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Productivity of thinned black locust (*Robinia pseudoacacia* L.) stands in Hungary: case study

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SUMMARY

Black locust (Robinia pseudoacacia L.) is one of the most important introduced tree species in Hungary, covering more than 24% of the stocked area and providing approximately 20% of the country's annual timber cut. Consequently, the research and development activities related to the improvement of the growing technology of black locust are also important, especially in mitigating the negative effects of climate change. The aim of this study was to quantify growth and yield, responses of even-aged 12–31–year–old black locust stand to thinning in Hungary. The study has proved that irrespective of the yield class, age and thinning intensity, thinning could not increase effectively the cumulative volume production. As percentage of the control it has changed between +0.6 and -8.4%. On the other hand, it could increase the stand value based on stem quality index by 10–21%.

Keywords: *thinning; black locust; growth; yield*

INTRODUCTION

Black locust (*Robinia pseudoacacia* L.) is one of the most planted broadleaved tree species globally (especially in Central Europe and Asia) (Wojda et al., 2015; Vítková et al., 2017; Lee et al., 2019; Nicolescu et al., 2020). In Hungary, it is covering more than 24% of the stocked area (HCSO, 2020). However, regeneration by species conversion of the one-third of Hungarian black locust stands would be reasonable. The importance of this species' adaptability to degraded (caused by deflation or erosion) and poor soils with high temperature variations is expected to increase globally (Nicolescu et al., 2018; Rédei et al., 2011, 2018).

Thinning is carried out repeatedly in plantations, young high forest and high forest stands, targeting the individual tending of trees by a vigorous artificial selection and creation of favourable conditions for the development of remaining trees. It is well known, that the increased volume growth of individual trees normally occurs as diameter rather than height growth. With a wide range of tree density per acre height growth is relatively constant for a given species and site. The primary effect of thinning, therefore, is to increase diameter growth of remaining trees. Effective thinning will stimulate this growth within a few years (Wiedemann, 1943).

Foresters have long observed that old and large trees do not respond to thinning as readily and as dramatically as small, young trees. This is particularly true for species that are intolerant of shade. Shade-tolerant species are more likely to respond to thinning at older age (Pardé, 1965; Persson, 1986; Pretzsch, 2009).

Thinning applies to the stands of trees rather than to individual ones. The fact that thinning ordinarily increases the growth of individual remaining trees does not mean total stand growth is increased – there are fewer trees in a thinned stand (Assmann, 1961).

Most of the relevant publications in Hungary declare that thinning cannot increase effectively total stand production with various tree species; however, in many cases, thinning can increase stand value (Majer, 1969; Béky, 1983; Halupa, 1987; Béky & Solymos, 1991; Rédei & Meilby, 2009; Rédei et al., 2019).

Limited information exists on the growth and yield of black locust stand following thinning. The correct use of tending regimes and the investigation of their impact on yield are important parts in the improvement of black locust growing technology. This is the aim of the long-term tending experiments, presented and evaluated in this study (review).

MATERIALS AND METHODS

The experiments were established at KEFAG Kiskunsági Erdészeti és Faipari Zrt. (State forest company in Hungary), in 3 subcompartments (Kunbaracs 6 C, Mélykút 33 A and Paks 92 A), located in the central part of Hungary (*Figure 1*). The subcompartments are on free-draining site, sandy soil in the forest-steppe climate zone (according to Hungarian forestry climate classification). In this part of the country the annual precipitation is 527 mm, in the last 3 decades (based on data of the weather station in Kecskemét, Hungary) (HMS, 2020).

The site types – according to the Hungarian soil and forestry climate classification (Járó & Lengyel, 1988) – of the subcompartments are in *Table 1.*

In the experiment different thinning treatments were executed when the stands were 12 (Kunbaracs 6 C), 14 (Mélykút 33 A) and 21 (Paks 92 A) years old. We used one-factor experimental designs in Kunbaracs 6 C and Mélykút 33 A experimental plots, and two-factor design in case of Paks 92 A. Each plot area was 1000 m^2.

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Figure 1: **Location of the experimental subcompartments**

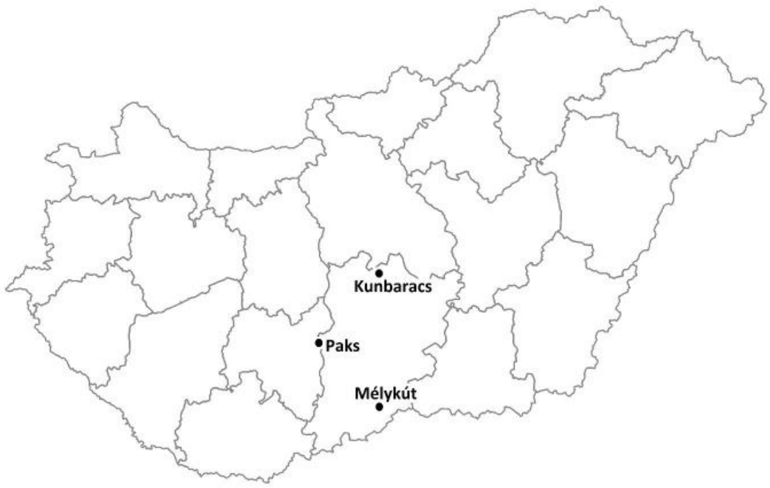

Table 1: **The site types of the subcompartments**

Subcompartment	Site				
	Climate	Hydrology	Genetic soil type	Depth of the soil	Soil texture
Kunbaracs 6 C	Forest-steppe	Free-draining site	Humic sand soil	Medium deep	Sand
Mélykút 33 A	Forest-steppe	Free-draining site	Humic sand soil	Deep	Sand
Paks 92 A	Forest-steppe	Free-draining site	Rusty brown forest soil	Medium deep	Sand

The growing space index (GSI) provided a very good guide to the intensity of the tending cuttings (thinning). It is a ratio of the average distance (a) between trees and their average height (H) expressed as a percentage. It is calculated using the following formula:

$$GSI\ (\%) = (a\ 100)\ H^{-1} \quad (1)$$

The following GSI values were used in the three thinning experimental plots in the thinned stand sections described below:

- In the 1st thinning experiment at age 12: 20% (Kunbaracs 6 C)
- In the 2nd thinning experiment at age 14: 22% (Mélykút 33 A)
- In the 3rd thinning experiment at age 21: 20 and 24% (Paks 92 A)

The following parameters were measured: stem number, diameter at breast height, and tree height. The calculated parameters were the following: basal area, mean tree volume, volume of dead trees, stand volume (growing stock), total production, mean annual increment as well as stem-quality index (SQI). Mean tree volume was calculated using the volume function based on the volume table for black locust (Sopp & Kolozs, 2013):

$$v = 10^{-8}\ d^2h^1\ (h/[h-1.3])^4\ (-0.6326\ dh + 20.23\ d + 3034) \quad (2)$$

where
v = mean tree volume (m^3),
d = diameter at breast height (cm),
h = height of the tree (m).

Growing stock (V) has been determined by means of a computer program developed by the Hungarian Forest Research Institute (FRI) for calculating wood volume; the volume of the average tree (v_m) is computed according to the relation:
$v_m = V\ (N-1)$, where
N = number of stems per hectare.

The stem quality classes at the ages of 12–31 are as follows (for calculating the stem-quality index):

- (x_1) Straight, cylindrical, healthy stems. Crooks are tolerated in one dimension only.
- (x_2) The stem is straight, forks are tolerated. Crooks are tolerated in one dimension only.
- (x_3) The stem is crooked and leaning. Minor crookedness in a second dimension is tolerated.
- (x_4) Very crooked in more than one dimension. Forked trees with stem defects.

The stem-quality index (SQI) was determined based on the following formula:

$$SQI = (x_1 n_1 + x_2 n_2 + x_3 n_3 + x_4 n_4)\ (n_1 + n_2 + n_3 + n_4)^{-1} \quad (3)$$

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where
x_1, x_2, x_3, x_4 = tree quality classes,
n_1, n_2, n_3, n_4 = tree numbers belonging to the single tree quality classes.

RESULTS

The most important yield and stem-quality data of the experiments are shown in *Table 2*, *Table 3* and *Table 4*. The tables were compiled using data obtained from full inventories in the experimental plots carried out between 12 and 17 years (Kunbaracs 6 C), 14 and 23 years (Mélykút 33 A) as well as 21 and 31 years (Paks 92 A).

In subcompartment Kunbaracs 6 C, the difference in percentage of the initial growing stocks at the age of 12 years and the cumulative growing stocks of at age of 17 years to the control plot is 0.9%. The stem quality index of the 17-year-old stand (after thinning) in ratio of the control is 0.89 (11%) (*Table 2*).

Table 2: **Yield and stem-quality data of 12–17 years (subcompartment Kunbaracs 6 C) Yield Class: III (Rédei, 1984)**

	Factors	**Plots**	
		1. (control)	**2.**
1	Initial growing stock before the thinning (m^3 ha^{-1})	111.6	114.6
	As a percentage of the control (%)	100.0	102.7
2	Volume removed during the thinning (m^3 ha^{-1})	0.0	31.2
3	Growing stock after thinning (m^3 ha^{-1})	111.6	83.4
4	5 years later:		
	Growing stock (m^3 ha^{-1})	138.3	117.3
	Growing stock as a percentage of the control (%)	100.0	84.8
	Mortality (m^3 ha^{-1})	8.4	3.1
	Wood stock (growing stock + mortality) (m^3 ha^{-1})	146.7	120.4
	As a percentage of the control (%)	100.0	82.1
5	Change in growing stock 5 years later (m^3 ha^{-1})	26.7	33.9
	As a percentage of the control (%)	100.0	127.0
6	Cumulative volume production (m^3 ha^{-1})	146.7	151.6
	As a percentage of the control (%)	100.0	103.3
7	Mean annual increment of the cumulative volume production (m^3 ha^{-1} yr^{-1})	7.0	7.4
	As a percentage of the control (%)	100.0	105.7
8	Stem-quality index (SQI) at the age of 17 years	2.14	1.90
	In ratio of the control	1.00	0.89

Table 3: **Yield and stem-quality data of 14–23 years (subcompartment Mélykút 33 A) Yield Class: IV (Rédei, 1984)**

	Factors	**Plots**	
		1. (control)	**2.**
1	Initial growing stock before the thinning (m^3 ha^{-1})	110.0	116.2
	As a percentage of the control (%)	100.0	105.6
2	Volume removed during the thinning (m^3 ha^{-1})	0.0	27.7
3	Growing stock after thinning (m^3 ha^{-1})	110.0	88.5
4	9 years later:		
	Growing stock (m^3 ha^{-1})	148.3	140.3
	Growing stock as a percentage of the control (%)	100.0	94.6
	Mortality (m^3 ha^{-1})	17.5	4.2
	Wood stock (growing stock + mortality) (m^3 ha^{-1})	165.8	144.5
	As a percentage of the control (%)	100.0	87.2
5	Change in growing stock 9 years later (m^3 ha^{-1})	38.3	51.8
	As a percentage of the control (%)	100.0	135.2
6	Cumulative volume production (m^3 ha^{-1})	165.8	172.2
	As a percentage of the control (%)	100.0	103.9
7	Mean annual increment of the cumulative volume production (m^3 ha^{-1} yr^{-1})	6.2	6.2
	As a percentage of the control (%)	100.0	100.0
8	Stem-quality index (SQI) at the age of 23 years	2.41	1.93
	In ratio of the control	1.00	0.80

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The difference in percentage of the initial growing stocks at the age of 14 years and the cumulative growing stocks of at age of 23 years to the control plot, in subcompartment Mélykút 33 A, is 2.3%. The stem quality index in ratio of the control is 0.80 (20%) (*Table 3*).

In subcompartment Paks 92 A, the differences in percentage of the initial growing stocks at the age of 21 years and the cumulative growing stocks of at age of 31 years to the control plot are -8.4% and -3.2%. The stem quality index in ratio of the control is 0.88 (12%) in plot 2. In plot 3 it is 0.79 (21%) (*Table 4*).

Table 4: **Yield and stem-quality data of 21–31 years (subcompartment Paks 92 A) Yield Class: III (Rédei, 1984)**

	Factors	Plots		
		1. (control)	2.	3.
1	Initial growing stock before the thinning (m^3 ha^{-1})	198.9	209.7	210.2
	As a percentage of the control (%)	100.0	105.4	105.7
2	Volume removed during the thinning (m^3 ha^{-1})	0.0	35.3	68.1
3	Growing stock after thinning (m^3 ha^{-1})	198.9	174.4	142.1
4	10 years later:			
	Growing stock (m^3 ha^{-1})	233.0	218.8	191.7
	Growing stock as a percentage of the control (%)	100.0	93.9	82.3
	Mortality (m^3 ha^{-1})	39.1	9.8	19.1
	Wood stock (growing stock + mortality) (m^3 ha^{-1})	272.1	228.6	210.8
	As a percentage of the control (%)	100.0	84.0	77.5
5	Change in growing stock 10 years later (m^3 ha^{-1})	34.1	44.4	49.6
	As a percentage of the control (%)	100.0	130.2	145.5
6	Cumulative volume production (m^3 ha^{-1})	272.1	263.9	278.9
	As a percentage of the control (%)	100.0	97.0	102.5
7	Mean annual increment of the cumulative volume production (m^3 ha^{-1} yr^{-1})	7.3	5.4	6.9
	As a percentage of the control (%)	100.0	74.0	94.5
8	Stem-quality index (SQI) at the age of 23 years	2.21	1.95	1.75
	In ratio of the control	1.00	0.88	0.79

The data in all three tables clearly demonstrate the hypothesis that for the vast majority of tree species, including black locust, thinning does not significantly increase the total yield of stands. There is also a consensus among experts in the field of arboriculture that the total yield of all trees in the same or very similar sites can be considered constant.

The evaluation of the presented black locust silvicultural experimental series also proves that different rate of thinning does not cause major differences in total yield. In other words, the overall performance of the site in terms of volume is independent of the system of thinning. At the same time, timely and planned thinning can increase the value of the stand by 20%.

DISCUSSION AND CONCLUSIONS

The primary objective of thinning is to control the stand density by reducing competition among trees and concentrating growth in a smaller number of trees. Generally, in forest practice, the effect of thinning on the size of the mean tree or future crop trees is of more importance than its effect on stand growth and yield, particularly for species like black locust, the wood value of which varies greatly with stem size.

A study on the diameter and volume of increment of black locust stand (age 10–27 years, yield class II) have shown that in comparison to the periodic annual increment (PAI) of the breast height diameter of tree in height class I, trees in height class II have reached 83.3% while in class III only 43.9. The same relations for volume were found 59.0% and 24.5% respectively. The mean values of the whole stand were close to those of height class II. According to the distribution of the PAI of volume between 10 and 27 years of age, 50% of the values were between 2.00 and 13.88 dm^3, 73% were between 2.00 and 19.82 dm^3, and 96% were between 2.00 and 37.64 dm^3. The range of 13.88–19.82 dm^3 had the highest occurrence (24.5%) (Rédei & Ábri, 2021).

Thinning can temporary raise the growth above the level of neighbouring unthinned plots. But this benefit of thinning should not be expected to last over the entire life time of the stand.

The periodically re-measured long-term experiments provide substantial information on both the short-term and long-term effects of density reductions on stand growth and yield. In the short term, the volume growth can be accelerated, presumably by stimulating the nutrient cycling or by increasing the light supply after opening up. In the long term, this stand density reduction and short-term growth acceleration can have the opposite effect on tree and stand growth. The absence of the removed and a faster aging of the remaining ones may result in a decrease of the stand growth below the level the neighboring unthinned plots (Rédei & Melby, 2009; Pretzsch, 2020).

According to our experiments, thinning did not increase effectively the amount of cumulative volume

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production and it had no actual effect on the cumulative production volume. As percentage of the control it changed between +0.6 and -8.4%. The different thinning intensities did not increase either the stumpage value or the harvested timber volume, as compared to the unthinned control. The thinning timber inventories, expressed as a percentage of the control, were always less than the final stumpage and harvested wood volume, whenever the stands were thinned. Similarly, the growth stimulating effects of thinning could not be detected even when the number of thinning was increased. Based on the results of our research to date, in a 30 to 35 years rotation the probability that the total harvested volume of a thinned stand would greatly (>5%) exceed that of the control is very small. Nevertheless, they could improve the stand quality. The indicator of the related stand quality exceeded that of the control by 10–21%. So, based on our results, we can conclude, that thinning could improve the stand quality and increase the stand value. Further research is needed to establish more precisely the correlation between the gains in value that can be achieved with the potential reduction in total yield during thinning.

REFERENCES

Assmann, E. (1961): Waldertragskunde. BLV Verlagsgesellschaft, München-Bonn-Wien.

Béky, A. (1983): A nevelővágások hatása a faegyedek vastagsági növekedésére kocsánytalan tölgyesekben. (The effect of tending operations on the diameter increment in *Quercus petraea* stands). Erdészeti Kutatások, Volume 75, pp. 173–177. (in Hungarian).

Béky, A.–Solymos, R. (1991): Egy kocsánytalan tölgy erdőnevelési kísérleti sor tanulságai. (Conclusions from a thinning experiment in *Quercus petraea* stand). Erdészeti Kutatások, Volume 82, pp. 227–235. (in Hungarian).

Halupa, L. (1987): A nyárnevelési kísérletek újabb eredményei. Erdészeti Kutatások, Volume 79, pp. 79–84. (Further results obtained from poplar tending operations experiments.) (in Hungarian).

Hungarian Central Statistical Office (HCSO): https://www.ksh.hu/stadat_files/kor/hu/kor0004.html (in Hungarian), (accessed on 04.01.2022)

Hungarian Meteorological Service (HMS): https://odp.met.hu/climate/homogenized_data/station_data_series/from_1901/, (accessed on 04.01.2022)

Járó, Z.–Lengyel, Gy. (1988): Stand establishment. In: Keresztesi B. (ed.): The Black Locust. Budapest, Akadémiai Kiadó, pp. 87–115.

Lee, H.–Lim, H.–Kang, J.W. (2019): Growth performance of exotic trees in Korea. Journal of forest and environmental science, Volume 35(2), pp. 115–120.

Majer, A. (1969): A gyérítések racionalizálása. (Rationalisation of thinnings.) Az Erdő, Volume XVIII. 9, pp. 385–389. (in Hungarian).

Nicolescu, V.N.–Hernea, C.–Bakti, B.–Keserű, Zs.–Antal, B.–Rédei, K. (2018): Black locust (*Robinia pseudoacacia* L.) as a multi-purpose tree species in Hungary and Romania: a review. Journal of Forestry Research, Volume 29(6), pp. 1449–1463. https://doi.org/10.1007/s11676-018-0626-5 (accessed on 04.01.2022)

Nicolescu, V.N.–Rédei, K.–Mason, W.L.–Vor, T.–Pöetzelsberger, E.–Bastien, J.C.–Brus, R.–Benčať, T.–Đodan, M.–Cvjetkovic, B.–Andrašev, S.–La Porta, N.–Lavnyy, V.–Mandžukovski, D.–Petkova, K.–Roženbergar, D.–Wąsik, R.–Mohren, G.M.J.–Monteverdi, M.C.–MuschShow, B.–Klisz, M.–Perić, S.–Keça, L.–Bartlett, D.–Hernea, C.–Pástor, M. (2020): Ecology, growth and management of black locust (*Robinia pseudoacacia* L.), a non-native species integrated into European forests. Journal of Forestry Research, 31(4), 1081–1101. https://doi.org/10.1007/s11676-020-01116-8 (accessed on 04.01.2022)

Pardé, J. (1965): Intensité des éclaircies et production ligneuse. Revue Forestiéra Francaise, pp. 936–945. (in French)

Persson, O. (1986): Thinning in Norway spruce stands in Sweden. Swedish University of Agricultural Sciences. Report 18, pp. 3–24.

Pretzsch, H. (2009): Forest Dynamics, Growth and Yield. Springer, Berlin.

Pretzsch, H. (2020): Density and growth of forest stands revisited. Effect of the temporal scale of observation, site quality, and thinning. Forest Ecology and Management, 460, 117879. https://doi.org/10.1016/j.foreco.2020.117879

Rédei, K. (1984): Akácosok fatermése. (Yield of black locust stands). FRI Report. (in Hungarian).

Rédei, K.–Meilby, H. (2009): Effect of Thinning on the Diameter Increment in Black Locust (*Robinia pseudoacacia* L.) Stands. Acta Silvatica et Lignaria Hungarica Volume 5, pp. 63–74.

Rédei, K.–Ábri, T. (2021): Increment analysis in black locust (*Robinia pseudoacacia* L.) stand–A case study. International Journal of Horticultural Science, Volume 27, pp. 106–109.

Rédei, K.–Csiha, I.–Keserű, Zs. (2011): Black locust (*Robinia pseudoacacia* L.) short-rotation crops under marginal site conditions. Acta Silvatica et Lignaria Hungarica, Volume 7, pp. 125–132.

Rédei, K.–Keserű, Zs.–Csiha, I.–Rásó, J.–Bakti, B.–Takács, M., (2018): Improvement of black locust (*Robinia pseudoacacia* L.) growing under marginal site conditions in Hungary: Case studies. Acta Agraria Debreceniensis, Volume 74, pp. 129–133. https://doi.org/10.34101/actaagrar/74/1677 (accessed on 04.01.2022)

Rédei, K.–Keserű, Zs.–Rásó, J.–Gál, J. (2019): The Effects of Thinnings on Yield and Value Changes in Black Locust (*Robinia pseudoacacia* L.) Stands: A case study. Acta Silvatica et Lignaria Hungarica Volume 15(1), pp. 47–52. https://doi.org/10.2478/aslh-2019-0004 (accessed on 04.01.2022)

Sopp, L.–Kolozs, L. (2013): Fatömegszámítási táblázatok (Volume tables). 4th Ed. Budapest, National Food Chain Safety Office, State Forest Service: pp. 280. (in Hungarian)

Vítková, M.–Müllerová, J.–Sádlo, J.–Pergl, J.–Pyšek, P. (2017): Black locust (Robinia pseudoacacia) beloved and despised: A story of an invasive tree in Central Europe. Forest Ecology and Management, Volume 384, pp. 287–302. https://doi.org/10.1016/j.foreco.2016.10.057 (accessed on 04.01.2022)

DOI: 10.34101/ACTAAGRAR/1/10638

Wiedemann, E. (1943): Der Vergleich der Massenleistung des Mischbestandes mit der Reinbestand. Allgemeine Forst- und Jagd- Zeitung Volume 119, pp. 123–132.
Wojda, T.–Klisz, M.–Jastrzebowski, S.–Mionskowski, M.–Szyp-Borowska, I.–Szczygiel, K. (2015): The geographical distribution of the black locust (*Robinia pseudoacacia* L.) in Poland and its role on non-forest land. Papers on Global Change, pp. 22. https://doi.org/10.1515/igbp-2015-0018 (accessed on 04.01.2022)