recherche sur les plantations mélangées en Italie. Forêt-entreprise 170 (5), 51–55.

BURESTI, E., P. MORI and S. RAVAGNI (2001b): Piantagioni miste con pioppo e noce comune: vantaggi e svantaggi di una scelta complessa. Sherwood Foreste ed alberi oggi 71, 11–17.

BURESTI LATTES, E., R. CAVALLI, S. RAVAGNI and L. ZUCCOLI BERGOMI (2007): Impianti policiclici di Arboricoltura da Legno: due esempi di progettazione e utilizzazione. Sherwood Foreste e alberi oggi 139, 37–39.

BURESTI LATTES, E. and P. MORI (2003): Progettazione e realizzazione di impianti di Arboricoltura da Legno. ARSIA, Regione Toscana, Firenze.

BURESTI LATTES, E. and P. MORI (2006): Legname di pregio e biomassa nella stessa piantagione. Sherwood Foreste ed alberi oggi 127, 5–10.

CAMPBELL, G.E. and J.O. DAWSON (1989): Growth, yield, and value projections for black walnut interplantings with black alder and autumn olive. Northern Journal of Applied Forestry 6 (3), 129–132.

CHIFFLOT, V., G. BERTONI, A. CABANATTES and A. GAVALAND (2006): Beneficial effects of intercropping on the growth and nitrogen status of young wild cherry and hybrid walnut trees. Agroforestry systems 66, 13–21.

CLARK, J., G.E. HEMERY and P.S. SAVILL (2008): Early growth and form of common walnut (Juglans regia L.) in mixture with tree and shrub nurse species in Southern England. Forestry 81, 613–644.

COLPACCI, G. (1971): Nuciferele in fondul forestier. ICSPS, Bucuresti.

CONTU, F. and R. MERCURIO (2005): Risultati di piantagioni sperimentali di latifoglie a legname pregiato in Abruzzo. In: Atti del IV Congresso Nazionale SISEF "Meridiani Forestali". Potenza 7–10 Ottobre 2003, 141–144.

CRAVE, M.-F. (1990): L'effet du vent sur les noyers. Forêt-entreprise 66, 13–17.

CUTTER, B.E., M.V. COGGESHALL, E., P.J. and D.D. STOKKE (2004): Impacts of forest management activities on selected hardwood wood quality attributes: a review. Wood and Fiber Science 36 (1), 84–97.

DELANNOY, E. (2003): Créer une ambiance forestière pour une plantation de noyers en terre agricole. Forêt-entreprise 154, 25–28.

DELATE, K., E. HOLZMUELLER, D.D. FREDERICK, C. MIZE and C. BRUMMER (2005): Tree establishment and growth using forage ground covers in an alley-cropped system in Midwestern USA. Agroforestry systems 65, 43–52.

DI VAIO, C. and G. MINOTTA (2005): Indagine sulla coltivazione del noce da legno in Campania. *Forest@* 2, 185–197.

EHRING, A. (2005): Nussanbau zur Holzproduktion. In: Merkblätter der forstlichen Versuchs- und Forschungsanstalt Baden-Württemberg. 52, Freiburg, Deutschland.

EHRING, A. and B. METZLER (2005): Wann soll die Walnuss geästet werden? FVA-Einblick 2.

EVANS, J. (1984): Silviculture of broadleaved woodland. Forestry Commission Bulletin 62, H.M.S.O., London.

FADY, B., F. DUCCI, N. ALETA, J. BECQUEY, R. DIAZ VASQUEZ, F. FERNANDES LOPEZ, C. JAY-ALLEMAND, F. LEFEVRE, A. NINOT, K. PANETSOS, P. PARIS, A. PISANELLI and H. RUMPF (2003): Walnut demonstrates strong genetics variability for adaptive and wood quality traits in a network of juvenile field tests across Europe. New Forests 25, 211–225.

FALCONI, S., I. DE MEO and E. BURESTI (1996): La potatura del noce. Descrizione delle tecniche più usate. Sherwood Foreste 12, 11–16.

FRATTEGGIANI, M. and R. MERCURIO (1991): Il fattore di competizione delle chiome (CCF) nella gestione delle piantagioni di legno di noce comune (*Juglans regia* L.). Monti e boschi 5, 59–62.

FRATTEGGIANI, M., R. MERCURIO and F. PRIMAVERA (1996): Relazione tra tessitura del suolo e coltivazione del noce da legno. Atti del 91° Congresso della Società Botanica Italiana, Ancona. Sessione poster. Giornale Botanico Italiano 130 (1), 421.

GAVALAND, A., H. DUVAL, J. WILLM and L. BURNEL (2006): Exemples d'amélioration de la croissance et de la forme du noyer hybride pour l'accompagnement ligneux. Forêt-entreprise 170 (5), 26–31.

GELLINI, R. and P. GROSSONI (1997): Botanica forestale. CEDAM, Padova.

GIANNINI, R. and R. MERCURIO (1997): Il Noce comune per la produzione legnosa. Avenue media, Bologna.

GRAESCHIKE, M.-A. and P. GÜRTH (1993): Untersuchung über das Wachstum der Walnuss (*Juglans regia*) als Waldbaum. Forst-und-Holz 48 (11), 309–313.

HEMERY, G.E. and S.I. POPOV (1998): The walnut (*Juglans regia* L.) forests of Kyrgyzstan and their importance as a genetic resource. Commonwealth Forestry Review 77 (4), 272–276.

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

HEMERY, G.E., P. SAVILL and A. THAKUR (2005b): Height growth and flushing in common walnut (*Juglans regia* L.): 5-year results from provenance trials in Great Britain. Forestry 78 (2), 121–133.

HUBERT, M. (1979): La culture des noyers a bois. I.D.F., Paris.

HUBERT, M. and R. COURRAUD (1998) Elagage et tailles de formation des arbres forestiers. Institut pour le développement forestier, Paris.

JACAMON, M. (1987): Guide de dendrologie. Arbres, arbustes, arbrisseaux des forêts françaises.Tome II Feuillus. Ecole Nationale du Génie Rural, des Eaux et des Forêts (ENGREF), Nancy.

KLEMP, C.D. (1979): Walnut cultivation under forest condition for timber production. Allgemeine Forstzeitschrift 27, 732–733.

KURTZ, W.B., H.E. GARRET and W.H.J. KINCAID (1984): Investment alternatives for black walnut plantation management. Journal of Forestry 10, 604–608.

LEHMKUHLER, M.S., M.S. KERLEY, H.E. GARETT, , B.E. CUTTER and R.L. Mc GRAW (1999): Comparison of continuous and rational silvopastoral systems for established walnut plantations in southwest Missouri, USA. Agroforestry systems 44, 267–279.

LÜTHY, H. (2005): Ein Versuch der ETH Zürich. Nachzucht und Anbau des Nussbaums als Walsbaum. Wald und Holz 6, 49–53.

LYR, H. (1996): Effect of the root temperature on growth parameters of various European tree species. Ann. Sci. For. 53, 317–323.

MARCHINO, L. and S. RAVAGNI (2007): Effetti del diradamento in impianti puri di noce. Sherwood Foreste ed alberi oggi 139, 40–41.

MASSON, G. (2005): Autoécologie des essences forestières, comment installer chaque essence à sa place. TEC and DOC Lavoisier, Londres, Paris et New-York.

MINOTTA, G. (1990): La cultura del noce da frutto e a duplice attitidine produttiva in collina e montagna. Monti e boschi 41 (1), 27–33.

MINOTTA, G. (1992): La nocicoltura a duplice attitudine. In: Atti del 12° convegno pomologico "La coltura del noce" Caserta 4 luglio, 140–150.

NEGULESCU, E.G. and A. SĂVULESCU (1965): Dendrologie. Editura Agro-Silvică de Stat, Bucurefl ti.

OOSTERBAAN, A. (2004): Multipurpose plantations as a tool for periurban agroforestry. Urban Agriculture Magazine 13, 23.

OOSTERBAAN, A. (2005): Mogelijkheden voor notenteelt met tussengewas. De Fruitteelt 95 51/52, 16–17.

OOSTERBAAN, A., H. SCHEPERS and E. KWANTEN (2006): Walnut as a farm crop in the Netherlands: an agroforestry project in the east and selection of cultivars for organic cultivation in the north. In: Proceedings of the 5th international walnut symposium. Acta Horticulturae (ISHS), Leuven, Belgium. 27–34.

OOSTERBAAN, A. and C.A. VAN DEN BERG (1998): Houtproduktie van walnoot in Nederland. IBN-rapp 384.

PARIS, P. and G. OLIMPIERI (1993): Aspetti consociativi degli imboschimenti di noce: risultati preliminari di un impianto di consociazione noce (*Juglans sp.*) medica (*medicago sativa L.*). Atti del convegno "Imboschimenti con noce: orientamenti colturali e produttivi. Linea ecologica n. speciale, 39–42.

PARIS, P., G. OLIMPIERI and F. CANNATA (1995): Influence of alfalfa (*Medicago sativa*) intercropping and polyethylene mulching on early growth of walnut (*Juglans sp.*) in centre Italy. Agroforestry Systems 31, 169–180.

PARIS, P., A. PISANELLI, L. TODARO, G. OLIMPIERI. and F. CANNATA (2005): Growth and water relations of walnut trees (Juglans regia L.) on a mesic site in central Italy: effects of understorey herbs and polyethylene mulching. Agroforestry systems 65, 113–121.

PEDLAR, J.H., D.W. MC KENNEY and S. FRALEIGH (2006): Planting black walnut in southern Ontario: midrotation assessment of growth, yield, and silvicultural treatments. Can. J. For. Res. 36, 495–504.

PISANELLI, A., A. ECOSSE, A. PERALI, G. SCARASCIA-MUGNOZZA, F. CANNATA, G. OLIMPIERI and P. PARIS (2006): I sistemi Agroforestali in Europa. Alberi e territorio 12, 12–16.

RAVAGNI, S. (2001): Un caso di rinnovazione naturale sotto la copertura del noce. Sherwood Foreste e alberi oggi 69 (7), 11–15.

RAVAGNI, S. and E. BURESTI (2003): Piantagioni con pioppo e noce comune: accrescimento e sviluppo dopo i primi anni. Sherwood Foreste e alberi oggi 94, 19–24.

RIEBELING, R. (1991): Zum Wachstum der Schwarznuss in der hessischen Rheinniederung. AFZ/Der Wald 12, 596–600.

SALBITANO, F. and L. BAGNARA (2004): *Architettura comparata di chiome e apparati radicali di Juglans regia L: Risposta a diverse intensità di consociazione con specie azotofizzatrici* http://www.arboricoltura.it/Ricerche/Potature/File/PosterSottoprogetto2-1-4.pdf.

SALBITANO, F., E. BURESTI and A. TANI (2001): Analisi comparata dell'architettura di apparati ipogei ed epigei di piante di Juglans spp. In: Pubblicazione n 44. Prefettura di Firenze, Ufficio stampa, Firenze.

SAVILL, P.S. (1991): The silviculture of trees used in British forestry. CAB International, Wallingford.

SCHLESINGER, R.C. (1976): Thinning black walnut plantations. In: North Nut Growers Association Annual Report 66, 160–162.

SCHÜTT, SCHUCK, LANG and ROLOFF (1994): *Enzyklopädie der Holzgewächse, Handbuch und Atlas der Dendrologie.* 1 edn. Ecomed Verlagsgesellschaft, Landsberg/Lech, Germany.

SCHULZE-BIERBACH, F.K. (1991): Der Anbau von Walnussbäumen in Bundesforstamt Nordrhein. AFZ/Der Wald 12, 601–604.

ŞOFLETEA, N. and L. CURTU (2007): Dendrologie. Editura Universităţii Transilvania, Braşov.

STĂNESCU, V., N. ŞOFLETEA and O. POPESCU (1997): Flora forestieră lemnoasă a României. Editura Ceres, Bucureşti.

TANI, A., A. MALTONI, B. MARIOTTI and E. BURESTI LATTES (2006): *Juglans regia* L. tree plantations for wood production in mining area of S. Barbara (AR): Evaluation of N-fixing accessory trees effect. Forest@ 3 (4), 588–597.

VIDAL, C. and J. BECQUEY (2008): Enseignements de deux plantations mèlangées de peupliers et de noyers hybrides. Forêt-entreprise 214, 31–36.

WINTER, R. (1982): Der Walnussbaum – die vergessene Baumart. Holz-Zentralblatt 52, 737–738.

WINTER, R. and P. GÜRTH (1990): Anmerkungen zum forstlichen Walnussanbau. Forst-und-Holz 5, 117–120.

Address of authors

Christophe Mohni, Bern University of Applied Sciences, Swiss College of Agriculture, Zollikofen, Switzerland
Francesco Pelleri, National Council for Agricultural Research, Forestry Research Centre, Arezzo, Italy
Gabriel E. Hemery, Forestry Horizons, Manor House, Little Wittenham, United Kingdom

Corresponding author

Christophe Mohni, E-mail: christophe.mohni@silviva.ch

Eingelangt am 30. November 2008
Angenommen am 19. Februar 2009