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YIELD OF BLACK LOCUST (*ROBINIA PSEUDOACACIA* L.) SHORT-ROTATION ENERGY CROPS IN HUNGARY: CASE STUDY IN A FIELD TRIAL

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Zakladanie lesných porastov s krátkou rubnou dobou a porastov na produkciu biomasy pre účely výroby paliva sú na celom svete predmetom záujmu už mnoho rokov. V tomto kontexte sa pestujú porasty s krátkou rubnou dobou aj v Maďarsku už dlhé obdobie. V Maďarsku je agát biely (*Robinia pseudoacacia* L.) jednou z najdôležitejších drevín tvoriacich porasty. Jeho porasty pokrývajú približne 23 % z celkovej lesnej plochy v Maďarsku (410 000 ha) a podieľajú sa 19 % na ročnej ťažbe dreva. Táto rýchlo rastúca drevina sa zdá byť vhodnou aj pre pestovanie s krátkou rubnou dobou. V práci sa popisuje experimentálna energetická kultúra, ktorá bola založená v Helvécii (stredné Maďarsko, oblasť s piesočnatými pôdami), pričom sa použil agát biely a jeho kultivary vyšľachtené v Maďarsku. Toto stanovište môže reprezentovať triedu s priemerným výnosom pre agát biely v Maďarsku. Použitý spon je 1,5 × 1,0 m a v založenom poraste sa pestujú štyri kultivary agáta bieleho – *'Üllői', 'Jászkiséri, 'Nyírségi'* a *'Kiscsalai'*, pričom plocha sa obnovila výmladkovým spôsobom. Vo veku 7 rokov dosiahol najväčší hrúbkový ročný prírastok (po vysušení) kultivar 'Üllői' (9,7 mg.ha^{-1}.rok^{-1}), po ňom nasledoval agát biely (8,4 mg.ha^{-1}.rok^{-1}) a kultivar 'Jászkiséri (7,6 mg.ha^{-1}.rok^{-1}). Na ploche kde rastie porast z výmladku, sa množstvo dendromasy v priemere pohybovalo od 6 do 8 mg.ha^{-1}.rok^{-1}

Kľúčové slová: *agát biely (Robinia pseudoacacia L.), energetická plodina, dendromasa*

Establishment of short-rotation tree plantations and forest stands for fuel production has been of international interest for many years. In this context, short-rotation crop plantations in Hungary have been conducted for a long time. In the country, the black locust (*Robinia pseudoacacia* L.) is one of the most important stand-forming tree species, covering approximately 23% of the forested land (410 000 ha) and providing about 19% of the annual timber output of the country. This fast growing species seems to be suitable also for short-rotation crops.This paper describes an experimental energy plantation that was established in Helvécia (Central-Hungary, sand-soil region) using common black locust and its cultivars bred in Hungary. The site may be considered a representative of an average yield class for black locust in Hungary. The experimental plantation was established with spacing 1.5 m × 1.0 m and included common black locust, four cultivars, *'Üllői', 'Jászkiséri, 'Nyírségi'* and *'Kiscsalai'*, and a plot regenerated by coppice. At the age of 7, the highest annual increment in stem oven-dry mass was produced by the cultivar 'Üllői' (9.7 Mg ha^{-1} yr^{-1}), followed by the common black locust (8.4 Mg ha^{-1} yr^{-1}) and the cultivar 'Jászkiséri (7.6 Mg ha^{-1} yr^{-1}). On the plot of coppice origin dendromass ranged from 6 to 8 Mg ha^{-1} yr^{-1} on average.

Key words: black locust (*Robinia pseudoacacia* L.), energy tree crop, dendromass

1. Introduction

The energy crisis of the early 1970's stimulated interest in short-rotation crops (tree plantations and forest stands) in temperate countries. Planted crops, which are subsequently coppiced in a 4 to 5 year cycle, are economically valued as alternative sources of wood, charcoal and liquid fuels, a basis for chemical processes, wood pulp, and sometimes as a fodder. Forest crops (tree plantations and forest stands), of course, are not the only sources of biomass for energy, though they are among the most efficient in terms of the ratios of energy contained in the harvested crop to total energy input.

In Hungary, the demand for timber is high leading to an annual wood harvest of about 7 million cubic meters. Wood harvested is used by building industry, furniture industry, packaging, and paper industries. About 3 million cubic meters of wood and approximately 0.5 million cubic meters of used-wood products is annually consumed to produce heat energy for industry or households.

Considering the total wood-consumption of black locust, 55% is utilized for fuel and 45% is used as industrial raw material. Only about 70% of the country's demand for timber can be met from current inland forest production. According to the EU regulations, the use of renewable energy sources in Europe should be increased by 20% till 2020. In Hungary this value should be 13%. Plantations established for biomass production (above-ground dendromass) and managed on a short rotation in general, may contribute to meet the demand of wood for energy purpose as a renewable source.

According to Halupa and Rédei (1992), the major advantages of establishing energy plantations are:

– They are renewable (continuous) and reproduce systematically;
– They provide an alternative for utilizing lands on which agricultural production is temporarily abandoned;
– They are environmentally compatible (protect against erosion) if the right silvicultural techniques are applied;
– They reduce the use of fossil energy sources, which pollute the environment with sulphur and ash;
– The ash of burnt wood can be used as fertilizer for plant crops;

– By establishing large scale energy plantations, the cost of geological research, mine openings and mining can be reduced;
– They can be distributed in the country more uniformly than the fossil energy sources;
– Capital for establishment is considerable less and the return on investment shorter than that of the fossil energy sources, especially compared to deep underground coal-mining;
– Their wood material can be used at most any time, and plantations can be established near the area of consumption, thus reducing the transportation cost;
– They could contribute to the employment of people in the given area.

Broadleaved, rather than coniferous species, are generally planted for short-rotation crops for two reasons:
– Costs can be reduced if more than one harvest can be made from one establishment operation; hence one of the most important attributes of a species for energy use is that it should be vigorously coppiced;
– Unlike evergreen conifers, deciduous broadleaved trees accumulate less assimilated material in their leaves and the leaves are, per unit area, photosynthetically more efficient than those of conifers; hence a larger amount of assimilate is available from an early age for the growth of stems, branches and roots.

In Hungary, black locust is the most promising tree species for energy plantations (Halupa and Rédei 1992, Rédei 2003). Under the country's site conditions the following tree species would also be suitable for this purpose: *Populus, Salix species* and *Ulmus pumilla* (Rédei *et al*. 2004).

2. The role of black locust in establishing energy crops in Hungary

In Hungary the black locust covered 37,000 ha in 1885, 109,000 ha in 1911, 186,000 ha in 1938 and 410,000 ha in 2007. One-third of black locust stands are high forests, while two-thirds of them are a coppice. In the 1960's, Hungary had more black locust forests than all the other European countries (Rédei 2003).

Black locust timber can be used by industry (mining, construction, furniture), agriculture (posts and poles), and black locust stands are the main basis for Hungarian apiculture and honey production. It is one of the most suitable tree species for establishing energy plantations and for transforming existing traditional forests into energy forests.

The frequently expressed misconception that rapid growth rate is associated with low wood density is clearly not proved by black locust. Not only the species has a very high density (690 $kg.m^{-3}$), but its fast height growth rate, 2–6 $cm.day^{-1}$ in its juvenile stage, places it among the most fast growing plants. With this combination of both high density and volume increment, black locust can achieve impressive dendromass yield when growing on good sites. Moreover, because of its ability to fix atmospheric nitrogen, it requires little or no nitrogen fertilization. Considering the yield criteria (volume and density) and the symbiotic associations of both bacteria and mycorrhizal fungi, black locust offers an excellent opportunity for energy plantations.

Black locust energy forests can also be established by coppicing. Advantages of energy forests of coppice origin are that the cost of establishment is low compared to that of soil preparation, plantation and cultivation. From the developed root system of the previous stand, a large biomass (above-ground dendromass) can be produced within a short time period. The disadvantage is that the distribution of trees in coppice stands is not as uniform as in plantations optimized for energy production. In coppice stands, the quantity of the produced above-ground dendromass is lower and the rotation is highly influenced by the uneven distribution of stems.

More and more agricultural land is set aside without field crops and can be used for energy production plantations. Black locust is one of the best tree species for this purpose, thanks to its excellent properties, such as vigorous growing potential in the juvenile phase, excellent coppicing ability, high wood density, dry matter production, favourable combustibility of its wood, relatively fast drying and easy harvesting and processing (Halupa and Rédei 1992; Halupa *et al.* 2000).

3. Materials and methods

Data used in this study came from a short-rotation plantation trial established in Hungary in the sub compartment Helvetia 80A in Central-Hungary, Danube-Tisza Interfluves. The sub compartment has slightly humic sandy soil without ground-water influence. The annual precipitation amounts to only 500 mm in some years, of which only less than 300 mm comes in the dry summer period. It means that the water supply is a factor limiting. The trial at Helvetia is not of the best sites available in Hungary but can be considered as an average yield class site for black locust in Hungary (Rédei and Veperdi 2005, Rédei and Veperdi 2007).

The trial was established in a spacing of 1,5 m × 1,0 m, with three repetitions and four treatments representing different plant materials: common black locust and four cultivars '*Üllői*', '*Jászkiséri*', '*Nyírségi*', and '*Kiscsalai*'. Each treatment corresponds to a plot of 15 by 20 m. One-year-old rooted cuttings were used in the case of cultivars and one-year-old seedlings in the case of common black locust.

In the same sub compartment, tree stand surveys were carried out in two experimental plots where common black locust was regenerated by root suckers.

Measurements were made at the ages of 3, 5 and 7 years. At each of these ages, all stems in each plot were counted and 10 trees were randomly selected for destructive sampling, and their volume (v) was determined with Smalian's formula (Vaan Laar and Akca 1997). The mean tree volume (v_{mean}) was computed as an arithmetic mean of the felled trees volume. Stand volume (Vha^{-1}) was estimated through multiplication of v_{mean} by stand density (Nha^{-1}). In the plots of coppice origin the measurements were carried out at the age of 4 by using the above-mentioned method including counting all the trees. The stem oven-dry dendromass was determined in laboratory with using a drying temperature of 70°C.

4. Results

Results concerning the trial with cultivars and common black locust at the age of 3, 5 and 7 are provided in Table 1 and partly in Figure 1. At the age of 5, the highest increment of oven-dry stem dendromass was produced by the cultivar '*Üllői*' (8.0 Mg ha^{-1} yr^{-1}), followed by '*Jászkiséri*' (7.4 Mg ha^{-1} yr^{-1}) and the common black locust (6.7 Mg ha^{-1} yr^{1}). At the age of 7, the order was the following: '*Üllői*' cultivar (9.7 Mg ha^{-1} yr^{-1}), common black locust (8.4 Mg ha^{-1} yr^{1}) and '*Jászkiséri*' cultivar (7.6 Mg ha^{-1} yr^{-1}) (Fig. 2).

Table 1. Evaluation of a short-rotation plantation with black locust cultivars on the base of plot averages (Helvetia 80/A)

Cultivars	Age (yrs)	Mean		Oven-dry stem dendromass (Mg ha^{-1})	Increment of oven-dry stem dendromass (Mg ha^{-1} yr^{-1})
		H (m)	DBH (cm)		
'Üllői'	3	4.1	3.1	8.9	3.0
	5	6.2	4.9	40.1	8.0
	7	9.3	6.4	68.1	9.7
'Jászkiséri'	3	3.6	2.9	7.1	2.4
	5	6.1	4.7	37.1	7.4
	7	8.8	6.2	53.2	7.6
'Nyírségi'	3	3.1	2.7	7.2	2.4
	5	5.3	4.2	28.4	5.7
	7	7.6	5.1	46.2	6.7
'Kiscsalai'	3	3.9	3.2	12.5	4.2
	5	6.1	4.6	31.1	6.2
	7	8.4	5.9	49.7	7.1
Common black locust	3	3.7	3.1	10.9	3.6
	5	6.1	4.7	33.5	6.7
	7	8.2	5.5	59.1	8.4

Spacing: 1.5 m × 1.0 m, H – height, DBH – diameter at the breast height (1.3 m)

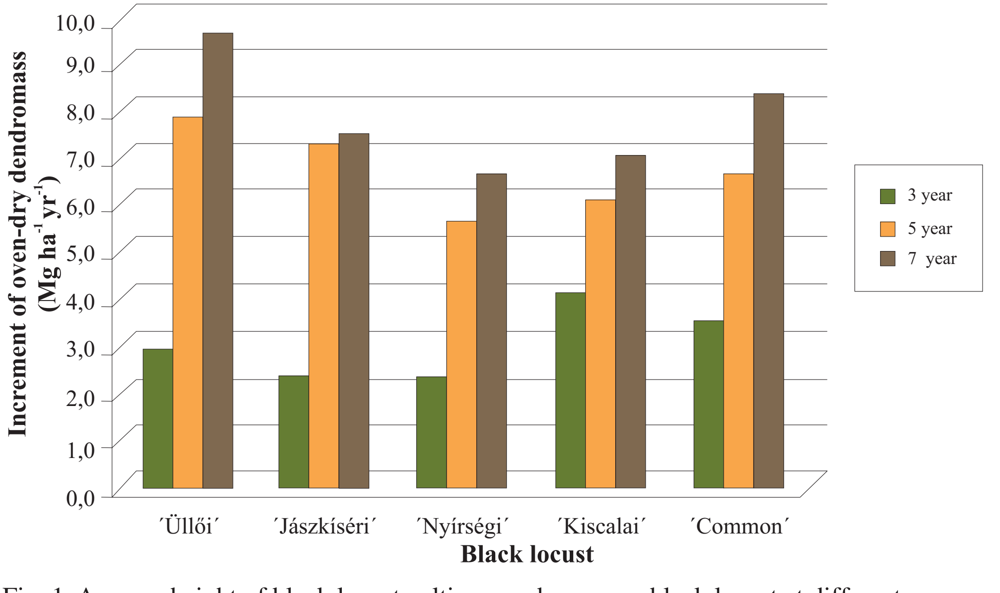

Fig. 1. Average height of black locust cultivars and common black locust at different ages.

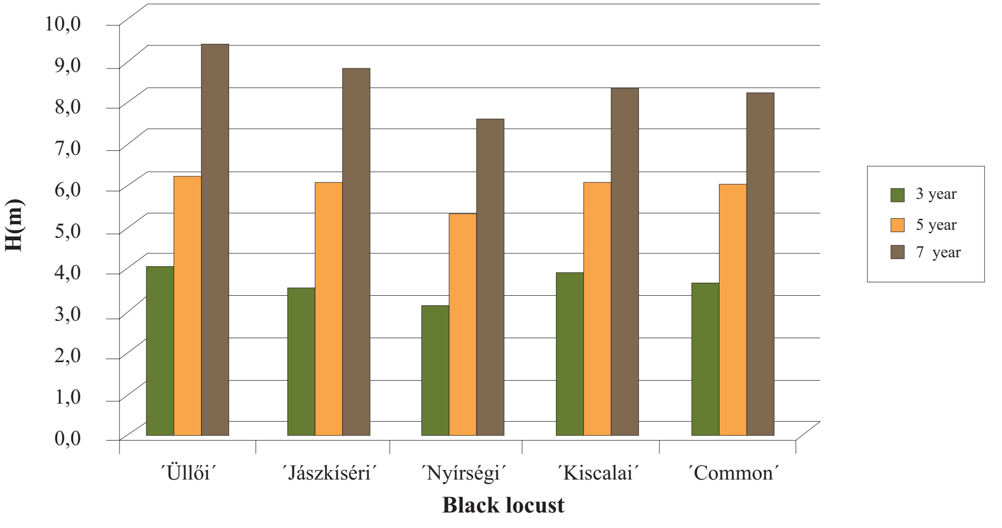

Fig. 2. Increment of oven-dry stem dendromass of black locust cultivars and common black locust at different ages.

The data from the Table 1 indicate that it is not reasonable to harvest in the first three years, as the increment of oven-dry stem dendromass at the age of 5 and 7 is 1.5–3 times higher than it was at age of 3. This result is important as it is known that too early harvesting may also increase the population of biotic pests (Rédei and Veperdi 2005).

Table 2 gives the most important structure and dendromass factors of the two black locust short-rotation crops of coppice origin based on stand surveys at the age of 4. Considering that height (H) and mean diameter (DBH), values are almost the same, and thus the mortality resulting in different stand densities must have been responsible for the differences in the stand oven-dry dendromass. The difference of 57% in stand density resulted in a surplus of about 15% in increment of oven-dry dendromass.

Table 2. Evaluation of a short-rotation black locust stand of coppice origin in the trial Helvetia 80/A

Factors		Mean		Oven-dry stem dendromass ($Mg\ ha^{-1}$)	Increment of oven-dry stem dendromass ($Mg\ ha^{-1}\ yr^{-1}$)
N (ha^{-1})	Age (yrs)	H (m)	DBH (cm)		
8333	4	4.8	2.5	31.2	7.8
5306	4	4.7	2.8	27.1	6.8

N – number of individuals, H – height, DBH – diameter at breast height 1.3 m.

5. Discussion and conclusions

The results of the experimental plots presented here are preliminary ones to the evaluation of short-rotation crops for energy purpose in Hungary.

Dendromass yields of tree plantations and forest stands for energy purpose can be very promising but show great variation depending upon site, species, and climatic region. From the first experimental results in the 1970's, Canell and Smith (1980) and Pardé (1980) suggested that in most temperate regions it would not be realistic to give field predictions higher than 6 to 8 Mg ha^{-1} yr^{-1} of wood dry weight in stems and branches. In some other papers, black locust increment in oven-dry weight of energy plantations from different temperate climate region ranged from 6 to 12 Mg ha^{-1} yr^{-1} (Frederick *et al.* 1989, Csiha *et al*. 2007), similar to which is the trial described in this paper. Good results were obtained with black locust (12.5 Mg $ha^{-1}year^{-1}$) in Italy. It proved to be resistant to most pests. In general it required fewer tending operations than poplar and willow (Facciotto *et al.* 2009).

In Hungary, as mentioned above, black locust is the most suitable tree species for establishing energy tree plantations. Technology improvements in converting wood to energy will increase wood use and help meet the rising global demand for energy. Black locust is planted extensively world wide and has desirable fuel wood characteristics. Its low moisture content enables reduced handling costs and enhances suitability for efficient energy conversion. Black locust is therefore considered the best fuel wood in Hungary, having good combustibility even when wet.

In energy tree plantations, where the average rotation period is 4–5 year, regarding game damage the most critical period is the first 1–2 year (following their establishment). In the case of black locust, main part of game damage is browsing which has a great negative effect of the annual increment, and subsequent denrodomass pro-

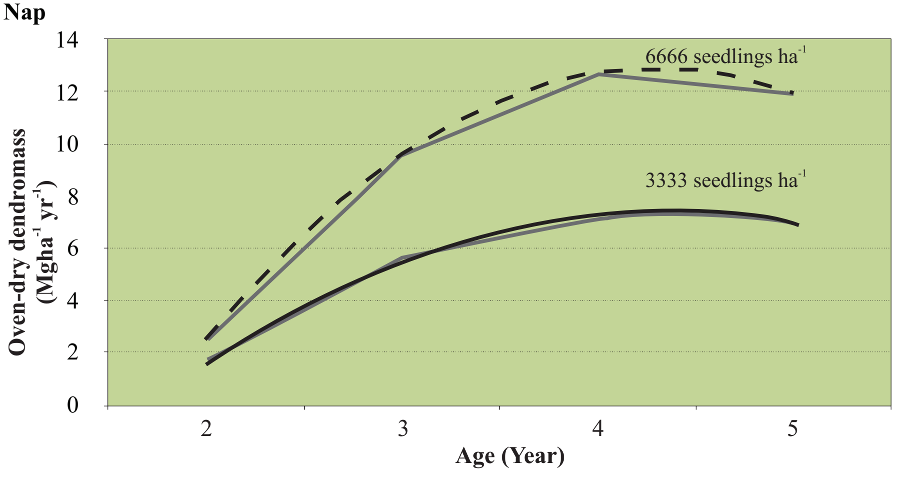

Fig. 3. Annual produce of black locust energy tree plantation Napkor 650B (Csiha *et al*. 2007).

duction. It could cause 30–35% shortfall in the annual increment. The most effective but most expensive way of game control is game fencing, or if there is a possibility, electric fence.

The results obtained in the experimental plots described in this paper show that the quantity of dendromass strongly depends on the plant material (cultivars) as well as on the number of stems per hectare. These factors are important for the determination of optimum rotation period.

Presented results are the initial step of a more comprehensive evaluation of short--rotation crops established for energy purpose. The preliminary results should be confirmed by other experiments in similar site conditions and with similar cultivar composition.

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Summary

Establishment of short-rotation tree plantations and forest stands for fuel production has been of international interest for many years. In Hungary, about 3 million cubic meters of wood is used each year for energy fuel and approximately 0.5 million cubic meters of used-wood products is annually consumed to produce heat energy for industry or directly marketed for the population. According to the EU regulations, the use of renewable energy sources in Europe should be increased to 20% till 2020. In Hungary this value should be 13%. Plantations established for producing wood biomass (above-ground dendromass) and managed on a short rotation in general, may help to meet the demand for wood for energy purpose.

The experimental plantation was established with a spacing of 1.5 m × 1.0 m and included common black locust and four cultivars, *'Üllői', 'Jászkiséri, 'Nyírségi'* and *'Kiscsalai'* as well as 2 plots regenerated by sprouting. At the age of 5 and 7, the annual increment in stem oven-dry mass varies between 6 to 9 Mg ha^{-1} yr^{-1}. In some cases it can reach the value of 10 to 12 Mg ha^{-1} yr^{-1}. The quantity of dendromass strongly depends on the site conditions, plant material (cultivars) as well as on the number of stems per hectare.