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REVIEW ARTICLE

Black locust (*Robinia pseudoacacia* L.) as a multi-purpose tree species in Hungary and Romania: a review

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Abstract Black locust (*Robinia pseudoacacia* L.) was the first North-American tree species imported to Europe at the beginning of the seventeenth century. It is commonly planted worldwide because of its adaptability to environmental stresses, its valuable wood, easy propagation, frequent and abundant seed production, excellent coppicing, high seedling survival, and relatively high wood yield. In Europe, Romania and Hungary have the most highly-developed black locust growing techniques and experiences. As a result of increasing interest in black locust in many countries, this review aims to provide a comprehensive overview of state-of-the-art site requirements, propagation, improvement and management (including growth and yield as well as use in energy plantations).

Keywords *Robinia pseudoacacia* · Site requirements · Selection · Propagation · Silviculture

Introduction

Black locust (*Robinia pseudoacacia* L.) was the first North-American tree species imported to Europe at the beginning of the seventeenth century. Jean Robin, the gardener of King Henri IV of France, planted the first individual in Place Dauphine, Paris. Even though that tree has since died, one of its offsprings, planted in Paris in 1601, still exists in René-Viviani Square (Demené and Merzeau 2007).

Black locust was extensively planted in Central Europe starting in the late eighteenth and early nineteenth centuries; it is now widespread across Europe from Sicily to southern Norway, and from the Portuguese littoral regions up to the Caucasus (Sitzia et al. 2016). Consequently it is the most used non-native tree species on the continent and covers an area of more than 2,306,000 ha (Brus 2016). Along with Hungary and Romania, countries such as the Ukraine (422,525 ha; Lavnyy and Savchyn 2016), Italy (377,186 ha; Monteverdi et al. 2016), France (191,000 ha$\pm$23,000 ha; Orazio and Bastien 2016), Serbia (169,153 ha; Andrašev et al. 2016), and Bulgaria (150,590 ha; Petkova et al. 2016) have extensive black locust plantations in Europe.

Worldwide, the species is important for improving soil chemical properties and fertility (Bolat et al. 2016; Papaioannou et al. 2016), reclaiming/rehabilitating degraded soils (Qiu et al. 2010; Wang et al. 2010; Lukić et al. 2015; Mantovani et al. 2015), sequestering carbon (Ussiri et al. 2006; Quinkenstein et al. 2011; Wang et al. 2015),

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and improving biodiversity (Evans et al. 2013). The soil improvement role is due to its nitrogen-fixing abilities, with roots nodulated by diverse *Rhizobium* communities. The species was designated by the nitrogen fixing tree (NFT) Association as one of the fifty NFTs "outstanding in its utility, economic or ecological importance" (Brewbaker 1990). The estimated symbiotic nitrogen fixation rates range widely from 23 to 300 kg $ha^{-1}a^{-1}$; this may generate substantial soil alterations, increasing total soil nitrogen, changing soil pH, and decreasing total phosphorus (Cierjacks et al. 2013). Its extensive root system, combined with nitrogen-fixation properties, provides black locust with an advantage over native or exotic species to soils with low nitrogen contents or poor soils (Qiu et al. 2010; Cierjacks et al. 2013; Straker et al. 2015).

The use of black locust to establish crop protection shelterbelts, playing important protection and land reclamation roles and providing es habitats for small mammals is highly recommended (Lęcki 2004; Catrina 2005; Nuță and Niculescu 2011).

The species can easily coppice, is fast-growing, and produces large amounts of dense wood with high combustion potential on a short rotation. It is not only preferred for classical wood products (e.g., flooring, poles, props, firewood), but is also considered important for short rotation energy crops **(**Böhm et al. 2011; Straker et al. 2015).

Last but not least, black locust is used as raw material in biotherapy, apiculture, food industries (Beldeanu 2004, 2008), and for landscaping (Pârvu 2006).

Conversely, black locust is amongst the 100 most invasive alien species on the continent (Vilà et al. 2009), and one of the 40 most invasive woody angiosperms globally (Richardson and Rejmánek 2011, in Vítková et al. 2017). However, the number of European countries where the species is officially considered to be invasive is relatively low—only 17 out of 35 reporting countries (Brus 2016). In addition, expected climate change could favor its further expansion in both forested and non-forested areas, as it is extremely difficult to control (repeated girdling, cut-stump herbicide application, hand-pulling, and mowing; Straker et al. 2015), and entail considerable costs and often have limited success (Kleinbauer et al. 2010).

Black locust in Hungary and Romania: past and current distributions

For many years it has been acknowledged that "…introduced in Europe by the French, researched for a long time by the Germans, recommended warmly then forgotten, black locust has 'landed', by various ways and naturally in the south-east of Europe, especially in Hungary and Romania, where this remarkable woody species has found a second homeland and where it has its destiny as forest species…" (Drăcea 1928). Black locust currently covers large areas in Romania and Hungary and has continuously increased (Drăcea 1928; Rédei et al. 2014; Enescu and Dănescu 2015) to approximately 23% of forested land in Hungary and 4% in Romania (Table 1).

In the 1960s, Hungary possessed more black locust forests than all other European countries combined (Keresztesi 1988). Currently, black locust stands are managed as coppice in Romania; in 1975, two-thirds of black locust were in coppice stands, the rest being managed as high forests (Enescu 1975). In Hungary, one-third of stands are currently treated as high forests and two-thirds are coppice. Black locust stands provide approximately 21% of the annual timber supply of Hungary. Initially, the species was planted to stabilize loose shifting sands, for afforestation of abandoned agricultural lands/degraded lands, and for shelterbelts (Haralamb 1967). Factors promoting the rapid spread of black locust include abundant seed yields, seed vitality, excellent sprouting potential, ability to fix free atmospheric nitrogen, the wide range of uses for its wood (e.g., tools, fuel wood, poles and props, pit-wood, parquet; Haralamb 1967), and foraging of its flowers by bees (Rédei et al. 2008).

It is one of the most suitable species for establishing environmentally valuable recreational plantations. According to initial estimates, approximately 720,000 ha of agricultural land will be available for afforestation in Hungary in the next 50 years; 30 to 35% of the new plantations will consist of black locust. Afforestation with black locust will also be an important part of any strategy to improve the environment and the population's quality of life (Rédei et al. 2008). The most important black locust growing regions in Hungary are located in south and south-west Transdanubia (hill ridges of Vas and Zala County, Baranya, Somogy and Tolna Counties), the Danube-Tisza Interfluve (central Hungary) and north-east Hungary (Nyírség region) (Fig. 1).

Black locust was introduced to Romania around 1750, likely from Turkey (the Romanian name for the species—*salcâm*—seems to be of Turkish origin), and then through Serbia and Austro-Hungary (Bîrlănescu and Belu 1968; Enescu 1975). The first plantation of black locust was established in the south-west of Romania (Băilești-Oltenia) in 1852 (Negulescu and Săvulescu 1957, 1965; Stănescu 1979). The species was subsequently introduced into all regions but the most important areas are Bărăganului Plain-Oltenia in the south, introduced in 1852; Careiului Plain and Someșului Plain in the north-west close to the Hungarian border, introduced in 1892 (Spârchez et al. 1961); and Tecuciului Plain-Hanul Conachi in the east introduced in 1922 (Haralamb 1967; Bîrlănescu and Belu 1968) (Fig. 2).

Taking into account the increasing interest in black locust in many countries worldwide, this review aims to provide a comprehensive overview of the state-of-the-art of

Table 1 Evolution of area (ha and %) covered by black locust according to relevant references

Country	Area in year (ha)						Area (%)
	1885	1911	1922	1938	1960	2013–2014	
Hungary	37,000[a]	109,000[a]	–	186,000[a]	–	460,000[a]	23[a]
Romania	–	–	28,000[b]	–	90,000[c]	250,000[c]	4[c]

[a] According to Rédei et al. (2014)

[b] According to Drăcea (1928)

[c] According to Şofletea and Curtu (2007), Enescu and Dănescu (2015) and Marin 2015 (personal communication)

Fig. 1 The main growing regions for black locust in Hungary (Rédei et al. 2001)

Fig. 2 Geographical distribution (in red) of black locust stands (Ciuvăţ et al. 2013)

site requirements, propagation, improvement and management (including growth and yield as well as its use in energy plantations) in two countries with a long tradition of growing this important species.

Literature search on site requirements, propagation, improvement and management

Site requirements

Black locust stands have been established on good as well as on moderate and even poor quality sites. The assumed low ecological requirements, easy establishment, and initial fast growth have been the main reasons for using the species on different site conditions, sometimes incorrectly (Haralamb 1967). The species requires high soil nutrients so its cultivation is recommended only on moderately to highly fertile soils (Ivanschi et al. 1969). Under these conditions, it is able to efficiently exploit soil nutrients and water resources with its well-developed, dense, and frequently branched root system (Keresztesi 1988). The species requires loose to slightly compacted soils, well-aerated without too much moisture, with favorable depths over 60 cm, and moderately high to very high humus content (Ivanschi et al. 1969). Sites with periodic water supply and those that are well-drained (i.e., ground-water table deeper than 150 cm), are favorable (Keresztesi 1988). Growth is negatively influenced by soils with poor water regimes, coarse sands or stone-rich, shallow rooting depths (Keresztesi 1988), compacted, and the presence of calcium carbonates or soluble salts (e.g., chlorides, sulphites) (Bîrlănescu and Belu 1968; Ivanschi et al. 1969).

The most suitable regions are the lowlands with minimum 500–550 mm annual rainfall, most of which falls outside the growing season. In summer, drought is frequent and coupled with high temperatures (30–35 °C). Relative air humidity in July is usually between 20 and 50%.

The establishment of black locust stands for quality timber is possible only on sites with adequate moisture and well-aerated, loose-structured soil rich in nutrients and humus. Stands on moderate or poor sites are utilized for the production of firewood, fodder, poles and props, honey, and for soil protection and environmental improvements (Haralamb 1967; Rédei et al. 2008, 2011). Black locust stands were established in Romania for sand dune fixation but also on terraces or in plain regions with sandy soils. Consequently, the majority of these stands are located in areas of warm climates and a de Martonne Aridity index close to the dryness limit, with the exception of the north-west where the climate is more humid (Ivanschi et al. 1969).

The variable nature of geographical conditions in Hungary and the large area of black locust stands has made determination of its site requirements and characterization of suitable sites possible. This has been solved by the Hungarian system of forest site classification based on five dominant factors: climate, hydrologic conditions, genetic soil type, soil physical make-up, and rooting depth (Keresztesi 1988). This system allows for decisions about site types where black locust is recommended as well as enabling predictions of expected yields and profitability.

Clone and cultivar selection

Since the introduction of black locust into Hungary and Romania, the species has been closely associated with rural areas where its wood is used for many agricultural and domestic purposes. More recently, its culture targeted the production of high quality trees and an increase in industrial wood production and quality to meet consumers' demands. As the interest was not only on timber but also on honey-production quality, the demands of bee-keepers such as the onset and length of flowering and nectar yields had to be considered as well. To solve these problems, breeding programs have been developed both in Romania and Hungary. The selection of plus trees, their vegetative propagation, and the establishment of seed orchards were common tasks in both countries.

In Romania, 15 black locust populations were identified before 1970 to improve the productivity. One of the most important populations was the "Grindu cu bani", where *Robinia pseudoacacia* var. *oltenica* was identified and described as having a shipmast stem form, good natural pruning, and high growth rate (Bîrlănescu et al. 1966; Costea et al. 1970). Clonal tests were performed at the Forest Research and Management Institute (ICAS) using clones of the *palmate* type and *rectissima* variety; this last showed the lowest proportion of forked stems (Enescu 1975). Between 1972 and 1975, other plus trees (Fig. 3) were identified in terms of quality and wood production; consequently, 59 clones of Romanian origin were introduced into seed orchards (Bîrlănescu et al. 1977).

Currently, there are six qualified seed orchards (27.5 ha), as well as provenance and melliferous (honey producing) orchards in Romania (MMP-RNP-ICAS 2012). Unfortunately, research activities for black locust improvement ceased and there is currently no research program ongoing.

In Hungary, an artificial crossing program was developed simultaneously with plus tree selection. Breeding by crossing requires considerable work over several decades as black locust is a heterozygotic species with many features of polygene character. The results of breeding are thus influenced by chance. Though the prominent Hungarian black locust breeder Ferenc Kopecky worked with a carefully elaborated breeding program, his investigations

Fig. 3 Black locust plus tree in the north-west of Romania

Fig. 4 Fifteen year-old black locust plantation with selected cultivar in Hungary

into the performance of different provenances did not fulfill early expectations, despite some promising results (Keresztesi 1983, 1988). In Hungary, the breeding strategy aimed to improve the quality of black locust stands were considered to be separate provenances. The offsprings of these selected trees were vegetatively propagated and grouped into varieties. Thus, varieties are mostly composed of several clones but there are also some single clone varieties as well. Due to this breeding programme more varieties were introduced into practical forestry and can be considered as man-made cultivars (Rédei 2013).

Improvement by selection of plus trees followed by vegetative propagation was a multi-stage strategy started in 1961. The basic material produced served as starting material with the help of a variety trial established in Gödöllő Arboretum of the Hungarian Forest Research Institute (Fig. 4).

The development of this trial (50 ha with 210 clones and varieties) is currently on-going (Keresztesi 1983, 1988; Rédei et al. 2002). The results are evaluated depending on both the timber volume at rotation age, and honey or energy production (Keresztesi 1983, 1988; Rédei et al. 2008).

There are many cultivars and cultivar-candidates of black locust for different purposes: (1) high volume and high quality sawlogs; (2) poles and props; (3) honey; (4) fuelwood; and, (5) fodder. Currently, seven black locust varieties have been formally approved by the Hungarian national office (Keresztesi 1983, 1988; Rédei 2013). The aim of the new selection activities is to produce and improve black locust clones for quality wood material for industrial purposes, as well as clones that can adapt to the changing ecological conditions (Rédei et al. 2002, 2008).

As a result of the new selection program, twelve clones have been improved at the Hungarian Forest Research Institute over the last years. Five (‘KH 56A 2/5’, ‘MB17D 3/4’, ‘PV 201E 2/1’, ‘PV 35B/2’, and ‘PV 233A/1’) have been registered as “cultivar-candidates” (Rédei 2013). The breeding activities are combined with the preservation of gene resources of Hungarian black locust stands. This genetic variability is the basis of population selection. It is superior to plus tree-based breeding as this leads to a decrease of the natural gene-pool, whereas population selection does not and may instead lead to the selection of new promising provenances (Rédei 2013).

Black locust seed and seedling production

Black locust produces seed at 5–7 years of age and production is abundant and nearly annual (Negulescu and Săvulescu 1957; Enescu 1975). Seeds can be collected by hand or by sieving the top 5-cm layer of the litter layer. As the seeds remain dormant in the top layer for several years, the age of seed lots collected in this way is very heterogeneous. The viability however, is maintained at high levels for 10 years or even longer. This remarkable longevity is explained by their morphology and chemical content: the hard impermeable seed coat prevents water absorption and water loss, even in quite humid or dry conditions. At the same time, the seed water content is low (approximately 2% by weight) (Vlase 1982). By felling trees at the end of their rotation, 0.2–0.5 kg seeds/tree can be collected or 120–150 kg ha^{-1} in an average seed-producing year (Rédei et al. 2001; Rédei 2013). Seed quality is excellent, and if regularly cleaned, viability can be as high as 96%. The weight of 1000 seeds is 20–23 g and the seed yield from 100 kg of pods 20 kg (Haralamb 1967; Rédei et al. 2001; Rédei 2013).

Germination of black locust's hard-shelled seeds is facilitated by submersion in boiling water, mechanical treatment (scarification), or chemical treatment (using diluted sulphur acid) before sowing (Negulescu and Săvulescu 1957; Haralamb 1967; Costea et al. 1969; Damian 1978; Keresztesi 1988). The seeds are sown at the end of April or beginning of May to avoid late frosts. Profitable cultivation of black locust seedlings may be carried out on loam or sandy loam soils with a carbonate content not exceeding 5% (Rubțov 1958; Haralamb 1967), hygroscopicity of 0.8–3.5% and pH of 5.5–7.5. It is also desirable for the phosphorus content of the soil to be no less than 15–20 mg per 100 g and the easily soluble potassium content 10–15 mg per 100 g. If these values are not reached, phosphorus and potassium should be added in the form of chemical fertilizers (Keresztesi 1988).

The success of producing seedlings is influenced by soil preparation and cultivation. After spreading chemical fertilizer and/or manure in the autumn on the fields, it is desirable to plough at a depth of 35–40 cm before winter sets in. Preventive chemical weed control is advisable, and in the case of nematode infection, the soil should be sterilized (Keresztesi 1988). A table-smooth surface is the primary condition for uniform sowing. Inter-row spacing of seeds should be chosen in relation to the working width of the cultivating and weeding machine. In Hungary, the distance between rows should be 35–40 cm minimum. If spacing is narrower, one can face a decrease in growth, and an important number of undersized seedlings will have poor root systems unsuitable for planting (Keresztesi 1988). In Romania, seeds are sown in late spring at 3–4 cm depth (5–6 cm on sandy soils prone to excessive warming in the summer) using 1.6–2.0 g of seeds/m (Rubțov 1958; Iancu 1999). Seedlings are ready for planting after 1 year when having reached a minimum 6 mm diameter root collar (Iancu 1999).

Vegetative propagation of black locust

In Hungary, the propagation of cultivars was first planned based on seedlings but the seed orchards produced small amounts of seed. It was therefore necessary to develop techniques for vegetative propagation (i.e., using green cuttings, root cuttings, or micro-propagation) (Rédei et al. 2002). At the present, research is being carried out with international cooperation to seek the genetic background of quantitative and qualitative features of several varieties of clones. Clone identification markers are determined for this work at protein and DNA levels. The long-term aim is the investigation of the linkage between quantitative features and selected markers as well as the determination of genetic factors responsible for quantitative features (Malvolti et al. 2015).

Propagation from grafting

In Romania, was recommended, especially when multiplying selected clones, usually in nurseries but also in the field when establishing seed orchards (Costea et al. 1969). Grafting methods using a detached branch (e.g., cleft, whip, stub, four flap, awl) produced much better results (up to 97%) than did budding (about 3%). The most important factor is the quality of scion which is associated with the age of the mother tree (Enescu et al. 1962).

Propagation from root cuttings

Black locust clonal varieties must be propagated vegetatively. Research in Romania, produced a 63% rate of survival with 20–30 cm root cuttings taken from seedlings and positioned horizontally (Lăzărescu et al. 1961). Propagation by root cuttings has proven successful in practical forestry only in Hungary. Plants are produced from root cuttings or, alternatively, pieces of root, can be directly sown. In both cases, the basic material for vegetative propagation can be derived from the gene bank of the experimental nursery owned by the Hungarian Forest Research Institute (Keresztesi 1988).

Plants are delivered to nurseries involved in production and then established at $80 \times (30–40)$ cm to encourage the production of vigorous root systems. These plants are lifted every spring for 5 years and root cuttings are taken. Normally this takes 5–6 weeks but if storage of cuttings before planting or sowing is unavailable, they should be kept moist. After 5 years, the plants used for root production must be replaced by new ones from the gene bank (Keresztesi 1988).

Planting material for afforestation is produced by planting root cuttings at $80 \times 5–10$ cm. The size is (8–10) cm long and 5–8 mm in diameter. In cases of direct sowing, root pieces (3–4) cm long are used. Roots are inserted into well-prepared soil to a depth of (8–10) cm, with a distance of 5–7 cm between root pieces. With this spacing, 10–15 plants per linear m can be produced. All other roots can be used for further propagation. When propagating plants from root pieces, the emergence of plantlets may be expected 20–25 days after cutting. The average height of 1-year-old plants is 1.2–1.5 m (Keresztesi 1988).

Black locust roots require regular irrigation, which is reduced when the plants have reached 10–15 cm. In case of root pieces, the procedure is the same but the roots must be more carefully saved from withering. In both cases, waterlogging must be avoided (Keresztesi 1988).

Plant tissue culture method

Nearly sixty new cultivars and selected clones have been propagated in the past few decades. This research program is coordinated by the Hungarian Forest Research Institute. Tissue culture methods provide new means to speed up propagation of recently selected varieties and offer the opportunity to establish healthy stock plantations (Keresztesi 1983; Rédei 2013).

Cultures conveniently initiated from actively growing juvenile shoots; most actively growing shoot tips were collected from adult trees, part of a collection of clones and varieties of the Hungarian Forest Research Institute. May and June, and occasionally September, are the most suitable months for culture initiation, as the shoot growth is most active at these periods of the year. Micro-propagation may be carried out all year round. It is not advisable to initiate shoot cultures from dormant trees but rather to acclimatize plants in short-day conditions and keep acclimatized plantlets until mid-May in a glasshouse for over wintering. The plantlets are subsequently transplanted into 3-L plastic containers outside for a month under shading and watering conditions, and produce 1.5 m tall plants that may be planted out in November–December or the following spring (Keresztesi 1988; Rédei et al. 2002; Rédei 2013).

Micro-propagation protocol involves shoot tips 10–15 mm length, with apical and lateral buds and no leaves, surviving repeated disinfection in 1% $HgCl_2$ solution and remaining undamaged after rinsing with sterilized, bi-distilled water (Keresztesi 1988; Rédei 2013).

No black locust cultivars or selected clones have been propagated in Romania for production purposes; however, research on in vitro micro-propagation has been carried out. A micro-propagation technology was developed and allowed a high multiplication ratio in much shorter time than by conventional methods (Enescu 1989, 1991). More recently, good results were obtained on MS medium supplemented with IBA or IAA hormones (Mirancea 2002), humic acid and magnetic fluid (Corneanu et al. 2001), or MS prepared with depleted deuterium water.

Stand establishment, tending and yield

Black locust is established after soil preparation, whether afforestations or reforestations are carried out. The basic technologies and operations are as follow (Keresztesi 1988; Rédei 2013):

1. *Black locust afforestation with deep soil loosening* involves soil preparation without trenching by deep loosening of the soil, planting by machine or tractor-drawn pit-drilling machine, manual cultivation along the rows and machine cultivation inter-rows.
2. *Black locust afforestation with trenching or deep ploughing* involves trenching or deep ploughing, planting by machine or tractor-drawn pit-drilling machine, manual cultivation along the rows, and machine cultivation inter-rows.
3. *Semi-natural reforestation by root suckers* involves slash removal from the cutting area, bushcutting, root-ripping, knocking down of coppice shoots, and singling of clumps of shoots.
4. *Man-made reforestation by superficial soil preparation* involves slash removal, bushcutting, chemical treatment of stumps against sprouting, mechanized strip clearing, planting by machine or tractor-drawn pit-borer, knocking down of coppice shoots, manual soil cultivation along the rows, and mechanized cultivation inter-rows.
5. *Man-made reforestation by deep loosening* involves slash removal, bush cutting, chemical treatment against sprouting, deep loosening, planting by machine or tractor-drawn pit-borer, knocking down of coppice shoots, manual soil cultivation along the rows, and mechanized cultivation inter-rows.
6. *Man-made reforestation by complete soil preparation* involves slash removal, bush cutting, stump removal (stumplifting, knocking removal, and terrain leveling), trenching, planting by machine or tractor-drawn pit-borer, manual soil cultivation along the rows, and mechanized cultivation inter-rows.

In Romania, no more than 4000–5000 seedlings per ha are planted and then are cut 5 cm above the soil level in order to establish a new plantation (MAPPM 2000a). Usually black locust is planted in pure stands but it can be grown in mixed stands as well, for instance with grey poplar (*Populus* × *canescens*) in Hungary (Rédei et al. 2006) and, exceptionally, with black cherry (*Prunus serotina* Ehrh.) in north-western Romania (Fig. 5) on degraded sandy soils (Spârchez et al. 1961; MAPPM 1995, 2000a).

On degraded soils with land sliding, black locust may be up to 75% of species composition. It is planted with species such as common ash (*Fraxinus excelsior*) and undergrowth species and accounts for up to 50% of species on mining wastes (MAPPM 1995; Untaru 2005). Black locust is considered to be a principal species of shelterbelts established in the plain regions of Romania; it should be mixed with black cherry or undergrowth species such as

Fig. 5 Mixed black cherry (BC)–black locust (BL) stand, 53 years old in north-west Romania

Sambucus nigra L., *Acer tataricum* L., *Cornus sanguinea* L., and *Corylus avellana* L. (Catrina 2005).

Black locust stands show a full canopy by 10–15 years of age (Haralamb 1967; Rédei et al. 2014). The species rapidly closes the crown openings created by tending operations, although this takes longer in older stands. Subsequently, open canopy tends to reduce so that the ground is covered by a rich and dense herb layer (Haralamb 1967; Damian 1978).

Excellent growth can be expected when its high light requirements are met, increasing after 15 20 years, with a tendency to self-thinning. Its crown is loosely formed with relatively little foliage, whereas its branching depends on the provenance. There are few epicormic shoots and black locust tolerates artificial pruning well.

The peak of height growth occurs within the first 5 years, whereas diameter growth culminates in the first 10 years. Annual volume increment peaks at approximately 20 years of age, whereas mean annual volume increment occurs at 35 –40 years (Giurgiu and Drăghiciu 2004; Rédei et al. 2008). Most black locust stands are heterogeneous populations, which underlines the importance of mass selection in tending operations (Rédei et al. 2008).

In terms of vegetative propagation, there are differences between Hungarian and Romanian approaches: propagation occurs only by root suckers in Hungary but by both root suckers and stump stools in Romania. In terms of tending operations (Table 2), release cutting is applied only in Romania to avoid the dominance of stump stools over root suckers (Costea et al. 1969; MAPPM 2000b).

Cleaning-respacing (negative selection) is carried out when the canopy has closed and height differentiation occurs. In Hungarian coppiced stands, the first cleaning is carried out when the stands are 3–6 years old and stocking reduced to a maximum of 5000 stems ha^{-1} (Rédei 2013—Fig. 6).

In Romania, however, the aims of these operations are to remove low-quality individuals (e.g., forked, wounded, badly formed) and to reduce the stocking of stump shoots (2–3 remaining per stump) (MAPPM 2000b).

Artificial pruning for quality improvement of the final crop trees is considered very important in Hungary (Rédei 2013). In the past, it was also considered important in Romania when targeting the production of veneer logs (Bîrlănescu and Belu 1968; Costea et al. 1969). Unfortunately this is no longer the case as the practice has become too costly and there is no premium price for artificially pruned logs.

In stands of high and moderate yields, selective thinning is performed to promote valuable trees: those with narrow, full, and symmetrical crowns representing about one third of the height, a straight trunk of high quality with a strong central leader, rapid height growth, and good health. The objective of thinning is to produce a high proportion of good quality sawlogs from stands of yield classes I and II (Rédei 2013); some sawlogs and a high proportion of poles and props yield classes III and IV; and poles, props, and other small-size industrial wood from other yield stands (Rédei 2013). The number of final crop trees is generally 400–700 per ha, depending on the yield class. Artificial pruning must be carried out on the final crop trees up to a height of 4–6 m, resulting in a branchless stem up to this height (Rédei 2013).

Different methods are used for both cleaning and thinning: the so-called growing space index (the mean distance between trees in a triangular pattern as a percentage of mean dominant height) in Hungary, and the intensity index (percentage ratio of the extracted volume and initial volume of trees) in Romania. The mean value of space index should be 23–24% in Hungary; the intensity index is 15–20% in Romania. Only in Hungary is a sole thinning performed in I–III yield class stands at 22, 25 years to stimulate diameter increment. The increase in timber production is exclusively due to the diameter growth in this period (Rédei 2013).

Stands of selected varieties were established in Hungary but not in Romania, even though many valuable plus trees were selected in the past, seed orchards established, and seeds harvested. Tending technologies for these stands have not yet been elaborated. Based on results produced so far, the stocking at rotation age should be 500–600 trees ha^{-1} on good sites, whereas the initial stocking should be 2000–2500 stems ha^{-1}. The stocking for the final felling at 25–30 years may be attained with two thinning operations (Rédei 2013).

Another difference between the management of stands in Hungary and Romania is the regeneration pathway. In Hungary, both high forest and coppice are recommended, whereas in Romania only coppice is used. In Hungary,

Table 2 Tending operations in black locust stands in Hungary and Romania

Tending operation	Hungary		Romania	
	High forest	Coppice	Plantation	Coppice
Release cutting	No	No	No	1 year old Rotation of 1–3 years
Cleaning-respacing	5–8 years old Two rotations of 4–5 years	3–6 years old	4–5 years old Two rotations of 4 years	3–6 years old Two rotations of 3 years
Selective thinning	12–19 years old One to two rotations of 5–6 years	8–10 years old Two rotations of 4–6 years		
Increment thinning	22–25 years old only for yield classes I–III	No		
Artificial pruning	Up to 4–6 m	No		

regeneration from root suckers is permitted only in areas where the stands of good or medium productivity are of seed origin or first-generation coppice. Based on our trials, it is reasonable to question the regeneration of these stands from root suckers more than once. Unfortunately, forest management plans do not include data on how many times the stands were coppiced. The problem of whether or not the stand is to be regenerated by coppicing is therefore decided based on its growing stock and health. In general, black locust stands of good and medium productivity (yield classes I–III) may be regenerated from root suckers until their growing stock attains or exceeds the wood volume in the yield table. This is also possible if their health state is adequate, meaning that no more than 50% of the stumps have butt rot and the rot in trunks is no more than 1 m in height (Rédei et al. 2012). In Romania, black locust stands are regenerated by stump stools and root suckers when vegetative regeneration of stands (second and third generation) is targeted. After the third coppice, all stumps are removed and the stand is regenerated by seedlings (MAPPM 2000c).

The most important features of stand structure and yield factors of black locust standing crops (height, dbh, volume, total volume, mean annual increment of total volume) are shown in Fig. 7 (Hungary) and Fig. 8 (Romania).

The stand structure and yield may be described using formulas and coefficients. If general formulas for black locust in Hungary were set, the formulas in Romania were set depending on regeneration pathways and relative yield classes as follows in Hungary (Rédei 1984; Rédei et al. 2014):

$$H\% = 123.12\left(1 - e^{-0.070333A}\right)^{1.111638} \quad (1)$$

$$D_{\mathrm{BH}} = (69.9675 + 1.00625A)\frac{H}{100} \quad (\mathrm{r} = 0.8092,\ \mathrm{n} = 200) \quad (2)$$

$$N = e^{9.81801 - 1.15147 lnDBH} \quad (\mathrm{r} = 0.9421,\ \mathrm{n} = 200) \quad (3)$$

where H is mean height weighted by basal area (m^2), D_{BH} is diameter at breast height (cm), and A is age in years; H at 20 years=100%.

In Romania, for yield class I (vegetative propagation) (Giurgiu and Drăghiciu 2004):

$$h_{gT} = 83.04414e^{-3.7983T^{-0.35988}} \quad (4)$$

$$d_{gT} = -1 + 155.6236e^{-0.506333T^{-0.30498}} \quad (5)$$

where T is age in years, N is the number of stems per hectare, d_{gT} is quadratic mean diameter, and h_{gT} is the mean height of the quadratic mean diameter.

The average rotation age of black locust is 30 years in Hungary and Romania but this depends on the relative yield class. In Hungary, the longest rotation is used for the best stands (yield classes I and II) and the shortest for the poorest stands (yield classes V and VI). It was similar in Romania in the past, e.g., 30–35 years (yield classes I–III) and 20–25 years (yield classes IV-V) (Bîrlănescu and Belu 1968) but is now the opposite.

According to Hungarian yield tables, the volume of standing crop at 30 years of age ranges between 80 and 280 m^3 ha^{-1}, depending on yield class. Stands of yield classes I–II have a rotation of 35–40 years and an annual volume increment of 12–14 m^3 ha^{-1} a^{-1}. The stands with yield classes III–IV have a rotation of 30 years and an annual volume increment of 8–9 m^3 ha^{-1} a^{-1}. Finally, the poorest stands (yield classes V–VI) have a rotation of 20–25 years and an annual volume increment of 4–6 m^3 ha^{-1} a^{-1}. In first-generation coppice stands, growing stock, increment, and health are similar to those in high forests (Rédei 1984; Rédei et al. 2014).

In Romania, according to the domestic yield tables (Giurgiu and Drăghiciu 2004), the volume of the standing crop ranges between 81 and 365 m^3 ha^{-1}, depending on yield class. Yield classes I and II have a rotation of 25 years and an annual volume increment of 13.9–18.5 m^3 ha^{-1} a^{-1}. Stands of yield class III have a rotation of 30 years and an

Fig. 6 Black locust stand after the second cleaning-respacing in Hungary

annual increment of 9.7 m^3 ha^{-1} a^{-1}. Finally, the lowest yield classes IV and V have a rotation of 35 years and an annual volume increment of 3.7–7.3 m^3 ha^{-1} a^{-1} (Giurgiu and Drăghiciu 2004). Unfortunately, the yield tables do not emphasize the evolution of wood volume produced following repeated vegetative reproduction. This issue was studied by Bîrlănescu and Costea (1962) who showed that wood production is not the same in stands regenerated by seed (plantations), root suckers, and stump stools of different generations (Table 3).

Black locust energy plantations

In recent years, more and more agricultural land is being taken out of use for food crops. Some of this could be used for energy plantations. Black locust is one of the best species for this purpose since it has excellent energy production properties such as: (1) vigorous growth in its juvenile phase; (2) excellent coppicing; (3) high wood density; (4) high dry matter production; (5) favorable wood combustibility and relatively fast drying; and, (6) relatively easy harvesting and processing.

In the last decade, several energy plantations have been established in Hungary. Different spacing treatments have been evaluated, and black locust and its cultivars have been compared (Rédei 2013). For instance, in Helvécia (central Hungary on sandy soils), an energy plantation was established using common black locust and its cultivars. The spacing was 1.5×0.3 m, 1.5×0.5 m, and 1.5×1.0 m. At 5 years, the closest spacing (1.5×0.3 m) produced the largest annual increment in oven-dry mass (6.5 t ha^{-1} a^{-1}). This exceeded the increment of the two wider spacing by 33% and 51%, respectively. According to the results of the yield trial with cultivars planted at 1.5×1.0 m, the highest yield at 5 years was produced by the cultivar 'Üllői' (8.0 t ha^{-1} a^{-1}), followed by 'Jászkiséri' (7.3 t ha^{-1} a^{-1}), and the species itself (6.7 t ha^{-1} a^{-1}) (Rédei et al. 2011).

Black locust energy stands may also be established by coppicing, with the advantages being the low cost of establishment compared to that by artificial regeneration, the relatively large amount of biomass produced within a short time from the root system of the previous stand, and the disadvantage being the uneven distribution of trees compared to distribution in plantations optimized for energy production specific to coppice stands. In such crops, the quantity of biomass is lower and the length of rotation is highly influenced by the irregular diameter distribution (Rédei et al. 2011).

The first peak of annual volume increment in energy forests established from sprouts is between 3 and 5 years. The annual increment then declines and a new peak occurs between 9 and 12 years after establishment. A further maximum is expected after approximately 15 years because of an even higher degree of mortality. Approximately one-third of stems are lost by the age of 7 or 8 years. By 12–13 years, the stem numbers decrease to less than 50% (Rédei et al. 2011).

Experiences with both planted and coppiced energy plantations and other stands indicate that it is not reasonable to harvest in the first 3 years, as the yield in the fifth year in oven-dry weight is two to three times greater than it is in the fourth year. Harvesting too early may also increase the population of biotic pests (Rédei et al. 2011).

Research on biomass production using black locust was carried out in Romania during 1984–1987. Following the high consumption of nutrients (especially nitrogen, potassium, and calcium) and soil water, the choice of land upon which to establish the cultures is very important. In this respect, the following conditions should be fulfilled in case

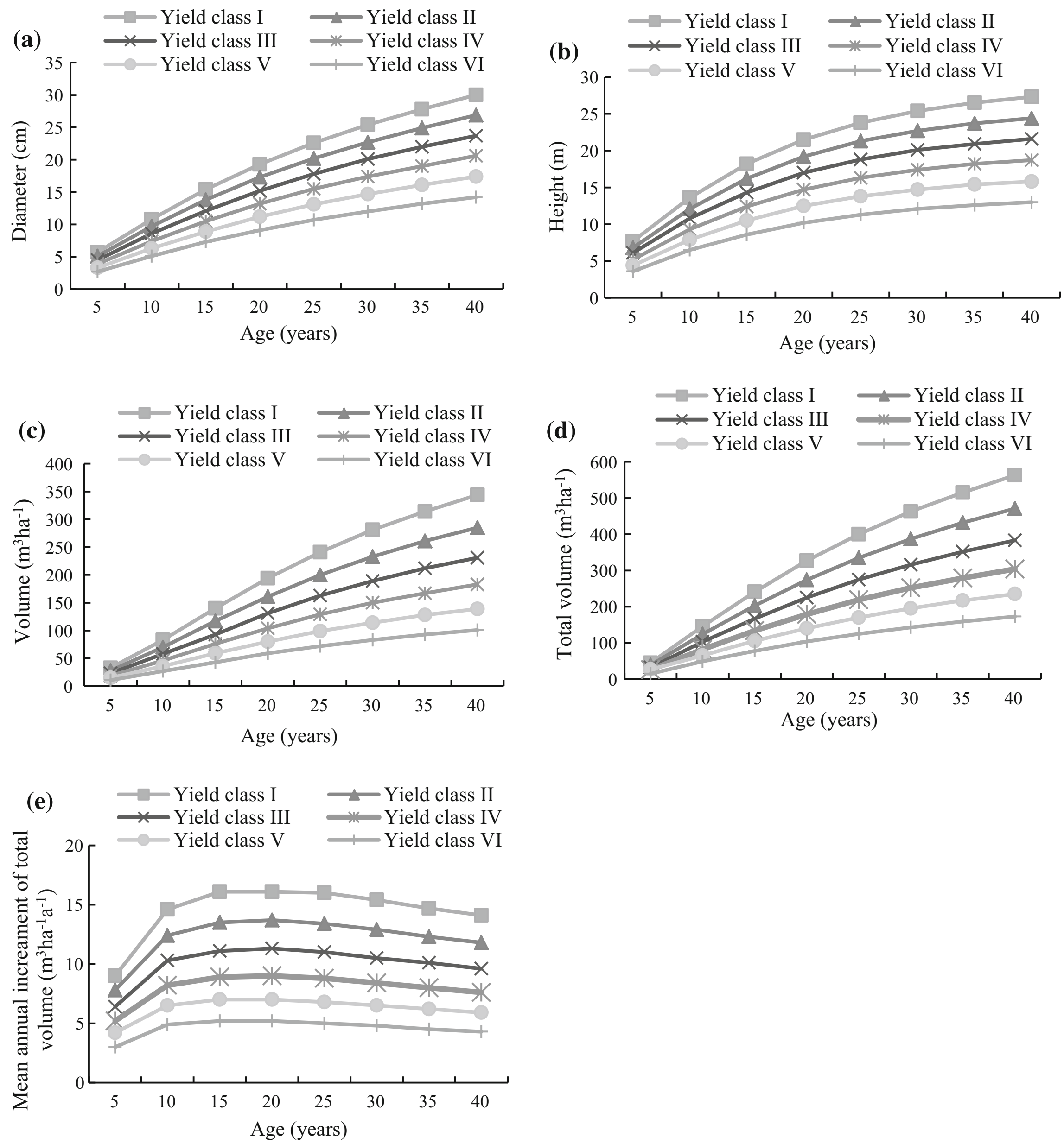

Fig. 7 Black locust stand structure factors depending on age. Hungarian yield tables in $m^3ha^{-1}a^{-1}$ (Rédei 1984)

of short rotation cultures: pH 5.5–7.0; content of soluble salts < 0.10% for chlorine and < 0.15% for sulphur; $CaCO_3$ content (%) < 6 or 7, humus content (%) > 1.7; clay content (%) of 10–37; spacing 1.0 × 0.5 m; harvest every 3–4 years (MS 1988).

Black locust as a non-native species in plantation forestry

Some parts of Europe lack highly productive native species with timber or growth characteristics suited to plantation forestry, and foresters must rely largely on exotic species such as black locust as it can easily be established on certain sites, has better growth rates than native species, and possesses broader physiological adaptability with regard to site conditions. The species has been widely used for various purposes such as ornamentation, timber, firewood, short-rotation coppice, re-vegetation of dry land, soil stabilization, and as source of nectar for honey production (Keresztesi 1988; Rédei et al. 2008).

Conversely, significant uncertainties exist at a regional scale that extensive commercial production with black locust could have negative effects on biodiversity, particularly in areas of high nature conservation value. In our opinion, however, the integration of black locust into agricultural landscapes could stimulate rural economies,

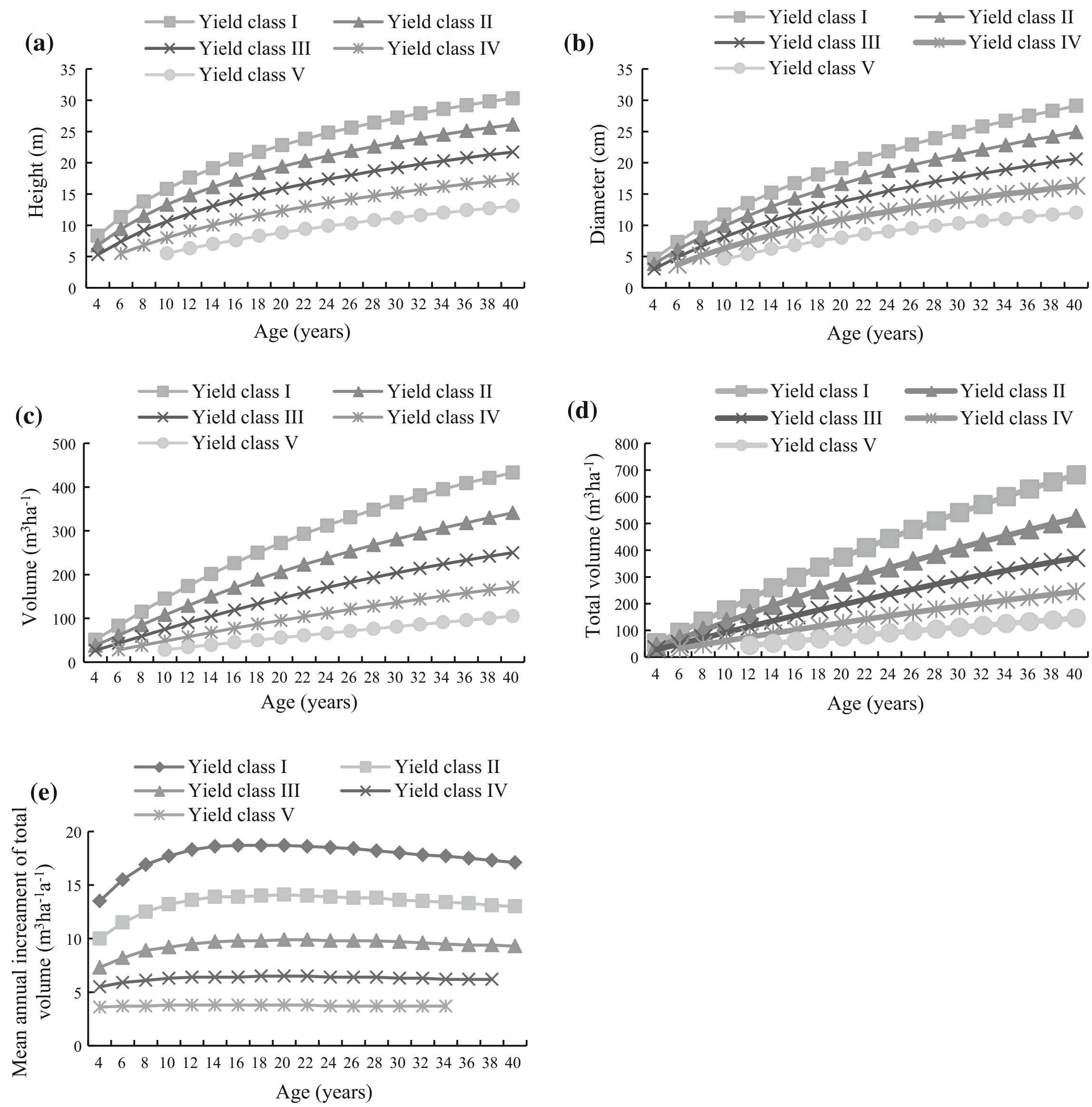

Fig. 8 Black locust stand structure factors depending on age. Romanian yield tables in $m^3\ ha^{-1}a^{-1}$ (Giurgiu and Drăghiciu 2004)

Table 3 Evolution of wood production in stands regenerated by planting, stump stools, and root suckers, depending on the generation (Bîrlănescu and Costea 1962)

Plantations (%)	Stump stools (%)			Root suckers (%)		
	1st generation	2nd generation	3rd generation	1st generation	2nd generation	3rd generation
100	86	70	40	89	89	89

counteracting to some extent the negative impacts of farm abandonment, or supporting the restoration of degraded land which results in improved biodiversity values.

As previously noted at the beginning of this paper, it is predicted that the area suitable for planting black locust will increase in Europe under on-going climate changes. In this respect, it is urged that management plans for European nature reserves should incorporate changes to more explicitly address invasion risk by species such as black locust. Avoiding planting of black locust close to protected areas/endangered habitats would be a simple way of reducing the risk of further invasions by this species under future climate conditions.

Conclusions

Black locust has a special history associated with each country into which it has been introduced and cultivated. Without a doubt, it has been utilized most intensively in eastern and southern European countries, including Hungary and Romania.

This review provides a full picture of past and current distribution of black locust in both Hungary and Romania, followed by a review of the state-of-the-art of site requirements, propagation, improvement and management of this important species which has been widely accepted and used in Hungary and Romania for many years. The review also emphasizes the important positive economic impacts of black locust planted for wood and honey production on local and national economies in the two countries.

Despite its high adaptability and potential for land reclamation/rehabilitation, the expansion of the species in forest sites more suit to native species such as oaks have often led to sharp conflicts of interest. However, the species is not officially regarded as invasive in Hungary and Romania.

In the context of climate change, the importance of this species adaptability to poor soils with high temperature variations (e.g., continental sand dunes) is expected to increase. We also consider that future research, a follow-up of the long-term projects completed in the past and ongoing, is required in order to scientifically qualify the black locust as the paradigm species for biological research and multi-purpose uses.

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