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# STAND STRUCTURE AND YIELD OF MIXED BLACK LOCUST (*ROBINIA PSEUDOACACIA* L.) AND WHITE POPLAR (*POPULUS ALBA* L.) STANDS UNDER SANDY SOIL CONDITIONS IN HUNGARY: A CASE STUDY

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**Abstract:** The paper deals with the stand structure and yield of black locust *(Robinia pseudoacacia* L.) forests mixed with white *(Populus alba* L.) in various proportions, partly applying a new methodological approach. The main stand structure and yield factors were determined separately for each species, measured stem by stem, using the volume functions prepared for each species. The ratio of the volumes of the species (A and B) in mixed and in pure stands (based on volume tables) was determined. A close relationship has been found between the ratio by relative total volume and the proportion (by the number of stems) of the species. The relative surplus in the volume of the mixed stands varied between 1.32-1.80 at age 16 and 21 years compared to the control, i.e. the yield of pure stands of the species concerned. The trial has also proven that if two species have a fast initial growth rate and a similar rotation age, they can be planted in mixed stands resulting in mutual advantages.

**Key words:** stand structure, yield, white poplar, black locust, sandy soil

## *STRUKTURA SASTOJINE I PRINOS MEŠOVITIH SASTOJINA BAGREMA (ROBINIA PSEUDOACACIA L.) I BELE TOPOLE (POPULUS ALBA L.) NA PESKOVITIM STANIŠTIMA U MAĐARSKOJ: STUDIJA*

***Izvod:*** *Rad se bavi strukturom sastojina i prinosom bagremovih šuma (Robinia pseudoacacia L.) sa belom topolom (Populus alba L.) kao vrstom primešanom u različitim odnosima, primenjujući, delimično, nov metodološki pristup. Glavna struktura sastojine i faktori koji utiču na prinos su određeni odvojeno za svaku vrstu, mereni stablo po stablo, koristeći zapreminske funkcije određene za svaku vrstu. Odnos zapremina vrsta (A i B) u mešovitim i čistim sastojinama (zasnovani na zapreminskim tablicama) su određene. Bliska veza je pronađena između odnosa po relativnoj ukupnoj zapremini i odnosa (po broju stabala) između vrsta. Relativni dobitak u zapremini kod mešovitih sastojina je varirao između 1.32-1.80 u 16. i 21. godini, u poređenju sa kontrolom, tj. prinos u čistim sastojinama za datu*

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*vrstu. Ogled je takođe dokazao da ako dve vrste imaju brz početni prirast i sličnu dužinu turnusa, one mogu da budu sađene u mešovitim sastojinama i rezultirajući u prednostima za obe strane.*

***Ključne reči:*** *Struktura sastojine, prinos, bela topola, bagrem, peskovito zemljište*

## INTRODUCTION

Technical guidelines of primary forest production are usually aimed at the establishment and management of pure stands. However, mixed stands may provide advantages that justify mixed cultivation of two or three species, provided that the site conditions are suitable. Mixing has mainly biological and ecological advantages, but it may also have a positive effect on yield. In addition, non-material benefits of mixed forests, e.g. improvement of the environment and satisfaction of social expectations, are increasingly acknowledged. The scientific study of mixed forests is a more complex task than the study of pure stands. This partly explains why only limited efforts have been made so far to quantify the growth and yield of mixed stands and to compare the results with pure stands.

Forestry professionals started the description of the structure and species composition of mixed forests by the end of the 18$^{th}$ century. Oak was studied first, followed the admixed tree species. Later other mixed forests types were studied. In the beginning of the 19th century mainly monoculture forests were established but from the middle of the century there was a shift back to mixed forests (Heyer, 1854).

Early in the 20th century analyses made in Central Europe showed that the volume production of mixed spruce and Scots pine stands exceeded that of pure stands (Schilling, 1925; Busse, 1931). Similarly, it has been observed that the admixing of birch in spruce forests does not reduce the yield of spruce (Fiedler, 1966). For instance, a mixture of 40% birch and 60% spruce provided a greater total yield than the same proportions of these species when grown in pure stands (Lappi-Seppala, 1930). Furthermore, at fertile sites Wiedemann (1943) reported that the yield of mixed beech and spruce forests was higher than that of pure spruce stands. By contrast, at poor sites the yield of mixed stands was lower than of pure spruce stands.

Assmann (1970) paid great attention to the study of mixed stands in this book, 'The Principles of Forest Yield Study'. Although it is almost impossible to define comparable pure and mixed experimental plots (for a given set of species), the main finding of the author is that mixing generally results in a greater total yield.

In practice the choice between mixed or pure stands is a complex issue. Mixed stands are often more resistant to pests and have a higher production level than pure ones. In most cases, the total yield of mixed stands exceeds that of light-demanding tree species grown in monocuture (Smith, 1986). On the other hand, a balanced development of mixed stands is only obtained when the competition between the species involved is not too assymetric. This implies that the species composition of mixed stands and the thinning regime should be adjusted to the site

conditions and, as attemts to do this are not always succesful, mixed stands are frequently claimed by foresters to be more difficult to control than pure stands.

Black locust and white poplar are forest tree species of high significance in Hungary (Rédei *et al*., 2010; Rédei and Veperdi, 2009). Black locust is frequently planted together with white poplar on the sandy ridges between the Danube and Tisza rivers in Central Hungary. In forests covering more than 14,000 ha in this region the joint share of black locust and white poplar exceeds 80%, and 70% of the stands are less than 20 years old.

The objective of this study was to examine the stand structure and growth in an experiment with mixed white poplar and black locust plantations in Hungary. Particularly, the observations from the experiment are used as a basis of estimating the potential advantage of mixed stands and the optimal basal area share of each of the two species.

## MATERIAL AND METHODS

The experiment examined in this paper is located in the Danube-Tisza Interflow region, in the central part of Hungary (location: Ballószög, altitude: less than 80 m; latitude: N 46º 42'; longitude: E 19º 40'). The trial was estblished in a 16-year-old stand that was planted in an agricultural field (one-year old seedlings). The initial proportions of the tree species in scattered mixture were 70% black locust and 30% white poplar. According to the Hungarian classification of forest site types, the study area is located in the forest steppe climate zone with a humidity of less than 50% in July at 2 pm and an annual precipitation of less than 550 mm. The soil is humic with a very shallow rootable depth (<20 cm).

Within the sub-compartment Kecskemét-Ballószög 20 C five plots were established, in which black locust and white poplar occurred in various proportions. The area of plots 1-4 was 0.1 ha each, whereas that of plot 5 was only 0.035 ha. The breast height diameter and x,y coordinates of all trees were measured. The crown diameters were measured in four directions corresponding to the four points of the compass. Finally, height was measured for 20 per cent of the trees in plots 1-4 and 30 per cent of the trees in plot 5. The plots were measured again at age 21.

The main stand structure and yield statics were determined sepeately for each species at ages 16 and 21 years. Volumes were calculated on the basis of stem-by-stem estimates. First, semi-logarithmic diameter-height regressions for each species were prepared. Subsequently, these regressions were used for estimating the height of each tree. Finally, volumes were estimated using the volume functions developed by Sopp (1974):

For white poplar: $v=10^{-8}d^{2}h^{1}(h/[h-1.3])^{2}[-0.4236d\,h+12.43d+4.6h+3298]$

For black locust: $v=10^{-8}d^{2}h^{1}(h/[h-1.3])^{2}[-0.6326\,d\,h+20.23d+0.00h+3034]$

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

The ratio of the volumes of the species in the mixed stands and in pure stands (based on volume tables) was determined this way:

$$RV_A = \frac{volume\ of\ \ A\ species\ in\ mixed\ \ stand}{volume\ of\ \ A\ species\ in\ \ pure\ stand}$$

$$RV_B = \frac{volume\ of\ \ B\ species\ in\ mixed\ \ stand}{volume\ of\ \ B\ species\ in\ \ pure\ stand},$$

where:

$RV_{A.B}$ = the ratio of each species by relative volume,
$RTV_{A+B}$ = $RV_A + RV_B$, where:
$RTV_{A+B}$ = the ratio of the tree species by relative total volume.

The volume of the tree species in the mixed stand in proportion to their pure stands was determined on the basis of yield tables edited by Redei in 1984 for black locust and in 1992 for white poplar.

**RESULTS AND DISCUSSION**

We started by testing the effects of plot and species on the relationship between diameter (cm) and height (m) at age of 16 and 21. At age of 16 it turned out that there was an almost significant effect of plot (p=0.06), and at age of 21 there was a significant effect of species (p=0.01). Accordingly, we used the following four models to estimate tree height:

*P. alba*, at age of 16:
h=-3.29+6.81 ln(d) RMSE= 1.16 m

*R. pseudoacacia*, at age of 16:
h=-3.26+6.94 ln(d) RMSE= 1.57 m

*P. alba*, at age of 21:
h=-5.44+8.72 ln(d) RMSE= 1.96 m

*R. pseudoacacia*, at age of 21:
h=-5.58+8.28 ln(d) RMSE= 2.02 m

Summary statistics regarding the stand structure and increment at age of 16 and 21 are shown in Table 1 and Table 2 for each species and plot.

Table 1 The main stand-structure and yield factors of total stands in black locust and white poplar mixed stand at the age of 16
*Tabela 1 Glavna struktura sastojine i faktori prinosa ukupne sastojine za mešovite sastojine bagrema i bele topole starosti 16 godina*

| Species factors *Faktori vrste* | Plot 1. *Polje 1.* | | | Plot 2. *Polje 2.* | | | Plot 3. *Polje 3.* | | | Plot 4. *Polje 4.* | | | Plot 5. *Polje 5.* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Black locust *Bagrem* | White poplar *Bela topola* | average sum *srednina suma* | Black locust *Bagrem* | White poplar *Bela topola* | average sum *srednina suma* | Black locust *Bagrem* | White poplar *Bela topola* | average sum *srednina suma* | Black locust *Bagrem* | White poplar *Bela topola* | average sum *srednina suma* | Black locust *Bagrem* | White poplar *Bela topola* | average sum *srednina suma* |
| Height, m | 14.8 | 15.5 | - | 14.1 | 15.9 | - | 14.9 | 15.5 | - | 15.0 | 17.4 | - | 15.9 | 20.8 | - |
| DBH, cm | 14.2 | 14.8 | - | 12.2 | 15.0 | - | 12.6 | 14.5 | - | 12.2 | 19.2 | - | 12.6 | 23.0 | - |
| Number Stems/hm$^2$ | 280 | 1320 | 1600 | 560 | 980 | 1540 | 590 | 950 | 1540 | 1150 | 270 | 1420 | 1457 | 57 | 1514 |
| % | 18 | 83 | 100 | 36 | 64 | 100 | 38 | 62 | 100 | 81 | 19 | 100 | 96 | 4 | 100 |
| Basal area m$^2$/hm$^2$ | 4.5 | 22.6 | 27.1 | 6.5 | 17.4 | 23.9 | 7.4 | 15.7 | 23.1 | 13.5 | 7.8 | 21.3 | 18.3 | 2.4 | 20.7 |
| % | 16 | 84 | 100 | 27 | 73 | 100 | 33 | 68 | 100 | 63 | 37 | 100 | 89 | 11 | 100 |
| Volume m$^3$/hm$^2$ | 39.1 | 184.1 | 223.1 | 55.1 | 144.7 | 199.7 | 64.2 | 128.1 | 192.3 | 117.5 | 70.4 | 187.9 | 166.0 | 24.9 | 190.9 |
| % | 18 | 82 | 100 | 28 | 72 | 100 | 33 | 67 | 100 | 63 | 37 | 100 | 87 | 13 | 100 |

Table 2 The main stand-structure and yield factors of total stands in black locust and white poplar mixed stand at the age of 21
*Tabela 2 Glavna struktura sastojine i faktori prinosa ukupne sastojine za mešovite sastojine bagrema i bele topole starosti 21 godine*

| Species factors *Faktori vrste* | Plot 1. *Polje 1.* | | | Plot 2. *Polje 2.* | | | Plot 3. *Polje 3.* | | | Plot 4. *Polje 4.* | | | Plot 5. *Polje 5.* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Black locust *Bagrem* | White poplar *Bela topola* | average sum *srednina suma* | Black locust *Bagrem* | White poplar *Bela topola* | average sum *srednina suma* | Black locust *Bagrem* | White poplar *Bela topola* | average sum *srednina suma* | Black locust *Bagrem* | White poplar *Bela topola* | average sum *srednina suma* | Black locust *Bagrem* | White poplar *Bela topola* | average sum *srednina suma* |
| Height, m | 17.2 | 19.3 | - | 16.1 | 19.7 | - | 16.3 | 19.3 | - | 15.9 | 22.3 | - | 16.1 | 24.2 | - |
| DBH, cm | 15.6 | 17 | - | 13.7 | 17.8 | - | 14.1 | 17.1 | - | 13.4 | 24.2 | - | 13.8 | 29.8 | - |
| Number Stems/hm$^2$ | 280 | 1300 | 1580 | 560 | 900 | 1460 | 580 | 910 | 1490 | 1150 | 270 | 1420 | 1453 | 57 | 1510 |
| % | | 82 | 100 | 38 | 62 | 100 | 39 | 61 | 100 | 81 | 19 | 100 | 96 | 4 | 100 |
| Basal area m$^2$/hm$^2$ | 5.4 | 29.6 | 35 | 8.3 | 22.4 | 30.7 | 9 | 20.8 | 29.8 | 16.2 | 12.4 | 28.6 | 21.6 | 4 | 25.6 |
| % | 15 | 85 | 100 | 27 | 73 | 100 | 30 | 70 | 100 | 57 | 43 | 100 | | | 100 |
| Volume m$^3$/hm$^2$ | 53.3 | 302.6 | 355.9 | 78.7 | 234.6 | 313.2 | 86.3 | 213.3 | 299.6 | 150.2 | 141.6 | 291.8 | 205.8 | 50.9 | 256.7 |
| % | 15 | 85 | 100 | 25 | 75 | 100 | 40 | 60 | 100 | 51 | 49 | 100 | 80 | 20 | 100 |

We have determined the function describing the relationship between the ratio by relative total volume and the proportion (by the number of stems) of the species in question both for black locust and white poplar, as follows:

$RV_{BL} = 0.0286 + 0.0095E_N\%$, (r=0.94),
$RV_{WP} = 0.0165 + 0.1334E_N\%$, (r=0.96).

White poplar grows faster in height than black locust if they are planted together. Black locust could never overgrow white poplar in mixed stands made up of these two species. The difference is particularly impressive if white poplar is scattered in the stand.

Table 3 Changes in the relative volume of mixed black locust-white poplar stands at the age of 16
*Tabela 3 Promene u relativnoj zapremini kod mešovitih sastojina bagrema i bele topole u 16. godini*

| Plot number *Broj polja* | Tree species *Vrsta* | EN % | V $_{\text{whole stand}}$ ($m^3/hm^2$) | $RV_A/RV_B$ | $RTV_{A+B}$ |
|---|---|---|---|---|---|
| 1 | Black locust *Bagrem* | 18 | 39 | 0.25 | 1.55 |
| | White poplar *Bela topola* | 82 | 184 | 1.30 | |
| 2 | Black locust *Bagrem* | 36 | 55 | 0.35 | 1.37 |
| | White poplar *Bela topola* | 64 | 145 | 1.02 | |
| 3 | Black locust *Bagrem* | 38 | 64 | 0.41 | 1.31 |
| | White poplar *Bela topola* | 62 | 128 | 0.90 | |
| 4 | Black locust *Bagrem* | 81 | 118 | 0.75 | 1.24 |
| | White poplar *Bela topola* | 19 | 70 | 0.49 | |
| 5 | Black locust *Bagrem* | 96 | 166 | 1.06 | 1.24 |
| | White poplar *Bela topola* | 4 | 25 | 0.18 | |
| Control *Kontrola* | Black locust *Bagrem* (Yield table: Rédei, 1984) *(Zapreminske tablice: Rédei, 1984)* | 100 | 157 | 1.00 | 1.00 |
| Control *Kontrola* | White poplar *Bela topola* (Yield table: Rédei, 1992) *(Zapreminske tablice: Rédei, 1984)* | 100 | 142 | 1.00 | 1.00 |

[1] - The proportion (by the number of stems) of the species in question *Udeo (prema broju stabala) date vrste*
[2] - Whole stand volume *Ukupna zapremina sastojine*
[3] - The ratio of each species by relative volume *Udeo vrste prema relativnoj zapremini*
[4] - The ratio of the tree species by relative total volume *Udeo vrste prema relativnoj ukupnoj zapremini*

It can be concluded from the comparison of the volume per hectare values that the relative volume surplus of mixed stands at the age of 16 varied between 1.24 and

1.55 and at the age of 21 varied between 1.32 and 1.80 compared to the control, i.e. the volume of pure stands of the species in the mixed stands (Table 3, Table 4). The greater the number of white poplar stems was, the greater the volume of the whole mixed stand was. The ratio by relative total volume in the plot with the highest proportion of white poplar (Plot 1) was 1.55 at the age of 16 and 1.80 at the age of 21, while the same value for Plot 4 and Plot 5, where the proportion of white poplar was the lowest, it was 1.24 at age of 16 and 1.32 as well as 1.49 at age of 16 only. The relative volume surplus of white poplar significantly exceeds that of black locust if the number of stems is more or less the same.

Table 4 Changes in the relative volume of mixed black locust-white poplar stands at the age of 21

*Tabela 4 Promene u relativnoj zapremini kod mešovitih sastojina bagrema i bele topole u 21. godini*

| **Plot number** *Broj polja* | **Tree species** *Vrsta* | **EN**[1] **%** | **V** $_{\text{whole stand}}$[2] **($m^3/hm^2$)** | **$RV_A/RV_B$**[3] | **$RTV_{A+B}$**[4] |
|---|---|---|---|---|---|
| **1** | Black locust *Bagrem* | 18 | 53 | 0.27 | 1.8 |
| | White poplar *Bela topola* | 82 | 303 | 1.53 | |
| **2** | Black locust *Bagrem* | 38 | 79 | 0.40 | 1.58 |
| | White poplar *Bela topola* | 62 | 235 | 1.18 | |
| **3** | Black locust *Bagrem* | 39 | 86 | 0.44 | 1.52 |
| | White poplar *Bela topola* | 61 | 213 | 1.08 | |
| **4** | Black locust *Bagrem* | 81 | 150 | 0.77 | 1.49 |
| | White poplar *Bela topola* | 19 | 142 | 0.72 | |
| **5** | Black locust *Bagrem* | 96 | 206 | 1.06 | 1.32 |
| | White poplar *Bela topola* | 4 | 51 | 0.26 | |
| **Control** ***Kontrola*** | Black locust *Bagrem* (Yield table: Rédei, 1984) *(Zapreminske tablice: Rédei, 1984)* | 100 | 195 | 1.00 | 1.00 |
| **Control** ***Kontrola*** | White poplar *Bela topola* (Yield table: Rédei, 1992) *(Zapreminske tablice: Rédei, 1984)* | 100 | 198 | 1.00 | 1.00 |

[1] - The proportion (by the number of stems) of the species in question *Udeo (prema broju stabala) date vrste*

[2] - Whole stand volume *Ukupna zapremina sastojine*

[3] - The ratio of each species by relative volume *Udeo vrste prema relativnoj zapremini*

[4] - The ratio of the tree species by relative total volume *Udeo vrste prema relativnoj ukupnoj zapremini*

## CONCLUSIONS

This trial proves that if two species have a fast initial growth rate and a similar rotation age, they can be planted in mutually advantageous mixed stands. However, planting (mixing) schemes have to be chosen in such a way that they

increase the compatibility of the two or more species in the stand. In addition to the effect on the yield, the method of mixing also affects the execution of intermediate cuttings. For example, if the site is suitable both for black locust and white poplar and they are mixed by single individuals, the dominating species having a larger number of stems is preferred during intermediate cuttings. In the case of mixing by groups, the proportion of the species within the groups and the growth determine which species shall be favoured. The significant effect of the mixing method on the yield requires further studies.

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***Rezime***

***STRUKTURA SASTOJINE I PRINOS MEŠOVITIH SASTOJINA BAGREMA (ROBINIA PSEUDOACACIA L.) I BELE TOPOLE (POPULUS ALBA L.) NA PESKOVITIM STANIŠTIMA U MAĐARSKOJ: STUDIJA***

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*Rad se bavi strukturom sastojina i prinosom bagremovih šuma (Robinia pseudoacacia L.) sa belom topolom (Populus alba L.) kao vrstom primešanom u različitim odnosima, primenjujući, delimično, nov metodološki pristup. Glavna struktura sastojine i faktori koji utiču na prinos su određeni odvojeno za svaku vrstu, mereni stablo po stablo, koristeći zapreminske funkcije određene za svaku vrstu. Odnos zapremina vrsta (A i B) u mešovitim i čistim sastojinama (zasnovani na zapreminskim tablicama) su određene. Bliska veza je pronađena između odnosa po relativnoj ukupnoj zapremini i odnosa (po broju stabala) između vrsta. Relativni dobitak u zapremini kod mešovitih sastojina je varirao između 1.32-1.80 u 16. i 21. godini, u poređenju sa kontrolom, tj. prinos u čistim sastojinama za datu vrstu. Ogled je takođe dokazao da ako dve vrste imaju brz početni prirast i sličnu dužinu turnusa, one mogu da budu sađene u mešovitim sastojinama i rezultirajući u prednostima za obe strane. Međutim, šema plantaže mora da bude izabrana tako, da uveća kompatibilnost datih vrsta. Mešanje vrsta utiče i na prorede te ako su pomešane na nivou pojedinačnih stabala treba proređivati dominantniju vrstu. U slučaju mešanja na nivou grupa, učešće vrsta unutar vrte i i njihov rast će uticati na to koja će vrsta biti favorizovana.. Značaj efekta mešanja vrsta na prinos ukazuje na potrebu daljnih istraživanja na ovoj problematici.*