

**Theses of PhD dissertation**

**EVALUATION OF ECOLOGY AND GROWING  
TECHNOLOGY OF SELECTED BLACK LOCUST  
CULTIVARS**

**Tamás Ábri**

*Supervisor:*

**Dr József Csajbók  
Professor**

*Co-supervisor:*

**Dr Károly Rédei  
Professor**



**UNIVERSITY OF DEBRECEN**

**Kerpely Kálmán Doctoral School**

**Debrecen  
2024**



## INTRODUCTION AND OBJECTIVES OF THE DOCTORAL RESEARCH

Black locust (*Robinia pseudoacacia* L.) is one of the most widespread exotic tree species in the world. Due to its high site plasticity, its versatile uses (wood industry, agriculture, beekeeping, environmental development) and its high quality, durable wood, it is a dominant tree species in Hungarian forestry (it occurs in a quarter of the nearly 2 million ha of forest area in Hungary). The ecological challenges facing forests and tree plantations, the negative effects of global and local climate change, and the various weather events (uneven rainfall, drought, frequent heat waves, etc.) have become increasingly frequent in recent years. A good example is the extremely dry year 2022. Under these conditions, relatively drought-tolerant tree species such as black locust will play an important role in new afforestation. Consequently, the growing and improvement of black locust is of increasing importance. Particular attention should be paid to selected black locust cultivars, candidate clones, which can be used to add value to marginal sites by adding value to plantations at a given age. The use of cultivars of high genetic value at commercial level can be strongly influenced by economical aspects in addition to direct technical considerations. Consequently, reducing the high costs of production of propagating material and the high costs of growing and maintaining trees (e.g. pruning) is a key issue.

Research work on the development of black locust cultivation technology, the production of selected black locust cultivars with good stem quality and yield and stress tolerance, started in the 1960s. Since then, there have been numerous publications and international interest (China, South Korea, Czech Republic, Poland, Romania, Bulgaria). So far, no comprehensive study has been carried out on the results of experiments on the cultivation of these black locust cultivars and the later black locust clones, but it would be beneficial for forest and agricultural producers to have more information on the basis of the above.

During my research, the stand structure factors (height, diameter at breast height, basal area, growing space, yield, crown structure) of experimental plantations of the cultivars 'Jászkiséri', 'Nyírségi' and 'Üllői', and the growth of the cultivar candidates 'Homoki', 'Bácska', 'Vacsi' and 'Oszlopos' as well as of newly produced black locust clones ('Laposi', 'Napkori', 'Püspökladányi' and 'Farkasszigeti'). In the latter case, in addition to height and thickness growth measurements with the methodology used in forestry practice, and plant health surveys, I also carried out UAV-based measurements of new black locust clones, and *in situ* phytophysiological (carbon fixation, photosynthetic and transpiration rates, WUE) studies.

## 1. MATERIALS AND METHODS

During my research, I evaluated the results of 59 experimental plantations with selected black locust cultivars (25 'Üllői'; 21 'Nyírségi'; 13 'Jászkiséri' cultivars) of different ages (5-35 years old), partly from literature sources, partly from NÉBIH and my own inventory data. They are located near the settlements of Tét, Tahitótfalu, Gödöllő, Isaszeg, Pusztavacs, Mikebuda, Helvécia, Szentkirály and Ófehértó. The experimental sites are located in a Turkey oak-sessile oak or forest-steppe climate, according to the Hungarian forest and soil typology classification, with hydrological conditions that are largely independent of excess water (free-draining site), humic sandy soils, clayey brown forest soils and rusty brown forest soils, with variable topsoil thickness (shallow to deep) and sandy or sandy loam bedrock (based on forest inventory data). Of the above, I have dealt in detail with the experimental black locust stands established in the subcompartments Szentkirály 47H and Helvécia 22E. The Szentkirály black locust cultivars comparison experiment was set up in February 1988 by the staff of the Forest Research Institute (FRI). In the 2.72 ha subcompartment (ideal black locust habitat: humic sandy soil with medium depth of humus layer, free-draining site), 8 plots of 48 × 50 m were established, in which 20 × 25 m sample plots were delineated. For the planting, 1-year-old vegetatively propagated rooted seedlings were used and planted in 2.4 × 1.0 m planting spacing (1000 plants per plot). The clones tested were 'Üllői', 'Nyírségi', 'Császártöltési', and 'Zalai'. Stand and crown structure tests were performed only on 'Üllői' black locust. The black locust clone trial in subcompartment Helvécia 22E was established in 2006 on a poorly endowed, drying, shallow site. The planting was carried out in two stages (spring and autumn). In the experiment, state-approved cultivars ('Jászkiséri'), candidate cultivars selected for drought tolerance ('Vacsi', 'Homoki', 'Oszlopos', 'Bácska') and common black locust propagated from seed from Kecskemét were tested and compared. In the first phase of the planting (hereafter referred to as Helvécia 22E/1), vegetatively propagated clones ('Vacsi', 'Homoki', PV 201E 2/3, PV 210A 2/2, KH 56A 2/2 and Chinese-1), 'Jászkiséri' and common black locust were planted in a 2.5 × 2.0 m planting spacing. Of the above-mentioned cultivars, the candidates 'Homoki' and 'Vacsi', as well as 'Jászkiséri' and common black locust were tested. In the second phase (Helvécia 22E/2), clones ('Bácska', 'Oszlopos', PV 201E 2/6), also vegetatively propagated in autumn 2006, and state-approved black locust cultivars ('Jászkiséri', 'Kiskunsági', 'Appalachia', 'Szajki') were planted in a wider 2.5 × 3.0 m planting spacing. Of the clones and cultivars described above, I have studied 'Bácska' and 'Oszlopos' and 'Jászkiséri'.

With the new clones, an experimental plantation of black locust for industrial timber was established in 2020 in a slightly acidic, low humus sandy soil, near the village of Napkor in the

Nyírség region. On the 2.66 ha site, 1-year-old vegetatively propagated rooted seedlings were planted in 3 different planting spacings ( $2.5 \times 2.5$  m;  $3 \times 3$  m;  $4 \times 4$  m). During the establishment of the experiment, 728-728 clones of 'Laposi' (breeding mark: NK1) and 'Püspökladányi' (breeding mark: PL251), 595 clones of 'Farkasszigeti' (breeding mark: PL040) and 356 clones of 'Napkori' (breeding mark: NK2) and 478 clones of 'Üllői' black locust were planted.

During the stand inventories, I measured stem number ( $n$ ), survival rate, height ( $h$ ), diameter at breast height ( $dbh$ ), root collar diameter ( $rcd$ ), as well as crown diameter ( $CD$ ) plant health status, vegetation indices ( $NDVI$  = Normalized Difference Vegetation Index and  $GNDVI$  = Green Normalized Difference Vegetation Index) and ecophysiological parameters (photosynthetic and transpiration rates, water use efficiency, intercellular  $CO_2$  levels, stomatal conductance, light response curve, leaf temperature, and environmental factors such as air temperature and precipitation). The last four of these factors were only measured in the Napkor experiment. In addition, I also assessed the height of the 'Üllői' black locust stand in the Szentkirály experiment (I-IV height class, h.c.), as well as tending operation class (1-4 tending classes, t.c.), and the clone stem quality in the Helvécia experimental stand. These measurements were carried out using the methods recommended in the national and international literature.

I measured the  $h$  with a Vertex IV (Haglöf) ultrasonic height measurer and the  $dbh$  using a Haglöf mechanical diameter caliper (50 cm). In the Napkor experiment, height was recorded using a levelling rod and a DJI Phantom 4 UAV (photogrammetry method), while  $dbh$  and  $rcd$  were recorded using a Powerfix digital caliper (150 mm). **Physiological traits** of clones were measured with a LI-6800 (LI-COR) portable photosynthesis meter, **vegetation indices (NDVI, GNDVI)** with a handheld NDVI meter (Trimble) and a UAV-mounted multispectral camera.

For the black locust cultivars 'Jászkiséri', 'Nyírségi' and 'Üllői', I determined and calculated the mean height ( $H$ ), diameter at breast height ( $DBH$ ), mean basal area ( $ba$ ), mean tree volume ( $v$ ), basal area per hectare ( $BA$ ), volume ( $V$ ) and number of trees ( $N$ ) of the total stand based on the full inventories. The stem number per hectare ( $N$ ) was obtained by multiplying the stem number ( $n$ ) in the experimental area by 1 hectare. The volume per hectare (total yield) was calculated using the formula  $V = v \times N$ .  $BA$  was given by the product of  $N$  and the calculated area of  $DBH$ . The yield classes (I - V) were determined on the basis of a yield table developed for the selected black locust cultivars. The experimental stands were evaluated as a function of height-age, diameter-age, stem number-age, stem number-diameter, and mean tree volume (using second-order and exponential functions).

In the Szentkirály experimental area, the h, dbh and CD of the specimens ( $n = 29$  trees) of the 'Üllői' black locust (35 years old) in the sample plot were measured in January 2022 (two measurements were made before that: at 13 and 20 years of age). Furthermore, height and tending operation classification were performed. To investigate the relationships between tree stand structure factors, I used linear equations for CD and dbh data and second-degree equations for  $v$  and CD using MS Excel.

In the Helvécia experimental stand, 2 measurements were made, the first at the age of 6 and 7 years in spring 2013 (these results were published earlier). The second measurement was performed in January 2021 at age 14 and 15 years. The latter was not a complete recording: randomly selected individuals were measured ('Homoki' 34, 'Vacsi' 50, common black locust 30, 'Bácska' and 'Oszlopos' 38-38, 'Jászkiséri' 45). Measurements of h and dbh were carried out in the same way as for the Szentkirály measurement, and  $v$  was calculated as described in the literature. For the classification of the trees, however, I used a different method previously used for the stem quality analysis of this stand. For the so-called stem quality index (SQI), I used a scale from 1 to 4, where 1 = straight stem, 2 = more or less straight stem, 3 = curved stem, 4 = very curved stem. The Helvécia experiment data set was analysed using the statistical software IBM SPSS 25.0. Differences between cultivar candidates were verified by one-way analysis of variance (ANOVA), LSD test ( $p = 0.05$ ). As  $v$  is derived data, clones from the Helvécia 22E/1 subcompartment were compared to the control, and Helvécia 22E/2 individuals to the state-approved 'Jászkiséri' black locust, in percentage form.

I performed the most detailed tests in the Napkor experiment. Height measurements were taken in May and November 2021 and one time per month between May and August 2022. During the latter recording, 30 random sample trees (the number of which was reduced by the end of the period of examination due to various damages such as crown fractures, but in all cases was 15 or more, which was considered a statistically small sample) were examined. Also for this period, the clone 'Napkori' was excluded from this study and only individuals from the  $2.5 \times 2.5$  m planting spacing were measured. Tree height was also recorded by UAV on one occasion (August 2023). This required two flights: the first one in February (out of the vegetation period) and the second one in August (in leafy conditions). The first measurement also provided the opportunity to model the topography. In order to separate the clones during processing, a geodetic GNSS (Global Navigation Satellite System) receiver was used in RTK mode to determine the coordinates of the plot boundaries, and the resulting data were used to simply construct a "mesh" on the orthophoto. In order to verify the accuracy of the UAV-based imagery results, a UAV comparison of height measurement tools (ultrasonic and laser meters and

levelling rod) used in forestry practice was carried out on 30 random sample trees. The rd was measured in 2021 (May and November) and the dbh was measured in May-August 2022. Physiological parameters were measured in June 2021, 2022 and 2023. The LI-6800 instrument was used to measure assimilation (A), transpiration (Tr), stomatal conductance ( $g_{tc}$  and  $g_{sw}$ ), intercellular CO<sub>2</sub> levels, VPD<sub>leaf</sub>, and air and leaf temperatures (T<sub>air</sub> and T<sub>leaf</sub>). The difference between the latter two was measured (T<sub>air</sub> - T<sub>leaf</sub>) to test the heat stress tolerance of the clones. From the A and Tr data, I calculated the water use efficiency (WUE) of clones and 'Üllői' black locust. The light can be controlled in the sample chamber of the instrument, in my case it was 1500  $\mu\text{mol photon m}^{-2} \text{s}^{-1}$  photosynthetically active radiation, 90% red (625 nm) and 10% blue (475 nm) light. A LI-6800-01A fluorometer head was used as light source, the measured area of the leaf was 2 cm<sup>2</sup>. The concentration of CO<sub>2</sub> was also controlled (400  $\mu\text{mol mol}^{-1}$ ) in the sample chamber using an injector and CO<sub>2</sub> cartridges. Light-adapted leaves were measured six times per leaf on three plants per plot (18 measurements/clone in total). Data were recorded after the measurement results had stabilised (coefficient of variation < 1%), but after at least 120 s. In 2023, the measured data only allowed for the construction of a light response curve. The light response curves of the best height and thickness of the clones 'Püspökladányi' and 'Napkori' and of the black locust 'Üllői' were observed with decreasing photosynthetic photon flux density (PPFD) using 9 levels (2000, 1500, 1200, 900, 600, 300, 150, 50, 20  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ). In August 2023, a UAV-based measurement and multispectral orthophotography was performed to examine the NDVI values of the clones. During the flights, 330 images were taken in 5 wavebands (Blue - Blue=B, Green - Green=G, Red - Red=R, Red Edge=RE, Near-InfraRed=NIR). The images were processed in Agisoft Metashape 1.7 regarding height measurements. In addition to NDVI values, GNDVI, which is more sensitive to chlorophyll content, was calculated from the data (based on formulae provided in the literature) and exported to MS Excel for further statistical processing. From the data set, the NDVI and GNDVI of 30-30 randomly selected sample trees from plots of the 2.5 × 2.5 m planting spacing were evaluated.

The vitality of clones were also tested in September 2022. Again, 30-30 sample trees were randomly selected for this study. All three planting spacings in the experimental area were sampled.

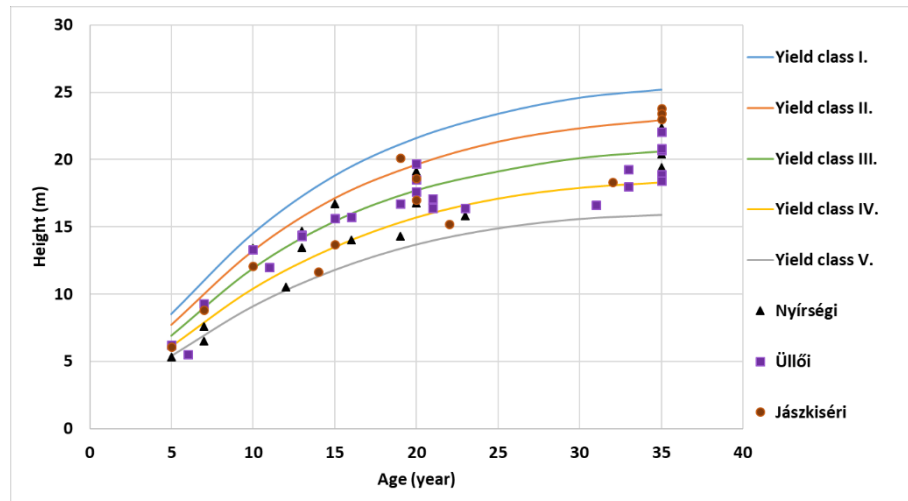
The data set of the Napkor experiment was analysed using IBM SPSS ver. 25.0. The differences between cultivar candidates were verified by one-way analysis of variance (ANOVA), LSD (for parametric dataset), Games-Howell and Kruskal-Wallis tests (for non-parametric data) ( $p = 0.05$ ). The correlation between phytophysiological parameters and height measurement

instruments was also tested by Spearman's correlation using IBM SPSS ver. 25.0. In all cases, Kolmogorov-Smirnov test and Shapiro-Wilk test ( $p < 0.05$ ) were used to test the normality of the data distribution.

## 2. RESULTS

### 3.1. EVALUATION OF THE GROWING EXPERIMENTS OF SELECTED BLACK LOCUST CULTIVARS ('JÁSZKISÉRI', 'NYÍRSÉGI', 'ÜLLŐI')

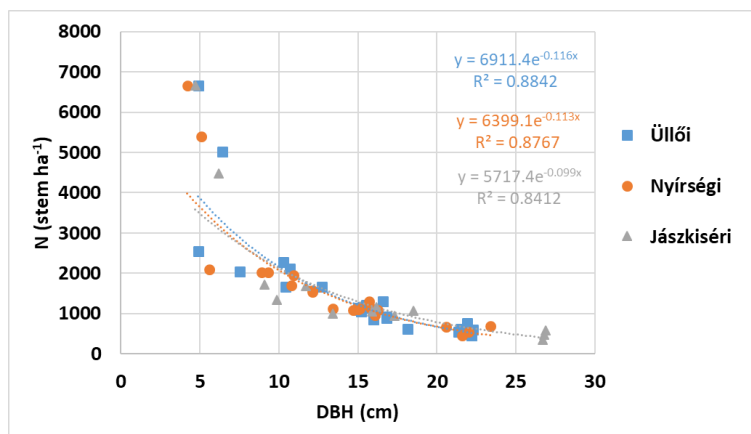
The cultivars suitable for the production of sawlogs are of decisive importance from the aspect of wood production. On this basis, I selected the black locust cultivars 'Jászkiséri', 'Nyírségi' and 'Üllői' for systematic wood production studies. Based on the data from their long term (5-35 years) experimental plots, it was possible to compare the experimental data series with the corresponding values of the timber yield table developed for the selected black locust cultivars.



**Figure 1.** Distribution of the 'Nyírségi', 'Üllői' and 'Jászkiséri' experimental stands as a function of full stand height and age on the height curves of the yield table developed for the selected black locust cultivars

It can be concluded that the vast majority of the 'Nyírségi', 'Üllői' and 'Jászkiséri' experimental black locust stands are located between yield classes II and IV, which means that they can achieve relatively high or medium yields under favourable site conditions (**Figure 1**).

I also investigated the relationships between different stand structure factors (age, H, DBH, N, v) of the experimental stands. Overall, it can be concluded that all results (H-age; DBH-age; N-DBH; N-age and v-DBH) show a very strong correlation between the studied parameters. Of particular note is the N-DBH relationship (**Figure 2**), which allows an approximate determination of the growing space considered necessary to reach a certain target diameter. This is of particular importance for black locust cultivars for industrial wood, as the main production objective is to maximise diameter growth above 10 years of age.

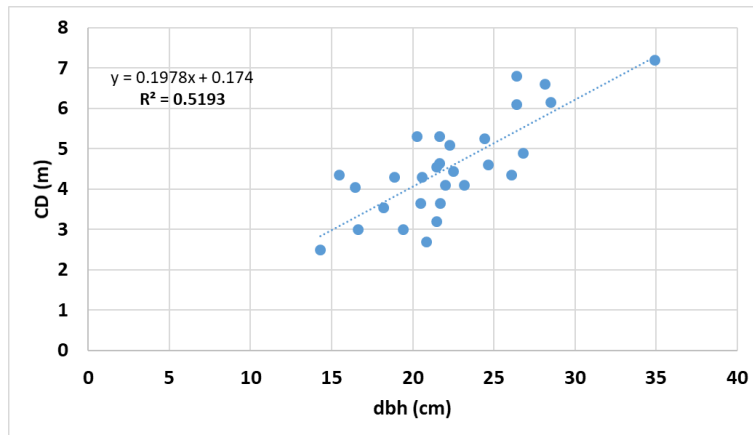


**Figure 2:** Evolution of the stem number (N) in the 'Üllői', 'Nyírségi' and 'Jászkiséri' experimental stands as a function of diameter at breast height (DBH)

### 3.2. THE RESULT OF THE STAND-STRUCTURAL STUDY OF THE 'ÜLLŐI' BLACK LOCUST (BASED ON THE SAMPLE PLOT OF SUBCOMPARTMENT SZENTKIRÁLY 47H)

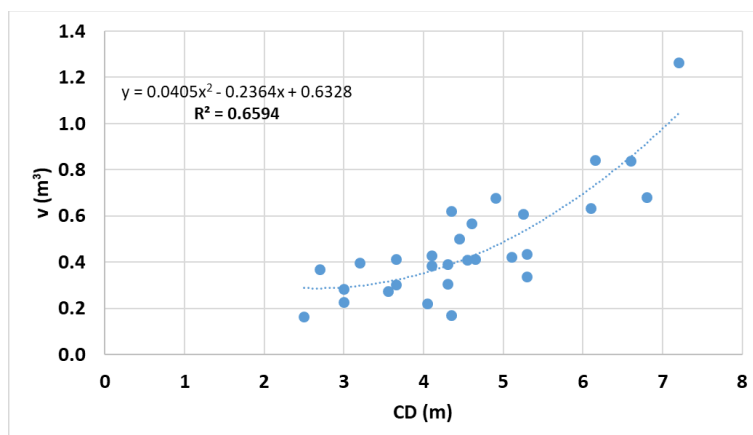
Examining the parameters of the experimental 'Üllői' black locust, it can be concluded that at the age of cutting (35 years), the H of the full stand is 22.1 m, the DBH is 21.91 cm, and the V is 325.49 m<sup>3</sup> ha<sup>-1</sup>. It can also be observed that the proportion of the main stand made up of superior trees (t.c. I) and subdominant trees (t.c. II) decreases drastically, while that of the dead trees (t.c. IV) increases: at the age of 35, only 44% of the stand is considered as main stand. The secondary stand accounts for 32 % and the dead trees for 24 %. According to the height classification, 18 % of the trees are classified in h.c. I, i.e. outstanding trees, and 16 % in h.c. II, i.e. dominant trees. A very high proportion of the 'Üllői' black locust (44 %) are intermediate trees (h.c. III) and 22 % are suppressed trees (h.c. IV). The h and dbh values of the height classes are well separated, with values decreasing downwards (I to IV). The main characteristics of the crown structure can be summarised as follows. Outstanding trees (h.c. I) have the largest CD, crown spread and crown projection area (CPA). There is no great difference in CD and CPA between dominant (h.c. II) and intermediate (h.c. III) trees. Furthermore, CD and CPA values decrease from height class to height class. The linear crown index is highest in the lowest height class (h.c. IV).

In order to make the analyses as complete as possible, I fitted a line between the dbh and CD values of the trees of the whole dataset to estimate the linear regression. The fit of the line is good ( $R^2 = 0.5193$ ), showing a close correlation ( $r = 0.72$ ) between the two parameters under study (**Figure 3**).



**Fig. 3.** Linear correlation between crown diameter (CD) and diameter at breast height (dbh) of individual trees ( $n = 29$ ) of a 35-year-old 'Üllői' black locust stand (subcompartment Szentkirály 47H, 1/25/2022)

I also applied a second-degree regression function to the values of  $v$  and CD. A strong correlation was found between these values. The  $R^2$  value is 0.6594, i.e. the regression function fits the measured values well also in this case (**Figure 4**).



**Fig. 4.** Correlation between mean tree volume ( $v$ ) and crown diameter (CD) of 35-year-old 'Üllői' black locust whole stand trees ( $n = 29$ ) (subcompartment Szentkirály 47H, 25/1/2022)

The above shows the mathematically proven effect of crown size on yield, i.e. the values derived from the crown structure analysis are suitable for determining the recommended stem number of 'Üllői' black locust trees and for modelling their expected volume.

### 3.3. EVALUATION OF THE GROWTH OF BLACK LOCUST CULTIVAR CANDIDATES 'BÁCSKA', 'HOMOKI', 'OSZLOPOS' AND 'VACSI' IN EXTREMELY DRY (MARGINAL) SITES

The results of the black locust clone trial in the Helvécia 22E subcompartment, the most important dendrometric characteristics (age,  $n$ , H, DBH,  $v$ , SQI) are summarised in Table 1 for Helvécia 22E/1 and in Table 2 for Helvécia 22E/2.

**Table 1.** Key dendrometric characteristics of 'Vacsi', and 'Homoki' candidate cultivars at 15 years of age compared to common black locust (control) in Helvécia 22E/1 subcompartment (7/1/2021) (mean±standard deviation)

Clones	Age (yr)	n	H (m)	DBH (cm)	v (dm <sup>3</sup> )	SQI
Vacsi	15	50	9.04 ± 1.25 bc	7.70 ± 1.34 b	32.7	1.66
Homoki	15	34	10.51 ± 2.46 ab	9.48 ± 3.15 a	62.6	2.32
Control	15	30	9.77 ± 2.05 b	7.56 ± 1.98 b	34.3	2.37

Legend: n = number of sample trees tested; H = mean height of sample trees; DBH = mean diameter at breast height (1.3 m) of sample trees; v = mean volume of sample trees; SQI = stem quality index. For H and DBH values, letters indicate significant ( $p = 0.05$ ) difference between clones

In the experimental area Helvécia 22E/1, the cultivar candidates 'Vacsi' and 'Homoki' were tested in comparison with the common black locust (control). Significant differences ( $p = 0.05$ ) were found between the 15-year-old clones in terms of H, DBH and v. The cultivar 'Homoki' proved to be the best. For H (10.51 m), it significantly ( $p = 0.05$ ) outperformed the candidate cultivar 'Vacsi' (9.04 m), while the height of the two candidate cultivars and the control (9.77 m) differed insignificantly. For diameter, 'Homoki' produced a significantly higher value (9.48 cm) than the other two clones tested ('Vacsi': 7.70 cm, control: 7.56 cm), with no significant difference between them. Also in v values, 'Homoki' proved to be the best (62.6 dm<sup>3</sup>). The mean tree volume of 'Vacsi' was 32.7 dm<sup>3</sup>, the control 34.3 dm<sup>3</sup>. Based on the SQI test results, 'Vacsi' was the best performer. There was minimal difference between 'Homoki' (2.32) and control (2.37). Based on the latter two parameters, the mean tree volume of the candidate 'Homoki' exceeded that of the control by 82.5 %, whereas 'Vacsi' showed a difference of -5 %. However, the latter candidate cultivar had a 43 % better TMI than the control. The SQI of 'Homoki' was minimally (2%) better than that of common black locust.

**Table 2.** Key dendrometric characteristics of 'Bácska', 'Oszlopos' candidate cultivars at 14 years of age compared with 'Jászkiséri' black locust in Helvécia 22E/2 subcompartment (7/1/2021) (mean±standard deviation)

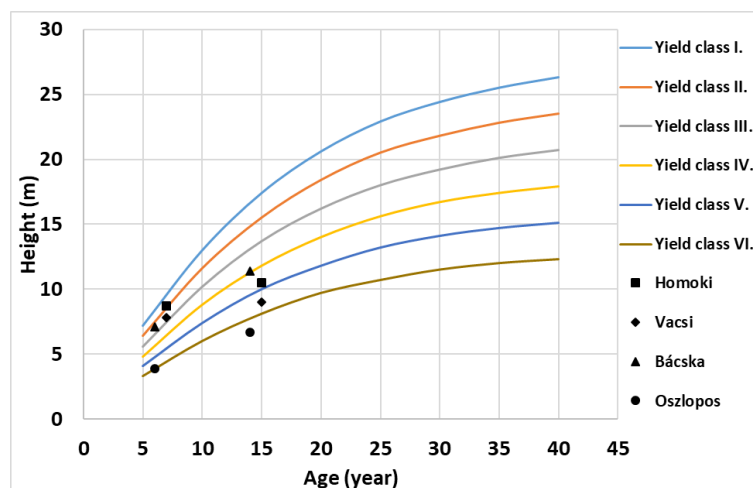
Clones	Age (yr)	n	H (m)	DBH (cm)	v (dm <sup>3</sup> )	SQI
Bácska	14	38	11.44 ± 1.87 a	11.17 ± 2.79 a	79.0	2.50
Oszlopos	14	38	6.67 ± 1.32 b	7.60 ± 1.78 c	31.2	2.32
Jászkiséri	14	45	11.66 ± 1.35 a	9.85 ± 2.58 b	61.6	1.96

Legend: n = number of sample trees tested; H = average height of sample trees; DBH = average diameter at breast height (1.3 m) of sample trees; v = average mean tree volume of sample trees; SQI = stem quality index of sample trees. For H and DBH values, letters indicate significant ( $p = 0.05$ ) difference between clones

In the Helvécia 22E/2 subcompartment, I tested the 'Bácska' and 'Oszlopos' candidate cultivars, compared with the state-approved 'Jászkiséri' black locust. Of the 14-year-old clones,

'Jászkiséri' was the best in H (11.66 m), while 'Bácska' did not differ significantly ( $p = 0.05$ ) in comparison (11.44 m). As regards DBH, however, 'Bácska' produced a significantly higher value (11.17 cm) than the other two clones tested. The DBH of 'Jászkiséri' was 9.85 cm. The clone 'Oszlopos' proved to be extremely poor in terms of both H (6.67 m) and DBH (7.60 cm). Also in the case of  $v$  values, 'Bácska' proved to be the best (79.0 dm<sup>3</sup>). The mean tree volume of 'Jászkiséri' was 61.6 dm<sup>3</sup>, and that of the candidate black locust cultivar 'Oszlopos' was 32.7 dm<sup>3</sup>. Based on the SQI test results, 'Jászkiséri' was the best (1.96). There was minimal difference between 'Bácska' (2.50) and 'Oszlopos' (2.32). Based on the latter two parameters, the mean tree volume of the candidate cultivar 'Bácska' exceeded that of the state-approved 'Jászkiséri' by 28 %. The clone 'Oszlopos' was 49 % below the control. In terms of SQI, both candidate cultivars performed worse than 'Jászkiséri'.

**Figure 5** shows the variation of the mean height of 6 and 7 years old (based on literature data), as well as 14 and 15 years old candidates ('Bácska', 'Homoki', 'Oszlopos', 'Vacsi') as a function of age in the curve of the yield classes of the yield table developed for black locust. It can be concluded that the tested black locust clones - with the exception of 'Oszlopos' - are in the wood yield classes II and III at 6-7 years of age, and between IV and VI at older ages (14-15 years), which means that a low to medium yield can be predicted under these site conditions. Clones 'Bácska' and 'Homoki' reach the lower limit of the requirements for plantation-type timber production (yield class IV). The candidate cultivar 'Oszlopos' showed very poor growth (yield class VI).



**Figure 5.** Height values of 'Homoki', 'Vacsi', 'Bácska' and 'Oszlopos' clones as a function of age (6-7, and 14-15 years of age) on the height curves of the yield table developed for black locust

### **3.4. EVALUATION OF THE GROWTH EXAMINATION OF THE 'LAPOSI' (NK1), 'NAPKORI' (NK2), 'FARKASSZIGET' (PL040), AND 'PÜSPÖKLADÁNYI' (PL251) BLACK LOCUST CLONES COMPARED TO THE 'ÜLLŐI' BLACK LOCUST (NAPKOR)**

The height and thickness growth of the clones and 'Üllői' black locust were tested twice in 2021 in the experimental plantation (full stand inventory), in May and November, and once a month from May to August in 2022 (based on 15-30 sample trees).

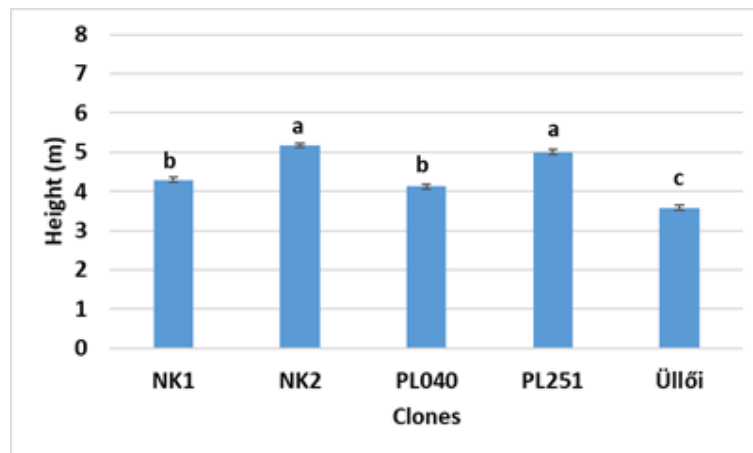
The results of the H and RCD measurements in May and November 2021 are shown in **Table 3**. In the one-way analysis of variance (LSD test), I found that there were significant ( $p = 0.05$ ) differences between clones for both parameters. The results of the 2021 height measurement were as follows. The clones NK2 (2.5 × 2.5 m planting spacing: 184.7 cm; 4 × 4 m planting spacing: 226.8 cm) and PL251 (2.5 × 2.5 m planting spacing: 176.9 cm; 4 × 4 m planting spacing: 226.3 cm) were the best, with the cultivar 'Üllői' provided the weakest results (2.5 × 2.5 m grid 117.7 cm; 4 × 4 m 138.3 cm). In terms of RCD, the 4 new clones did not differ as significantly as in H. Based on the results of the RCD measurements, NK2 (19.98 mm in the 2.5 × 2.5 m planting spacing; 23.80 mm in the 4 × 4 m planting spacing) and NK1 (18.65 mm in the 2.5 × 2.5 m planting spacing; 23.30 mm in the 4 × 4 m planting spacing) were the best, while the cultivar 'Üllői' (12.86 mm in the 2.5 × 2.5 m planting spacing; 14.65 mm in the 4 × 4 m planting spacing) was significantly the weakest.

Also in autumn (November 2021), clones NK2 (485.7 cm in a 2.5 × 2.5 m planting spacing; 476.4 cm in a 4 × 4 m planting spacing) and PL251 (424.8 cm in a 2.5 × 2.5 m planting spacing; 470.7 cm in a 4 × 4 m planting spacing) were the best in terms of H, and 'Üllői' (293 cm in a 2.5 × 2.5 m planting spacing; 317.6 cm in a 4 × 4 m planting spacing) was the weakest. For the November RCD results, NK2 (55.58 mm), PL251 (54.46 mm), and NK1 (53.12 mm) proved to be the best in the 2.5 × 2.5 m planting spacing. In the 4 × 4 m planting spacing, clones NK1 (71.05 mm) and PL251 (69.32 mm) produced the best results. In both planting spacings, the cultivar 'Üllői' showed the smallest RCD values: 44.56 mm (2.5 × 2.5 m) and 55.37 mm (4 × 4 m) (**Table 3**).

**Table 3:** Increase in clone height (H) and root collar diameter (RCD) (mean±standard deviation), as well as height increment (I<sub>H</sub>) and thickness increment (I<sub>RCD</sub>) during the examined period (May-November 2021). The value of n1 refers to the number of stems measured during the May stand inventory and n2 to the number of stems measured during the November stand inventory. Letters denote significant differences ( $p = 0.05$ ) between the parameters tested (2021, Napkor)

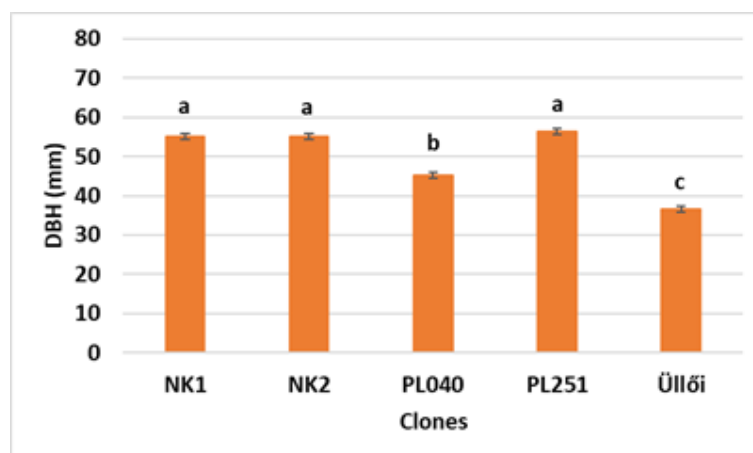
<b>Planting spacing: 2.5 × 2.5 m</b>							
<b>Clones</b>	<b>Date of measurement</b>		<b>n (trees)</b>	<b>H (cm)</b>	<b>I<sub>H</sub> (May-Nov) (cm)</b>	<b>RCD (mm)</b>	<b>I<sub>RCD</sub> (May-Nov) (mm)</b>
PL251	May	n1	216	176.9±42.31 a	248.0	17.94±3.82 c	<b>36.53</b>
	November	n2	224	424.8±39.44 B		54.46±7.21 AB	
NK1	May	n1	204	145.6±33.80 b	174.2	18.65±3.36 b	34.48
	November	n2	201	319.9±42.34 D		53.12±9.76 B	
PL040	May	n1	178	131.8±33.83 c	215.5	17.70±3.09 c	28.61
	November	n2	200	347.3±57.09 C		46.31±8.07 C	
NK2	May	n1	124	184.7±38.83 a	<b>301.1</b>	19.98±3.28 a	35.60
	November	n2	120	485.7±43.06 A		55.58±5.84 A	
Üllői	May	n1	87	117.7±31.70 d	175.3	12.86±2.72 d	31.70
	November	n2	81	293.0±44.73 E		44.56±8.60 C	
<b>Planting spacing: 4.0 × 4.0 m</b>							
<b>Clones</b>	<b>Date of measurement</b>		<b>n (trees)</b>	<b>H (cm)</b>	<b>I<sub>H</sub> (May-Nov) (cm)</b>	<b>RCD (mm)</b>	<b>I<sub>RCD</sub> (May-Nov) (mm)</b>
PL251	May	n1	94	226.3±55.48 a	244.4	22.29±4.65 b	47.04
	November	n2	93	470.7±45.27 A		69.32±9.01 A	
NK1	May	n1	133	199.5±41.29 b	193.6	23.30±3.90 ab	<b>47.74</b>
	November	n2	123	393.0±49.90 B		71.05±9.09 A	
PL040	May	n1	108	170.9±49.87 c	224.5	20.50±4.70 c	41.62
	November	n2	93	395.4±68.04 B		62.12±9.90 B	
NK2	May	n1	70	226.8±57.16 a	<b>249.6</b>	23.80±4.35 a	40.98
	November	n2	65	476.4±53.81 A		64.78±7.31 B	
Üllői	May	n1	64	138.3±37.56 d	179.3	14.65±3.12 d	40.72
	November	n2	49	317.6±36.95 C		55.37±8.63 C	

In June 2022, h and dbh of clones were measured in a  $2.5 \times 2.5$  m planting spacing ( $n = 30$ ). Significant ( $p = 0.05$ ) differences were found between clones for both parameters, which were verified by Games-Howell test. When evaluating the results of the height measurement, I found that clones NK2 (5.17 m) and PL251 (4.99 m) significantly outperformed the others (**Figure 6**), but no significant differences were found between these two clones.



**Figure 6.** Comparison of tested clones by height (m) based on 30 sample trees ( $n = 30$ ) in a  $2.5 \times 2.5$  m planting spacing (June 2022),  $\pm$ standard error, letters indicate significant difference between clones at the  $p = 5\%$  level (Napkor, 20/6/2022)

For DBH, the best clones were PL251 (56.30 mm), NK1 (55.23 mm) and NK2 (55.19 mm), with minimal - non-significant ( $p = 0.05$ ) - differences (**Figure 7**). 'Üllői' was the weakest in both parameters, with an average height of 3.58 m and an average diameter of 36.67 mm (**Figures 6 and 7**).



**Figure 7.** Comparison of tested clones by diameter at breast height (DBH) (mm) based on 30 sample trees ( $n = 30$ ) in the  $2.5 \times 2.5$  m planting spacing (June 2022),  $\pm$ standard error, letters indicate significant difference between clones at  $p = 5\%$  level (Napkor, 20/6/2022)

In the period May-August 2022, 16-26 sample trees per clone were tested in a  $2.5 \times 2.5$  m planting spacing. There was a significant difference ( $p = 0.05$ ) between clones and control

'Üllői' black locust in terms of growth calculated from measured h and dbh values, as verified by Games-Howell test. The obtained results are summarised in **Table 4**.

**Table 4.** Height ( $I_H$ ) and diameter ( $I_{DBH}$ ) increments of the sample trees (n) of the clones during the studied period (May-August 2022). Mean ( $\bar{x}$ ), standard deviation (SD), standard error (S.E.). Letters indicate significant difference between clones at  $p = 5\%$  level (Napkor, 2022)

Clones	n	$I_H$ (May-Aug) (m)			$I_{DBH}$ (May-Aug) (mm)		
		$\bar{x}$	SD	S.E.	$\bar{x}$	SD	S.E.
NK1	20	1.81 a	0.42	0.044	21.35 ab	5.34	0.526
PL040	25	1.54 b	0.31	0.044	23.76 a	5.27	0.526
PL251	16	1.23 c	0.27	0.044	19.97 b	3.09	0.526
Üllői	26	1.19 c	0.31	0.044	18.73 b	3.87	0.526

Clone NK1 produced the highest height increment (1.81 m), significantly ( $p = 0.05$ ) different from the other three clones tested, with clone PL040 being the second best (1.54 m). Clone PL251 increased 1.23 m, while clone PL251 increased 1.19 m, with no significant difference between the two. In the analysis of diameter growth, we found that the clone PL040 proved to be the best (23.76 mm), with a significant difference between clone PL251 (19.97 mm) and 'Üllői' black locust (18.73 mm). The diameter increment of clone NK1 (21.35 mm) was not significantly different from the other three clones tested.

### 3.5. THE RESULTS OF ECOPHYSIOLOGICAL ANALYSIS OF THE 'LAPOSI' (NK1), 'NAPKORI' (NK2), 'FARKASSZIGET' (PL040), 'PÜSPÖKLADÁNYI' (PL251) BLACK LOCUST CLONES COMPARED TO THE 'ÜLLŐI' BLACK LOCUST (NAPKOR)

Field experiments on photosynthesis and plant water management processes are essential for understanding the plant biology of black locust clones. Plant physiology has been the subject of numerous studies, but relatively few publications have reported the results of *in situ* measurements under field conditions.

There was a significant ( $p < 0.05$ ) difference between the clones for all ecophysiological parameters, which was confirmed by LSD for the 2021 results (parametric data set) and by Games-Howell test for the 2022 results (non-parametric data set). The results of the pairwise comparisons are summarised in **Table 5**.

**Table 5.** Ecophysiological parameters ( $T_{air} - T_{leaf}$ , A, Tr,  $g_{tc}$ ,  $C_i$ ,  $VPD_{leaf}$ , WUE) of NK1, NK2, PL040 and PL251 clones and 'Üllői' black locust, mean $\pm$ standard deviation of 18 measurements, letters indicate significant ( $p = 0.05$ ) difference between clones (Napkor, 29/6/2021 and 29/6/2022)

2021							
Clones	$T_{air} - T_{leaf}$	A	Tr	$g_{tc}$	$C_i$	$VPD_{leaf}$	WUE
	$^{\circ}C$	$\mu mol m^{-2} s^{-1}$	$mmol m^{-2} s^{-1}$	$mol m^{-2} s^{-1}$	$\mu mol mol^{-1}$	kPa	$kg m^{-3}$
NK1	0.01 $\pm 0.24$ bc	9.62 $\pm 4.85$ d	5.12 $\pm 1.01$ c	0.16 $\pm 0.04$ b	321.19 $\pm 18.63$ a	1.95 $\pm 0.10$ c	4.32 $\pm 1.33$ c

2021							
Clones	T <sub>air</sub> - T <sub>leaf</sub>	A	Tr	g <sub>tc</sub>	C <sub>i</sub>	VPD <sub>leaf</sub>	WUE
	°C	μmol m <sup>-2</sup> s <sup>-1</sup>	mmol m <sup>-2</sup> s <sup>-1</sup>	mol m <sup>-2</sup> s <sup>-1</sup>	μmol mol <sup>-1</sup>	kPa	kg m <sup>-3</sup>
NK2	0.35 ±0.18 a	18.44 ±2.85 a	6.53 ±0.73 a	0.20 ±0.03 a	273.09 ±3.67 b	2.05 ±0.15 bc	6.88 ±0.45 a
PL040	0.17 ±0.32 b	12.96 ±4.50 c	4.42 ±1.15 d	0.13 ±0.05 c	271.35 ±2.79 b	2.17 ±0.23 ab	7.02 ±0.62 a
PL251	-0.14 ±0.10 c	13.34 ±1.62 c	5.34 ±0.68 c	0.20 ±0.05 a	307.04 ±9.66 a	1.66 ±0.19 d	6.13 ±0.44 b
Üllöi	0.32 ±0.11 a	15.17 ±2.20 b	5.98 ±0.49 b	0.16 ±0.02 b	276.64 ±13.44 b	2.24 ±0.10 a	6.21 ±0.87 b
2022							
Clones	T <sub>air</sub> - T <sub>leaf</sub>	A	Tr	g <sub>tc</sub>	C <sub>i</sub>	VPD <sub>leaf</sub>	WUE
	°C	μmol m <sup>-2</sup> s <sup>-1</sup>	mmol m <sup>-2</sup> s <sup>-1</sup>	mol m <sup>-2</sup> s <sup>-1</sup>	μmol mol <sup>-1</sup>	kPa	kg m <sup>-3</sup>
NK1	-0.29 ±0.56 b	9.83 ±4.36 c	6.95 ±1.69 bc	0.12 ±0.03 c	286.15 ±22.45 a	3.70 ±0.31 a	3.27 ±0.87 b
NK2	0.84 ±0.44 a	20.25 ±1.43 a	10.08 ±0.92 a	0.20 ±0.02 a	260.74 ±4.22 b	2.99 ±0.14 c	4.92 ±0.24 a
PL040	1.03 ±1.30a	15.02 ±1.42 b	10.01 ±1.13 a	0.21 ±0.06 a	287.38 ±16.93 a	3.08 ±0.55 c	3.68 ±0.15 b
PL251	-0.44 ±0.65 b	12.94 ±3.62 bc	8.00 ±0.67 b	0.14 ±0.02 b	277.20 ±20.67 a	3.39 ±0.20 b	3.89 ±0.85 b
Üllöi	-0.06 ±0.45 b	11.30 ±1.34 c	5.81 ±0.87 c	0.10 ±0.02 c	248.30 ±8.18 c	3.65 ±0.21 a	4.78 ±0.18 a

Legend: T<sub>air</sub> - T<sub>leaf</sub> = difference between air and leaf temperature; A = net assimilation; Tr = transpiration, g<sub>tc</sub> = stomatal conductance; C<sub>i</sub> = intercellular carbon dioxide concentration; VPD<sub>leaf</sub> = leaf water vapour saturation; WUE = Water Use Efficiency

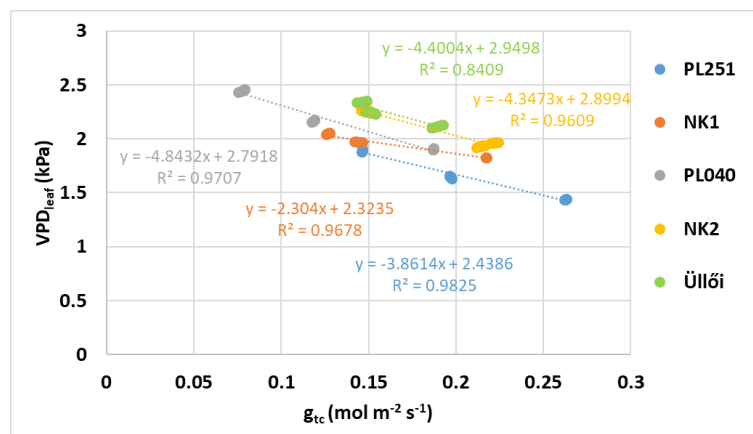
For the T<sub>air</sub>-T<sub>leaf</sub> values, in 2021, clone NK2 proved to be the best (0.35 °C), slightly outperforming the cultivar Üllöi (0.32 °C), with no significant difference ( $p = 0.05$ ) between the two. In 2022, clone PL040 produced the best result (1.03 °C), significantly outperforming the other clones, with the exception of NK2 (0.84 °C). In both years, PL251 performed the worst (2021: -0.14 °C, 2022: -0.44 °C). Negative values indicate that the clone was unable to cool itself properly in water deficit and was under heat stress.

The transpiration values were as follows: in 2021, clone NK2 was the best performing clone with the highest transpiration value (6.53 mmol m<sup>-2</sup> s<sup>-1</sup>). In 2022, this clone was also the best performing clone (10.08 mmol m<sup>-2</sup> s<sup>-1</sup>), but there was no significant ( $p = 0.05$ ) difference between NK2 and PL040 in this year. The weakest clone was PL040 in 2021 (4.42 mmol m<sup>-2</sup> s<sup>-1</sup>) and 'Üllöi' in 2022 (5.81 mmol m<sup>-2</sup> s<sup>-1</sup>), although there was no significant difference between the latter and clone NK1 (6.95 mmol m<sup>-2</sup> s<sup>-1</sup>)

The VPD<sub>leaf</sub> values show significant ( $p = 0.05$ ) differences between clones. In 2021, the lowest value was observed for clone PL251 (1.66 kPa) and the highest for the cultivar Üllöi (2.24 kPa).

Relatively low values were also observed for clones NK1 and NK2 (1.95 and 2.05 kPa), but these were significantly different from the value measured on the leaves of PL251. The results of the 2022 measurement were relatively high (3.0-3.7 kPa), suggesting that the very dry air surrounding the plants caused high water stress. The  $VPD_{leaf}$  values (2.99 and 3.08 kPa) of clones NK2 and PL040, respectively, were significantly lower than those of the other clones, indicating better stress tolerance. PL251 had a relatively high value this year (3.39 kPa), significantly higher than the two best performing clones (NK2 and PL040), but significantly lower than the poor performing clones NK1 (3.70 kPa) and 'Üllői' (3.65 kPa), which did not show any significant difference.

Based on the results of the  $g_{tc}$  measurement, significant differences (significant at the  $p = 5\%$  level) were observed between the clones tested in both years. In 2021, the highest values were observed for NK2 and PL251 ( $0.20 \text{ mol m}^{-2} \text{ s}^{-1}$ ), in 2022 for NK2 ( $0.20 \text{ mol m}^{-2} \text{ s}^{-1}$ ) and PL040 ( $0.21 \text{ mol m}^{-2} \text{ s}^{-1}$ ), which did not differ significantly from each other in either year. The lowest values were observed in 2021 for PL040 ( $0.13 \text{ mol m}^{-2} \text{ s}^{-1}$ ), and in 2022 for NK1 and 'Üllői' clones with values of  $0.12 \text{ mol m}^{-2} \text{ s}^{-1}$  and  $0.10 \text{ mol m}^{-2} \text{ s}^{-1}$ , respectively. The values of  $g_{tc}$  suggest that the stomata of clones PL251 (in 2021) and NK2 and PL040 (in 2022) were more open, which is associated with lower VPD values. The correlation between  $VPD_{leaf}$  and  $g_{tc}$  values was verified by linear regression ( $R^2$  value: 0.8409-0.9825), showing that  $g_{tc}$  decreases with increasing  $VPD_{leaf}$  value for all examined clones (**Figure 8**).



**Figure 8.** Comparison of the clones based on their  $VPD_{leaf}$  and  $g_{tc}$  values and linear relationship between the two test parameters (Napkor, 29/6/2021)

There were also significant differences in the assimilation rate of the clones ( $p = 0.05$ ). In both studied years, the highest value ( $18.44 \mu\text{mol m}^{-2} \text{ s}^{-1}$  and  $20.25 \mu\text{mol m}^{-2} \text{ s}^{-1}$ ) was measured for clone NK2 and the lowest ( $9.62 \mu\text{mol m}^{-2} \text{ s}^{-1}$  and  $9.83 \mu\text{mol m}^{-2} \text{ s}^{-1}$ ) for clone NK1. In pairwise comparisons, no significant differences were observed between clones PL251 and PL040, with values of  $13.34 \mu\text{mol m}^{-2} \text{ s}^{-1}$  and  $12.96 \mu\text{mol m}^{-2} \text{ s}^{-1}$  in 2021, and  $12.94 \mu\text{mol m}^{-2} \text{ s}^{-1}$  and  $15.02$

$\mu\text{mol m}^{-2} \text{s}^{-1}$  in 2022. The cultivar 'Üllői' was the second best in 2021 and the second worst in 2022, with values of  $15.17 \mu\text{mol m}^{-2} \text{s}^{-1}$  and  $11.30 \mu\text{mol m}^{-2} \text{s}^{-1}$ , respectively.

Significant ( $p = 0.05$ ) differences were also found in the intercellular  $\text{CO}_2$  concentration ( $C_i$ ) of their leaves. In 2021, the highest  $C_i$  values were measured in clones NK1 ( $321.19 \mu\text{mol mol}^{-1}$ ) and PL251 ( $307.04 \mu\text{mol mol}^{-1}$ ), the lowest in clone PL040 ( $271.35 \mu\text{mol mol}^{-1}$ ), but this differed significantly only from the two clones mentioned above. In 2022, the highest values were produced by clones NK1 ( $286.15 \mu\text{mol mol}^{-1}$ ), PL040 ( $287.37 \mu\text{mol mol}^{-1}$ ) and PL251 ( $277.20 \mu\text{mol mol}^{-1}$ ). The lowest value was measured for the cultivar 'Üllői',  $248.30 \mu\text{mol mol}^{-1}$ . The  $C_i$  value is influenced by several factors. It cannot be considered as a clear indicator for assessing the stress status of the plant or the functioning of the photosynthetic system. However, I observed a negative correlation between A and  $C_i$  values for most clones.

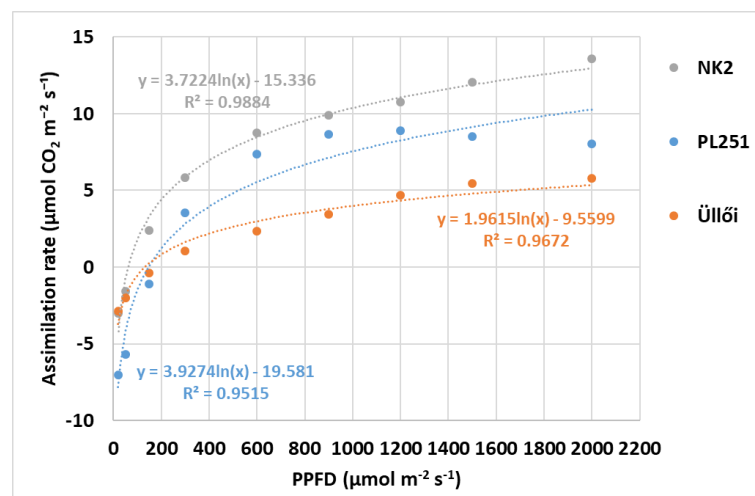
Using the A and Tr data, I calculated the water use efficiency ( $\text{kg CO}_2$  per  $\text{m}^3 \text{H}_2\text{O}$ ) for each clone. The differences were significant at the  $p = 0.05$  level. The best water use efficiency was observed in 2021 for clone PL040 and in 2022 for clone NK2 ( $7.02 \text{ kg m}^{-3}$  and  $4.92 \text{ kg m}^{-3}$ , respectively), while the lowest values ( $4.32$  and  $3.27 \text{ kg m}^{-3}$ ) were observed for clone NK1 in both years. However, pairwise comparisons showed no significant difference between PL040 and NK2 ( $6.88 \text{ kg m}^{-3}$ ) in 2021 and between clones 'Üllői' ( $4.78 \text{ kg m}^{-3}$ ) and NK2 in 2022.

The correlations between the physiological parameters of the clones were tested using Spearman's correlation. Although the results (year 2021 and 2022) showed a highly variable picture, it was found that there was a strong positive correlation ( $r > 0.750$ ) between A and Tr and  $g_{\text{sw}}$  and Tr for all clones, significant at the  $p = 0.01$  level. These correlations are decisive for further ecophysiological studies of selected black locust cultivars, clones.

In 2023, the assimilation and PSII light response curves of the two clones with the best height and thickness (PL251 and NK2) and the 'Üllői' black locust were observed in 9 steps with decreasing photosynthetic photon flux density (PPFD) (2000, 1500, 1200, 900, 600, 300, 150, 50,  $20 \mu\text{mol m}^{-2} \text{s}^{-1}$ ).

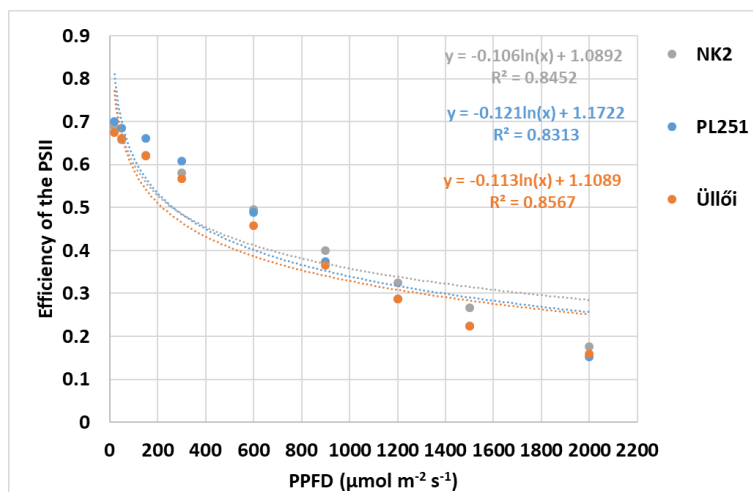
For A, the natural logarithmic regression functions fitted well to the measured data points ( $R^2$  value for clone NK2: 0.9884; for PL251: 0.9515; for the 'Üllői' cultivar: 0.9672), i.e. the curves of the functions showed the differences appropriately. Examining the assimilation rate of the 2 clones and 'Üllői' as a function of PPFD, it was found that, at the lowest PPFD level ( $0\text{-}20 \mu\text{mol m}^{-2} \text{s}^{-1}$ ), PL251 was the weakest, with a value of  $-7.04 \mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$ , and a minimal difference between the 'Üllői' ( $-2.86 \mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$ ) and NK2 ( $-3.03 \mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$ ). At the other PPFD levels, NK2 was found to be the best, with A increasing steadily as a result of increasing PPFD, but the curve flattens at the  $600 \mu\text{mol m}^{-2} \text{s}^{-1}$  PPFD level, which is due to the

effect of photorespiration on assimilation rates. The highest A value ( $13.58 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ ) is reached at the  $2000 \mu\text{mol m}^{-2} \text{ s}^{-1}$  PPFD level. The results of the 'Üllői' cultivar and PL251 showed a varied picture, which can be characterised as follows. Between 0 and  $150 \mu\text{mol m}^{-2} \text{ s}^{-1}$  PPFD levels, the 'Üllői' had a higher assimilation rate, but with increasing light intensity, the PL251 clone proved to be better. Although the curve of 'Üllői' ran lower than that of PL251 at higher PPFD levels, its A value showed a steady increase, with the best value ( $5.79 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ ) at the highest PPFD level of  $2000 \mu\text{mol m}^{-2} \text{ s}^{-1}$ . The assimilation rate of PL251 increased up to  $1200 \mu\text{mol m}^{-2} \text{ s}^{-1}$  PPFD level, reaching the highest A value ( $8.88 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ ) at this level (**Figure 9**).



**Figure 9.** Light response curves of black locust clones NK2, PL251 and 'Üllői' (Napkor, 30/6/2023): assimilation rate as a function of PPFD; PPFD = Photosynthetic Photon Flux Density

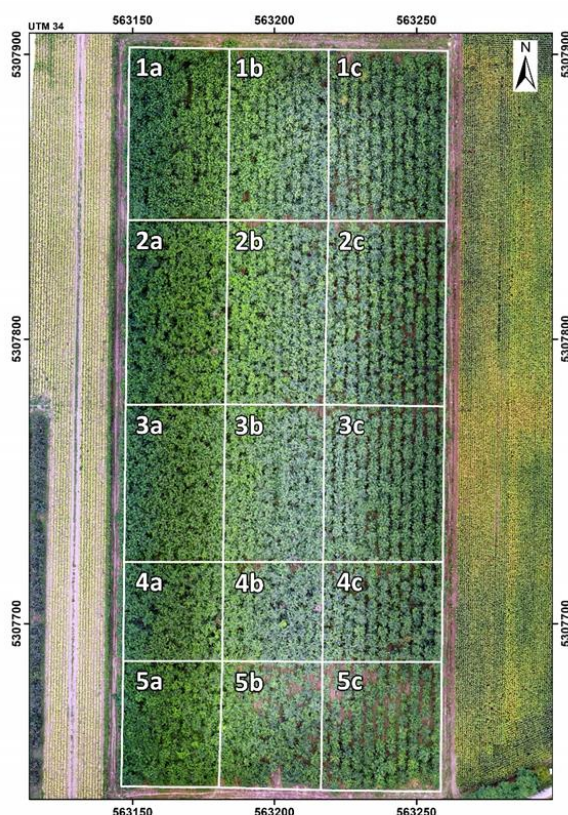
The natural logarithmic regression functions fitted well to the measured data points for the PSII efficiency values ( $R^2$  value for clone NK2 0.8452; for PL251 0.8313; for the 'Üllői' cultivar 0.8567), i.e. the curves of the functions showed the differences properly in this case as well. From the obtained results, I found that the PSII efficiency of the tested black locust clones and the 'Üllői' black locust decreased with increasing light intensity. At low PPFD levels ( $0-300 \mu\text{mol m}^{-2} \text{ s}^{-1}$ ), the clone PL251 (0.70-0.61) produced the best value (0.50-0.18), while at higher PPFD levels ( $600-2000 \mu\text{mol m}^{-2} \text{ s}^{-1}$ ), the clone NK2 produced the best value (0.50-0.18). However, it is worth noting that there were minimal differences between the clones tested and the 'Üllői' black locust, especially between clone PL251 and the 'Üllői' black locust, which both had similar PSII values at many of the same light intensities ( $900; 1200; 1500 \mu\text{mol m}^{-2} \text{ s}^{-1}$  PPFD levels 0.37; 0.29; 0.22 was the PSII efficiency index), NK2 at  $900 \mu\text{mol m}^{-2} \text{ s}^{-1}$  PPFD level was visibly distinct from the other two (**Figure 10**).



**Figure 10.** Light response curves of 'NK2', 'PL251' and 'Üllői' black locust (Napkor, 30/6/2023): PSII as a function of PPFD; PPFD = Photosynthetic Photon Flux Density

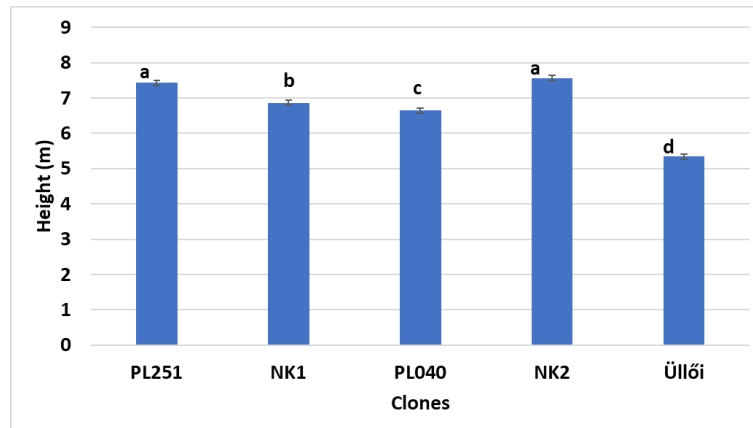
### 3.6. THE RESULTS OF THE UAV-BASED ANALYSIS OF THE 'LAPOSI' (NK1), 'NAPKORI' (NK2), 'FARKASSZIGETI' (PL040), 'PÜSPÖKLADÁNYI' (PL251) BLACK LOCUST CLONES COMPARED TO THE 'ÜLLŐI' BLACK LOCUST (NAPKOR)

Several orthophotos of the experimental plantation were taken. The one taken in August 2023 is presented below (**photo 1**).



**Photo 1.** Orthophoto of the experimental area (Napkor, 16/8/2023). The numbers indicate the clones tested (1 - PL251; 2 - NK1; 3 - PL040; 4 - NK2; 5 - 'Üllői'), the letters indicate the planting spacings (a - 2.5 × 2.5 m; b - 3 × 3 m; c - 4 × 4 m).

I found that there was a close correlation and minimal (non-significant) difference between field and aerial height measurement, especially the negligible difference between the levelling rod and the UAV. Since the UAV-based vegetation indices were investigated in a  $2.5 \times 2.5$  m planting spacing, I focused on this planting spacing when evaluating the height data. The aim was to compare the height values of the clones. As shown in **Figure 11**, there was a significant difference between the clones tested. The best clones were NK2 (7.6 m) and PL251 (7.4 m), while the 'Üllői' black locust cultivar was the weakest (5.3 m).



**Figure 11.** Comparison of clones ( $n = 30$ ) tested by height (m) in a  $2.5 \times 2.5$  m planting spacing,  $\pm$ standard error, letters indicate significant difference between clones at the  $p = 5\%$  level (Napkor, 16/8/2023)

The vegetation indices (VI) give an overview of the current state of plants. From the obtained values, we can infer the biomass yield, nutrient supply and health status of the trees. NDVI and GNDVI, which is more sensitive to photosynthetic activity and chlorophyll content, were calculated from multispectral aerial photographs. Pairwise comparisons (Games-Howell test) showed significant ( $p = 0.05$ ) differences between clones (**Table 6**).

**Table 6.** Comparison of tested clones by NDVI and GNDVI (mean $\pm$ score), letters indicate significant difference between clones (Napkor, 16/8/2023)

Clones	NDVI	GNDVI
PL251	0.9360 $\pm$ 0.00498 a	0.8027 $\pm$ 0.00914 a
NK1	0.9347 $\pm$ 0.00507 ab	0.7888 $\pm$ 0.01343 b
PL040	0.9260 $\pm$ 0.00498 c	0.7849 $\pm$ 0.00641 bc
NK2	0.9280 $\pm$ 0.00407 c	0.7964 $\pm$ 0.01062 ab
Üllői	0.9323 $\pm$ 0.00504 b	0.7911 $\pm$ 0.01543 b

The clones showed very high NDVI and GNDVI values. For both VIs, PL251 was the best performing clone (NDVI: 0.9360 $\pm$ 0.00498; GNDVI: 0.8027 $\pm$ 0.00914), but not significantly ( $p = 0.05$ ) different from NK1 (NDVI: 0.9347 $\pm$ 0.00507) for NDVI and NK2 (GNDVI: 0.7964 $\pm$ 0.01062) for GNDVI. PL040 was the weakest for both tested indicators, with NDVI of

0.9260±0.00498 and GNDVI of 0.7849±0.00641. Only clone PL251 significantly outperformed the vegetation index values of the control cultivar 'Üllói' (NDVI: 0.9323±0.00504; GNDVI: 0.7911±0.01543) at the p = 5% level.

### 3. NEW SCIENTIFIC RESULTS

1. The growth (height and diameter) of the 14-15 year old 'Bácska', 'Homoki', 'Oszlopos' and 'Vacsi' candidates was strongly influenced by the clonal effect: in addition to their height and diameter, there were significant differences in mean tree volume and stem quality index scores between the clones. 'Homoki' and 'Bácska' significantly outperformed the control in terms of yield (mean tree volume), while 'Vacsi' significantly outperformed the control in terms of stem quality. The mean tree volume of 'Homoki' was 82.5 % better than the control for common black locust, even the candidate clone 'Bácska' exceeded the corresponding value of the control 'Jászkiséri' black locust by 28 %. In terms of stem quality, 'Vacsi' seems to be promising, showing a 43 % better value than the common black locust.
2. Furthermore, it can be concluded that the candidate clones - with the exception of 'Oszlopos' - are in the range of yield classes II and III at 6-7 years of age and IV and VI at older ages (14-15 years), which means that a low to medium yield can be predicted under these site conditions. Candidates 'Bácska' and 'Homoki' reach the lower limit of the requirements for plantation-type wood production (yield class IV). 'Oszlopos' showed very poor growth (yield class VI). Based on the results obtained so far, it can be concluded that planting the candidate cultivars for yield production in such drying, marginal areas is not justified.
3. In the Napkor experiment, significant differences were observed in the height and thickness (root collar diameter and diameter at breast height) growth of the 'Laposi' (NK1), 'Napkori' (NK2), 'Farkasszigeti' (PL040), 'Püspökladányi' (PL251) clones and 'Üllői' black locust, which was used as control. The obtained results showed that, at young age (2-3 years), NK2 and PL251 had the best height and diameter indicators, while 'Üllői' had the weakest value. The results of the June 2022 measurement showed that NK2 exceeded the corresponding results of 'Üllői' by 44% in height and 52% in diameter, and PL251 by 39% and 53%, respectively. In the period May-August 2022, under extreme dry conditions, clones NK1 and PL040 showed the most intensive growth, the former in height (1.81 m) and the latter in diameter (23.76 mm). The clone PL251 and the 'Üllői' black locust performed very poorly in this period, with no significant difference in height (1.23 m and 1.19 m) and diameter (19.97 mm and 18.73 mm) growth values between these two.
4. Based on the results of physiological studies, it was found that NK2 had the best assimilation rate ( $18.44 \mu\text{mol m}^{-2} \text{s}^{-1}$  in 2021 and  $20.25 \mu\text{mol m}^{-2} \text{s}^{-1}$ ) and one of the best

water use efficiency (WUE) ( $6.88 \text{ kg m}^{-3}$  in 2021 and  $4.92 \text{ kg m}^{-3}$  in 2022) of the clones tested in the Napkor experimental plantation. For the latter parameter, PL040 ( $7.02 \text{ kg m}^{-3}$ ) in 2021 and 'Üllői' in 2022 also performed well ( $4.78 \text{ kg m}^{-3}$ ), with WUE values not significantly different from NK2 in the respective test years.

5. For the two best growing clones (NK2 and PL251) and for the cultivar 'Üllői', a light response curve was also generated, characterising the assimilation rate (A) and the PSII efficiency as a function of the photosynthetic photon flux density (PPFD) level. The natural logarithmic curve fitted the data series well in all cases ( $R^2$  value for A: 0,9515-0,9884; for PSII: 0,8313-0,8567). The A values of the tested clones, except for PL251, increased steadily with increasing illumination level, but the curve flattened at the  $600 \mu\text{mol m}^{-2} \text{ s}^{-1}$  PPFD level, which is presumably due to the effect of photorespiration on the assimilation rate. For PL251, the A value decreased from  $1200 \mu\text{mol m}^{-2} \text{ s}^{-1}$  PPFD level. In contrast to the results for A, the efficiency of PSII decreased with increasing PPFD level.
6. The experimental plantation was also surveyed by UAV, measuring height (using photogrammetry) and vegetation indices. Significant differences were found between clones. In terms of height, the best performing clones were the cultivars NK2 and PL251 with values of 7.6 m and 7.4 m, respectively, while PL251 showed the best results in terms of vegetation indices (NDVI: 0.94; GNDVI: 0.80). The reliability of the results for tree height is supported by the field surveys: the results of the UAV-based survey and the height measuring instruments used in forestry practice correlate.

#### 4. PRACTICAL RESULTS

1. The vast majority of the examined 'Nyírségi', 'Üllői' and 'Jászkiséri' black locust stands (5-35 years old) are between yield class II and IV. This corresponds to the requirements of plantation-type wood production.
2. There were also significant differences in the growth, mean tree volume and stem quality index scores of 14-15 year old 'Bácska', 'Homoki', 'Oszlopos' and 'Vacsi' cultivar candidates. The mean tree volume of 'Homoki' was 82.5 % better than the control for common black locust, even the candidate clone 'Bácska' exceeded the corresponding value of the control 'Jászkiséri' black locust by 28 %. In terms of stem quality, 'Vacsi' seems to be promising, showing a 43 % better value than the common black locust.
3. In the Napkor experiment, the obtained results showed that, at a young age (2-3 years), NK2 and PL251 have the best height and diameter indicators, while 'Üllői' has the weakest value.
4. Of the tested candidate cultivars, 'Bácska', 'Homoki' and 'Vacsi' are in the yield class II and III at 6-7 years of age and in the yield class IV to VI at 14-15 years of age. Candidates 'Bácska' and 'Homoki' reach the lower limit of the requirements for plantation-type wood production (yield class IV). The cultivar 'Oszlopos' showed very poor growth. Based on the results obtained so far, it can be concluded that planting of the candidate cultivars in such a drying, marginal site for timber production is not recommended.
5. The obtained results show that UAV-based imaging is suitable for measuring height and vegetation indices in forest experimental stands. Significant differences between clones could be detected. The reliability of the results was confirmed by field surveys using conventional methods.

# PUBLICATIONS OF THE ISSUE OF THESIS



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Subject: PhD Publication List

Candidate: Tamás Ábri  
Doctoral School: Kálmán Kerpely Doctoral School  
MTMT ID: 10071654

## List of publications related to the dissertation

### Hungarian books (1)

1. Rédei, K., **Ábri, T.**, Bach, I., Borovics, A., Keserű, Z.: Szelektált akácfajták termesztési technológiája. 2. kiad., Erdészeti Tudományos Intézet; MED-KÖR Bt., Kecskemét, 54 p., 2023. ISBN: 9786150179995

### Hungarian scientific articles in Hungarian journals (1)

2. **Ábri, T.**, Keserű, Z., Rédei, K.: A 'Nyírségi' akác (*Robinia pseudoacacia* 'Nyírségi') növekedési viszonyai.  
*Erdészettudományi Közlemények. 12* (1-2), 31-42, 2022. ISSN: 2062-6711.  
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3. **Ábri, T.**, Csajbók, J.: Comparative study of newly-bred black locust clones with regard to photosynthetic rate and water use efficiency: early evaluation.  
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9. **Ábri, T.**, Koltay, A.: Új akácklónok növényegészségügyi vizsgálatának előzetes eredményei. In: I. Magyar Agrártudományi Doktoranduszok Szimpóziuma 2023: Absztraktkötet. Szerk.: Hajdú Péter, Doktoranduszok Országos Szövetsége, Debrecen, 37, 2023. ISBN: 9786156457189

**List of other publications**

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10. **Ábri, T.**: Szelektált akácklónokkal létesített akác iparifa ültetvény faállomány-szerkezeti és NDVI vizsgálatának kezdeti eredményei =: Stand structure and NDVI study of selected black locust clones in an industrial tree plantation : early evaluation. In: Erdészeti Tudományos Konferencia : Konferencia Kiadvány. Szerk.: Czímber Kornél, Soproni Egyetemi Kiadó, Sopron, 46-52, 2022. ISBN: 9789633344200
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23. Honfy, V., Pödör, Z., Keserű, Z., Rásó, J., **Ábri, T.**, Borovics, A.: The effect of tree spacing on yields of Alley Cropping Systems: A case study from Hungary.  
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26. **Ábri, T.**, Keserű, Z., Szabó, F. M., Rédei, K.: Structure of black walnut (*Juglans nigra* L.) stands on sandy soils in Hungary.  
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28. **Ábri, T.**, Rásó, J., Szabó, G.: Akác állomány különböző ültetési hálózatainak összehasonlító elemzése térinformatikai módszerrel.  
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31. **Ábri, T.**: Szelektált akáclónokkal létesített akác iparifa-ültetvény faállomány-szerkezeti és NDVI vizsgálatának kezdeti eredményei.  
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*Erdészeti Lapok*. 157 (3), 86-89, 2022. ISSN: 1215-0398.

**Total IF of journals (all publications): 18,749**

**Total IF of journals (publications related to the dissertation): 7,5**

The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of the Journal Citation Report (Impact Factor) database.

09 November, 2023



