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Yield table for selected black locust (*Robinia pseudoacacia* L.) cultivars

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SUMMARY

*In Hungary, the black locust (*Robinia pseudoacacia *L.) can be considered as the most important fast-growing, stand-forming introduced tree species. Due to its positive growing technological characteristics as well as wood utilization possibilities, at the present, black locust is the most widely planted tree species in Hungary, covering 25% of the country's total forest area. One of the important tasks ahead of Hungarian black locust growers is to improve the quality of black locust stands with introducing selected cultivars. For the estimation of the growth rate and yield a numerical yield table has been constructed on the basis of surveys of the experimental plots established in pure, managed 'Nyirségi', 'Üllői' and 'Jászkiséri' black locust cultivars' plantations which can be suitable for sawlogs production. In the course of 56 stand surveys the key stand characteristics were measured, and then, were reconsidered the average height, diameter (DBH), volume, basal area and stem number given separately for the main (remaining), secondary (removal) and total stands per hectare. The programmable editing procedure allows to extention and formal change of information content of the yield table according to different demands.*

Keywords: *Robinia pseudoacacia L.; cultivars; growth; yield*

INTRODUCTION

Nowadays, black locust (*Robinia pseudoacacia* L.), the tree species native to North-America, is naturalized and widely planted throughout the world from temperate to subtropical areas (Nicolescu et al., 2018). It was the first North-American tree species imported to Europe at the beginning of the 17th century (Demené and Merzeau, 2007).

Since (1710s) its introduction into Hungary black locust has been closely associated with agriculture, and its wood could be utilized for many agricultural and domestic purposes. Recently, black locust has played a role of great importance in the Hungarian forest management, covering approximately 25% of the forested area. Almost half of the approximately 1.6 million m^3 of black locust harvested annually is of industrial wood quality, the rest is only suitable as firewood (Rédei et al., 2017; Nicolescu et al., 2018)

In Hungary, after World War II, significance of black locust changed, because large-scale farms had less demand for wood and the timber industry was not willing to buy black locust wood. It was necessary to improve the quality of final products of black locust. Selection breeding was a good option for it. The main target of the selection breeding was to improve the quality of stem, to increase the output of industrial wood. Besides the varieties recommended for timber production as their primary function, there are others that have been improved for honey production or energy production. New cultivars had to be produced by improvement techniques introducing them into the practical forestry use (Keresztesi, 1988; Rédei et al., 2011; 2017).

Mono- and multiclonal cultivars were developed and a seed orchard was established from the selections. Some cultivars are suitable for both forestry and honey production. Such double-use cultivars are '*Zalai*', '*Kiskunsági*', '*Császártöltési*', '*Egylevelű*', and '*Váti-46*' (Keresztesi, 1988).

Black locust cultivars that can be suitable for sawlogs production are of decisive importance for primary wood production. Based on this, we selected '*Nyírség*', '*Üllői*' and '*Jászkiséri*' cultivars for systematic yield studies. Based on the evaluations of long-term yield experimental plots (Bujtás, 1984; Keresztesi, 1988; Rédei, 1984, 1994, 2006, 2008, 2013; Hegede, 2018; Rédei et al., 2020) it has also become possible to compile their yield table, which is the first to be published in English in this publication.

The Hungarian primary wood production practice uses yield tables with 6 yield classes (Sopp and Kolozs, 2000). However, the cultivation technological objectives and economic aspects of plantation forestry are mainly take into account only the stands of I–IV. yield classes. Consequently, our table presented in this paper contains only 5 yield classes.

MATERIALS AND METHODS

The yield table was constructed from data gathered on 29 forest subcompartments (56 sampling plots), located in different parts of Hungary (*Figure 1*). The age of the examined stands varied between 5 and 35 years. Their sites are typically forest-steppe and Turkey oak-sessile oak forest climate, free-draining site, humic sand and brown forest soil. The initial stem number of afforestations varied between 3000–5000 stems/ha. In stands up to the age of 10 years, one, and in the case of stands over the age of 18–20 years, two stem number reductions were carried out.

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Figure 1. **Location of the forest subcompartments in Hungary**

The sampling plots were square shaped, their areas approximately 1000 m^2, the boundaries were marked. In the course of the stand surveys the key stand characteristics were measured, and then, on the basis of data collected were calculated the average height, diameter (DBH), volume, basal area and stem number given separately for the main (remaining), secondary (removal) and total stands per hectare (Husch et al., 1982; Avery and Buckhart, 1994; Röhle, 1999; Laar and Akca, 2007). We classified each tree according to their functional role as follows, class 1: future crop-tree, class 2: subdominant trees, and class 3: trees to extract.

Stem volume was estimated by the following volume function (Sopp and Kolozs, 2000),

$$v = 10^{-8} d^2 h^1 (h/[h-1.3])^2 \left[-0.6326\, d\, h + 20.23\, d + 0.0\, h + 3034\right] \qquad \text{(Eq.1)}$$

where v is stem volume (m^3), d is diameter at breast height (cm), and h is tree height (m).

The yield table was constructed using the following formulas and coefficients,

1. Age of stand (A),
2. H_{bam} = average height of main crop (remaining stand) (height of dominant and codominant trees) in m (base age: 20 year, where $H_{bam}\% = 100$), where

$$H_{bam} = 19.4669 - 57.08546 * [\log(A)] + 73.57742 * [\log(A)]^2 - 22.80025 * [\log(A)]^3 + 28.08599 * [\log(A)]^4 \qquad \text{(Eq.2)}$$

3. D_{bam} = average DBH of main crop (remaining stand) in cm, where

$$D_{bam} = (0.69880+0.00770*A) * H_{bam} \qquad \text{(Eq.3)}$$

4. V_{bm} = volume of main crop (remaining stand) in $m^3 \cdot ha^{-1}$, where

$$V_{bm} = BA_m * H * F \qquad \text{(Eq.4)}$$

and H * F = form-height quotient

$$H * F = 1.60430 + 0.42390 * H_{bam} \qquad \text{(Eq.5)}$$

5. BA_m = basal area of main crop (remaining stand) in $m^2 \cdot ha^{-1}$,

$$BA_m = \frac{D_{bam}^2 * \pi}{4 * 10\,000} * N_m \qquad \text{(Eq.6)}$$

6. N_m = stem number of main crop (remaining stand) in ha^{-1},

$$\log N_m = 4.26810 - 1.11650 * \log D_{bam} \qquad \text{(Eq.7)}$$

7. H_{bar} = average height of removal stand in m,

$$H_{bar} = -0.54450 + 0.92508 * H_{bam} \qquad \text{(Eq.8)}$$

8. D_{bar} = average DBH of removal stand in cm,

$$D_{bar} = (85.11323 - 0.37705 * A) * D_{bam} \qquad \text{(Eq.9)}$$

9. V_{br} = volume of removal stand in $m^3 \cdot ha^{-1}$,

$$V_{br} = BA_r * H * F \qquad \text{(Eq.10)}$$

10. BA_r = basal area of removal stand stand in $m^2 \cdot ha^{-1}$,

$$BA_r = \frac{D_r^2 * \pi}{4 * 10\,000} * N_r \qquad \text{(Eq.11)}$$

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11. N_r = stem number of removal stand calculated from reduction of stem number of main crop in five year intervals in ha^{-1}
12. H_t = average height of total stand in m,

$$H_t = -0.09666 + 0.98613 * H_{bam} \quad \text{(Eq.12)}$$

13. D_t = average DBH of total stand in cm,

$$D_t = \sqrt{\frac{BA_t * 10\,000}{N_t * \pi}} * 2 \quad \text{(Eq.13)}$$

14. V_{bt} = volume of total stand in m^3 ha^{-1},

$$V_{bt} = V_{bm} + V_{br} \quad \text{(Eq. 14)}$$

15. BA_t = basal area of total stand in $m^2 \cdot ha^{-1}$,

$$BA_t = BA_m + BA_r \quad \text{(Eq. 15)}$$

16. N_t = stem number of total stand in ha^{-1},

$$N_t = N_m + N_r \quad \text{(Eq. 16)}$$

17. Cumulative volume of intermediate cuttings = total volume of removal stands in $m^3 \cdot ha^{-1}$
18. Share of intermediate cuttings = Total intermediate cutting/V_{bt} * 100
19. V_{bt} = Total yield
20. Mean annual increment (MAI) of total yield = V_{bt}/A
21. Current increment of total yield = 1 year increment of total yield

RESULTS AND DISCUSSION

Yield class is called the intensity of height growth of a given stand compared to the all same tree species of the country, from best to worst from I to V marked by Roman numerals (stands are classified into the yield class I–V). The normative yield table prepared for the above mentioned black locust selected cultivars contains the most important stand structure and yield factors of the main, removal and total stand (height, diameter at breast height, basal area, volume, age and number of stems), divided into five yield classes with the same relative height growth.

When using the yield table for determining the actual volume per ha (V_{act}) of a stand, a basal area ratio is to be recommended:

$$V_{act} = V_{tab} \times BA_{act}\, BA_{tab}^{-1}, \text{ where:} \quad \text{(Eq. 17)}$$

V_{tab} = volume of the stand by yield table according to the age and yield class,
BA_{act} = actual basal area of the stand per ha,
BA_{tab} = basal area by yield table according to the age and yield class of the stand.

The standard deviation of the average height of the stands from cultivars is shown in *Figure 2*, and the numerical yield table with five yield classes is shown in *Table 1*.

Figure 2. **Mean height values of examined black locust cultivars in the function (based on data of full inventory)**

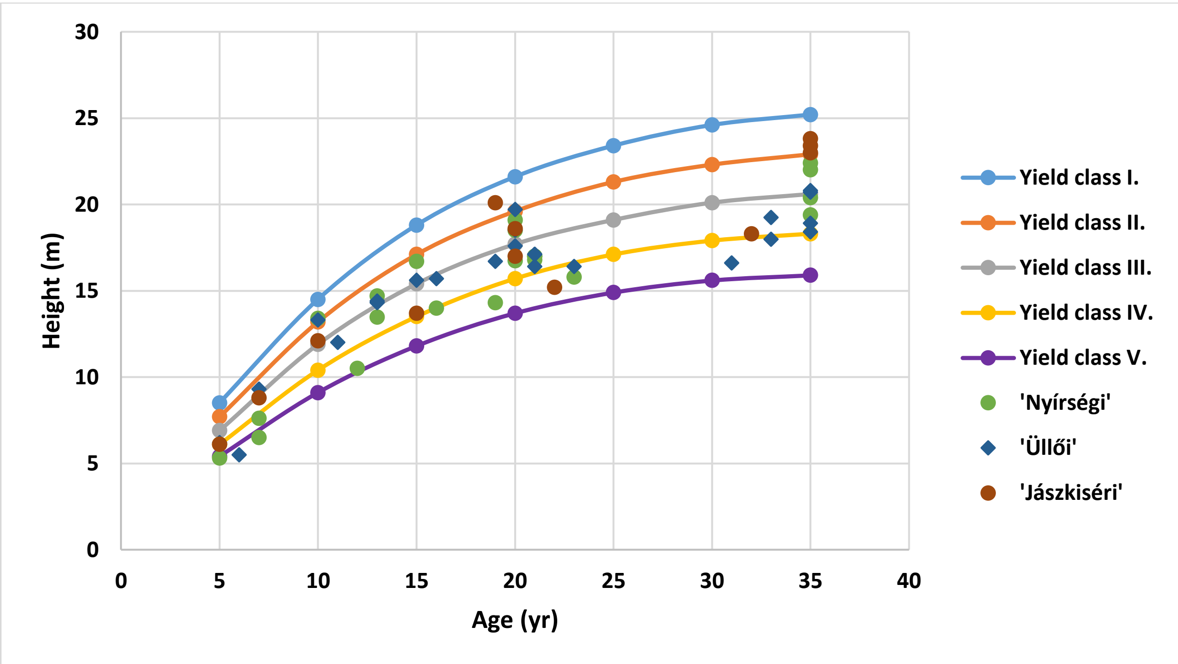

Figure 3.a to *3.e* show the height, DBH, and volume indices for main stand as well as the total volume and the mean annual increment of total volume indices in function of age and yield class.

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Table 1. **Yield table for selected black locust cultivars utilizable for saw log production**

	Main stand					**Removal stand**					**Total stand**							**Total yield**		
Age of stand	**Average**		**Volume**	**Basal area**	**Stem number**	**Average**		**Volume**	**Basal area**	**Stem number**	**Average**		**Volume**	**Basal area**	**Stem number**	**Cumulative volume of intermediate cuttings**	**Share of intermediate cuttings**	**Volume**	**Mean annual increment**	**Current increment**
	H	**DBH**				**H**	**DBH**				**H**	**DBH**								
yr	**m**	**cm**	**m^3ha^{-1}**	**m^2ha^{-1}**	**ha^{-1}**	**m**	**cm**	**m^3ha^{-1}**	**m^2ha^{-1}**	**ha^{-1}**	**m**	**cm**	**m^3ha^{-1}**	**m^2ha^{-1}**	**ha^{-1}**	**m^3ha^{-1}**	**%**	**m^3ha^{-1}**	**$m^3ha^{-1}yr^{-1}$**	**$m^3ha^{-1}yr^{-1}$**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**
Yield class I.																				
5	8.7	6.4	40	7.5	2327	8.4	5.3	30	5.9	2673	8.5	5.9	70	13.4	5000	30	42.9	70	14	–
10	14.8	11.5	99	12.6	1214	14.3	9.3	58	7.6	1113	14.5	10.5	157	20.2	2327	88	47.1	187	18.7	23.4
15	19.2	15.6	160	16.5	863	18.3	12.4	39	4.2	351	18.8	14.7	199	20.7	1214	127	44.3	287	19.1	20
20	22	18.7	212	19.4	703	20.9	14.5	27	2.6	160	21.6	18	239	22	863	154	42.1	366	18.3	15.8
25	23.8	21.2	253	21.6	612	22.6	16.1	21	1.9	91	23.4	20.6	274	23.5	703	175	40.9	428	17.1	12.4
30	25	23.2	286	23.4	554	23.7	17.1	15	1.3	58	24.6	22.7	301	24.7	612	190	39.9	476	15.9	9.6
35	25.7	24.8	311	24.9	513	24.3	17.9	12	1	41	25.2	24.4	323	25.9	554	202	39.4	513	14.7	7.4
Yield class II.																				
5	7.9	5.8	34	6.9	2588	7.6	4.8	16	4.4	2412	7.7	5.4	50	11.3	5000	16	32	50	10	–
10	13.5	10.4	84	11.5	1350	12.9	8.5	50	7	1238	13.2	9.6	134	18.6	2588	66	44	150	15	20
15	17.4	14.2	136	15.1	960	16.7	11.3	34	3.9	390	17.1	13.4	170	19	1350	100	42.4	236	15.7	17.2
20	20	17	180	17.8	782	19	13.2	23	2.4	178	19.6	16.4	203	20.2	960	123	40.6	303	15.2	13.4
25	21.7	19.3	215	19.9	681	20.6	14.6	18	1.7	101	21.3	18.8	233	21.6	782	141	39.6	356	14.2	10.6
30	22.7	21.1	242	21.5	616	21.6	15.6	13	1.2	65	22.3	20.6	255	22.7	681	154	38.9	396	13.2	8
35	23.4	22.6	263	22.9	571	22.2	16.2	10	0.9	45	22.9	22.2	273	23.8	616	164	38.4	427	12.2	6.2
Yield class III.																				
5	7.1	5.2	29	6.2	2911	6.8	4.3	13	3	2089	6.9	4.8	42	9.2	5000	13	31	42	8.4	–
10	12.1	9.4	71	10.5	1518	11.4	7.6	41	6.3	1393	11.9	8.6	112	16.8	2911	54	43.2	125	12.5	16.6
15	15.7	12.8	114	13.9	1080	15	10.1	28	3.5	438	15.4	12.1	142	17.4	1518	82	41.8	196	13.1	14.2
20	18	15.3	150	16.2	880	17.2	11.9	20	2.2	200	17.7	14.7	170	18.4	1080	102	40.5	252	12.6	11.2
25	19.5	17.4	179	18.2	766	18.6	13.1	14	1.5	114	19.1	16.9	193	19.7	880	116	39.3	295	11.8	8.6
30	20.5	19	202	19.6	693	19.5	14	11	1.1	73	20.1	18.5	213	20.7	766	127	38.6	329	11	6.8
35	21	20.3	219	20.8	642	20	14.6	9	0.9	51	20.6	20	228	21.7	693	136	38.3	355	10.1	5.2
Yield class IV.																				
5	6.3	4.6	24	5.6	3374	5.9	3.8	7	1.8	1626	6.1	4.3	31	7.4	5000	7	22.6	31	6.2	–
10	10.6	8.2	57	9.3	1769	9.9	6.7	22	5.7	1605	10.4	7.5	90	15	3374	40	41.2	97	9.7	13.2
15	13.8	11.2	92	12.3	1249	12.8	8.9	22	3.2	520	13.5	10.6	114	15.5	1769	62	40.3	154	10.3	11.4
20	16	13.6	122	14.6	1006	15.1	10.5	17	2.1	243	15.7	13	139	16.7	1249	79	39.3	201	10.1	9.4
25	17.4	15.5	147	16.4	869	16.5	11.7	13	1.5	137	17.1	15.1	160	17.9	1006	92	38.5	239	9.6	7.6
30	18.3	17	167	17.8	784	17.4	12.5	9	1	85	17.9	16.6	176	18.8	869	101	37.7	268	8.9	5.8
35	18.7	18.1	179	18.8	731	17.8	13	6	0.7	53	18.3	17.8	185	19.5	784	107	37.4	286	8.2	3.6
Yield class V.																				
5	5.6	4.1	20	5.1	3834	5.1	3.4	4	1.1	1166	5.4	4	24	6.2	5000	4	16.7	24	4.8	–
10	9.3	7.2	46	8.3	2046	8.5	5.9	26	4.9	1788	9.1	6.4	72	13.2	3824	30	39.5	76	7.6	10.4
15	12.1	9.9	74	11	1434	11.1	7.9	19	3	612	11.8	9.1	93	14	2046	49	39.8	123	8.2	9.4
20	14	11.9	98	13	1168	13	9.2	13	1.8	266	13.7	11.5	111	14.8	1434	62	38.8	160	8	7.4
25	15.2	13.5	117	14.5	1014	14.2	10.2	10	1.3	154	14.9	13.1	127	15.8	1168	72	38.1	189	7.6	5.8
30	15.9	14.8	131	15.7	915	14.9	10.9	7	0.9	99	15.6	14.4	138	16.5	1014	79	37.6	210	7	4.2
35	16.2	15.7	141	16.6	857	15.2	11.3	5	0.6	58	15.9	15.5	146	17.2	915	84	37.3	225	6.4	3

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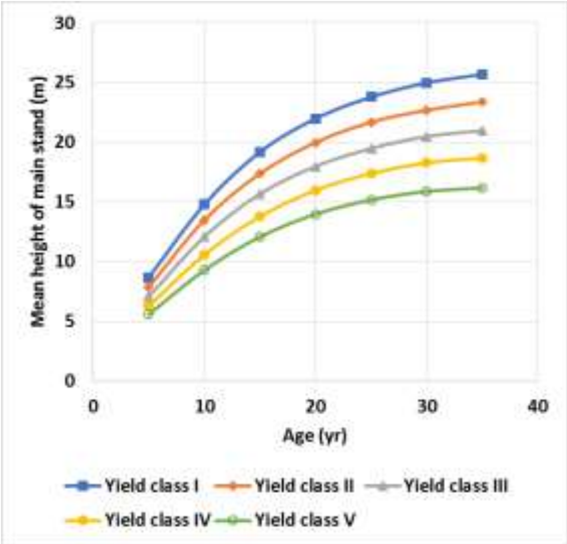
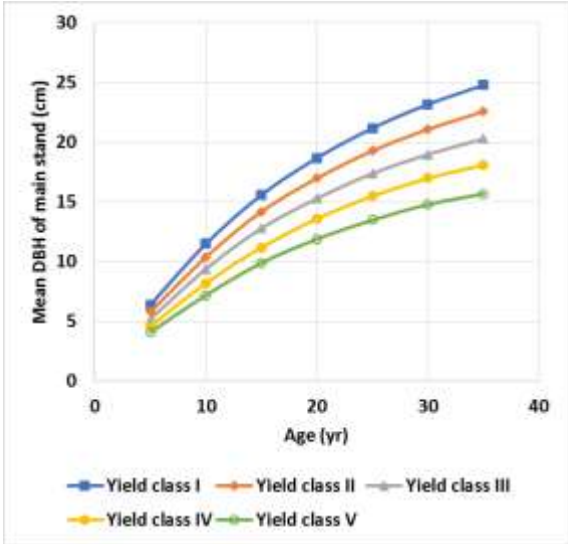
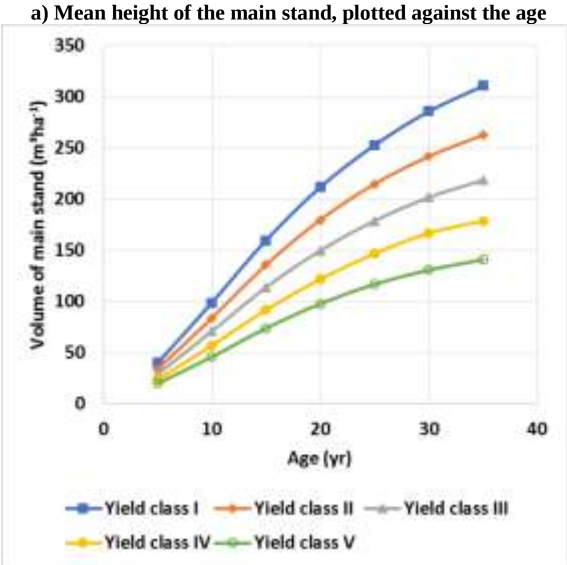
Figure 3 a – e. **Data of stand structure and yield of black locust cultivars' stands as a function of the age**



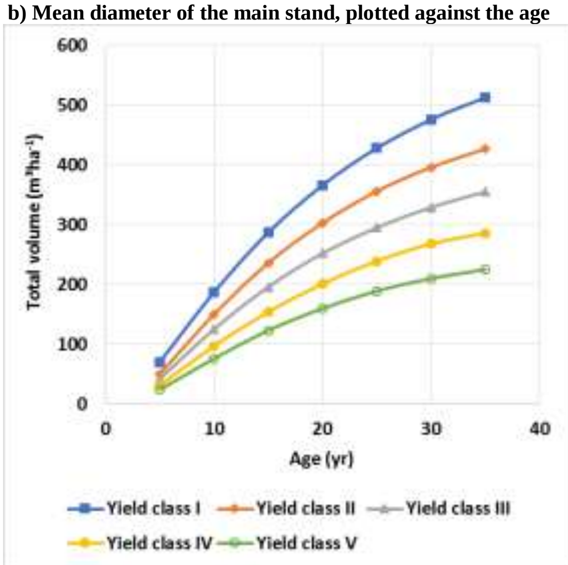
a) Mean height of the main stand, plotted against the age



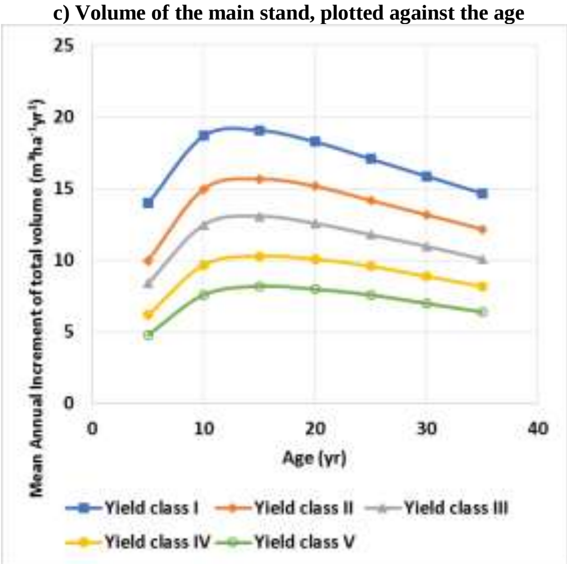
b) Mean diameter of the main stand, plotted against the age



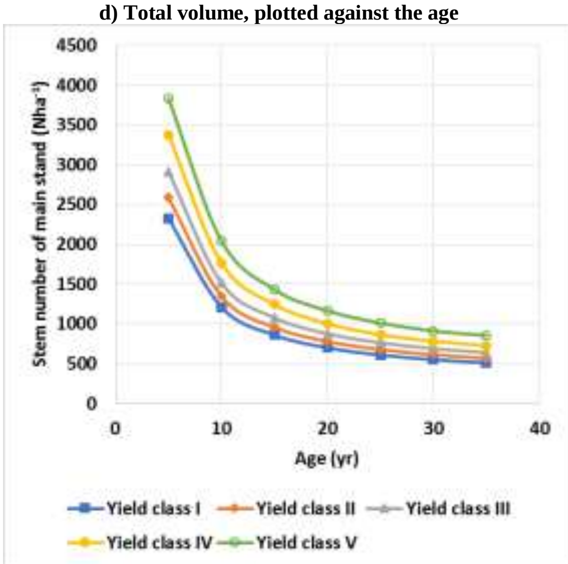
c) Volume of the main stand, plotted against the age



d) Total volume, plotted against the age



e) Mean annual increment of the total volume, plotted against the age



f) Stem number of the main stand, plotted against the age

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CONCLUSIONS

The yield table demonstrated in this paper supposedly applies to average rather than full stocking. In other words, an empirical yield table applies only to the average density levels found on the sample plots used. In the last decades, growth models focused on stand level data have gradually been replaced by stand growth models that predict stem number frequencies and individual-tree growth models. In spite of this fact yield tables will remain very useful tools for forest management and forest inventory in the future.

The published yield table can be widely utilized in the following fields of the Hungarian black locust cultivars' management,

- appraisal of statistical nature of the black locust cultivars' plantations and stands,
- harvest scheduling of black locust cultivars' stands, implementing the volume estimations,
- elaborating or further developing silvicultural (tending operation) models for black locust cultivars' stands.

Due to the characteristics of the experiments, the above presented results in connection with the research on the yield, stand structure and tending operations of improved black locust cultivars are preliminary investigations. Thus, the reported yield model and tending guidelines need further improving and care should be taken in applying them.

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