https://doi.org/10.17221/53/2024-JFS

Stand structural analyses of grey poplar (*Populus* × *canescens*) stands focused on the expected volume in Hungary

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Citation: Ábri T., Keserű Z., Honfy V., Borovics A., Rédei K. (2024): Stand structural analyses of grey poplar (*Populus* × *canescens*) stands focused on the expected volume in Hungary. J. For. Sci, 70: 539–544.

Abstract: Grey poplar (*Populus* × *canescens*) is a natural hybrid of white poplar (*Populus alba* L.) and Eurasian aspen (*Populus tremula* L.). It could play a significant role in the afforestation of marginal sites which stretch out on ever more areas due to the negative effects of local climate change. Based on stand structure analyses of grey poplar stands grown on the sandy sites of Hungary, the following relations were found: There is a strong relationship between tree height and stand volume (R^2 = 0.7256), as well as between basal area per ha and stand volume (R^2 = 0.9158). There is a moderate relationship between diameter at breast height and stand volume (R^2 = 0.6175). The results could contribute to a more accurate assessment of applied silvicultural technologies.

Keywords: marginal sites; poplars; tree growth; yield modelling

Grey poplar (*Populus* × *canescens*) is a natural hybrid of white poplar (*Populus alba* L.) and Eurasian aspen (*Populus tremula* L.). Since the parent species variability is high, grey poplar is also extremely rich in forms (Sivolapov et al. 2019). It can be found from Western Europe to Central Asia, wherever the habitat of white poplar and Eurasian aspen overlap. In Hungary, native poplar stands (including grey poplar) cover nearly 97 000 ha (NLC 2022), which is over 5% of the total area covered by for-

Supported by the Ministry of Culture and Innovation of Hungary in the TKP2021-NKTA-43 project frame, funded from the National Research, Development, and Innovation Fund, financed under the TKP2021-NKTA funding scheme.

https://doi.org/10.17221/53/2024-JFS

ests. About 80% of the native poplar stands can be found in central Hungary in the sand ridges of the Danube-Tisza interfluve. The average growing stock of native poplar stands is 213 $m^3 \cdot ha^{-1}$, and its average age at final cutting is 32 years. Grey poplar is one of the most valuable species in the native poplar stands of Hungary. It is due to its rapid growth, it only requires moderate site quality, it has relatively good tolerance to pests and diseases, and its wood can be used for multiple purposes (pulp and cellulose industry, plywood and packaging). All the above-mentioned facts contribute to the spread of grey poplar stands in the afforestation of sandy soils.

Hungary has a long history of investigating the yield of grey (and white) poplar stands (Sopp 1957; Szodfridt, Palotás 1973; Halupa, Kiss 1978; Halupa, Tóth 1988; Rédei 1992, 1994, 1999; Rédei, Keserű 2012; Rédei et al. 2010, 2019), while Pokorná et al. (2018, 2020) studied genetic diversity and gene preservation of grey poplar in the Czech Republic. Recently, in the USA, Rogers et al. (2023) conducted a literature review of the factors influencing poplar water use, taking into account non-hybrid and hybrid poplars, including grey poplar.

As the proportion of grey poplar has been rising in afforestation, it was justified to study its stand structure, analyse its yield and assess the results on central Hungary sandy sites. In this paper, we present the most relevant interrelations in an innovative way. The results can be used to predict the total volume as a function of either height, diameter at breast height, or basal area per ha. The results introduced here fill a gap at an international level, and therefore it is suggested to apply them in a wider context.

MATERIAL AND METHODS

Forty-six temporary plots (approx. 500–1 000 m^2) located in forest stands of the sand ridge of the Danube-Tisza interfluve were established for stand structural investigations. The pure stands are owned by the state and their age varies between 14 and 48 years. They have been managed on the basis of growth and according to the silvicultural model of white poplar stands.

The key stand characteristics were measured in the course of the stand surveys, and then, on the basis of collected data, major stand structure features were calculated, such as mean height (H), diameter at breast height (DBH), volume (V), basal area (BA), and number of stems per ha (N), see Table 1. Stem volume (v) was estimated by the volume function of Sopp and Kolozs (2013).

The conceptual outline for constructing the relationships (regressions) determined from the data is presented in Table 1 as follows:
– mean height (H) of the stand – f(DBH);
– stem number per ha (N) – f(DBH);
– volume per ha (V) – f(H);
– volume per ha (V) – f(DBH);
– volume per ha (V) – f(BA).

The regression analyses were computed using the Microsoft Excel. The strength of relationships was determined by the general rules of statistics (Moore et al. 2013).

Table 1. Stand structural parameters of the sample stands

Subcompartment	Age (years)	H (m)	DBH (cm)	V ($m^3 \cdot ha^{-1}$)	BA ($m^2 \cdot ha^{-1}$)	N ($tree \cdot ha^{-1}$)
Kunpeszér 26A	14	11.9	8.2	54.26	8.44	1 600
Kelebia 27E	16	16.0	14.3	125.50	14.41	900
Kelebia 79C	17	14.7	12.0	78.66	9.93	880
Kunadacs 42B	17	15.9	14.6	206.48	23.88	1 420
Hetényegyháza 10F	17	22.3	26.1	242.65	21.32	400
Hetényegyháza 10E	17	14.2	18.0	124.82	15.26	600
Kunpeszér 18B	18	11.9	11.0	106.48	16.11	1 690
Kecskemét 8A	18	12.9	12.1	136.86	19.24	1 660
Kelebia 3F	18	16.5	17.0	179.82	22.76	1 000

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Table 1. To be continued

Subcompartment	Age (years)	*H* (m)	*DBH* (cm)	*V* ($m^3 \cdot ha^{-1}$)	*BA* ($m^2 \cdot ha^{-1}$)	*N* ($tree \cdot ha^{-1}$)
Kelebia 26E	18	21.4	22.0	211.50	22.07	580
Tompa 53E	18	13.9	12.5	95.42	12.69	1 040
Kelebia 107C	18	15.6	13.6	102.58	12.14	840
Kecskemét 7D	19	15.3	16.2	136.66	16.13	780
Kunadacs 41G	20	13.6	11.4	74.94	10.17	1 000
Kelebia 38F	20	16.7	18.4	153.34	15.86	600
Kunpeszér 11C	21	12.5	11.7	119.12	17.39	1 620
Kunpeszér 11E	22	18.5	18.5	176.49	18.01	670
Kunpeszér 19H	22	21.5	22.4	277.67	25.17	640
Tompa 58I	22	17.6	17.0	161.46	17.24	760
Kunpeszér 8C	23	15.5	15.2	146.66	17.68	970
Kunpeszér 25B	24	19.3	22.7	149.41	14.60	360
Kelebia 61B	25	20.4	21.6	370.50	34.99	960
Tompa 52I	26	17.4	18.8	180.46	20.46	740
Tompa 16A	26	22.2	23.4	272.68	24.16	560
Tompa 52H1	26	14.7	16.4	144.68	17.77	840
Tompa 52H2	26	17.5	20.7	203.10	21.45	640
Kelebia 53C	26	20.3	22.6	222.18	20.87	520
Kunpeszér 10D	26	17.0	19.0	177.24	19.51	690
Kunmadaras 36D	27	16.5	16.3	142.93	16.22	780
Kunadacs 41H	27	21.8	25.6	247.33	22.19	430
Tompa 51F	27	21.4	21.8	212.78	20.12	540
Tompa 12C	27	16.6	18.3	184.84	20.44	780
Tompa 50J	28	18.2	19.7	190.18	19.57	640
Hetényegyháza 12B	28	20.3	21.3	242.38	22.91	640
Hetényegyháza 15B	28	25.2	29.0	293.16	23.70	360
Tompa 56A	29	21.5	21.8	225.22	22.31	600
Kelebia 6D	30	26.1	28.2	396.04	31.21	500
Tompa 1E	30	19.6	20.0	254.96	27.13	860
Tompa 7A	30	21.2	27.1	219.80	21.91	380
Hetényegyháza 5D	30	21.8	29.3	288.40	25.63	380
Tompa 50F	31	16.3	14.8	96.94	11.36	660
Kunadacs 42L	33	13.7	13.6	78.82	10.48	720
Kerekegyháza 23A1	38	23.9	23.3	295.26	24.79	580
Kerekegyháza 23A2	41	23.2	25.5	336.80	29.51	580
Kelebia 76C	42	19.8	18.0	323.16	31.45	1 240
Kunadacs 43E	48	19.5	22.9	303.42	29.50	720

H – mean height; *DBH* – mean diameter at breast height; *V* – volume per ha; *BA* – basal area per ha; *N* – number of trees per ha

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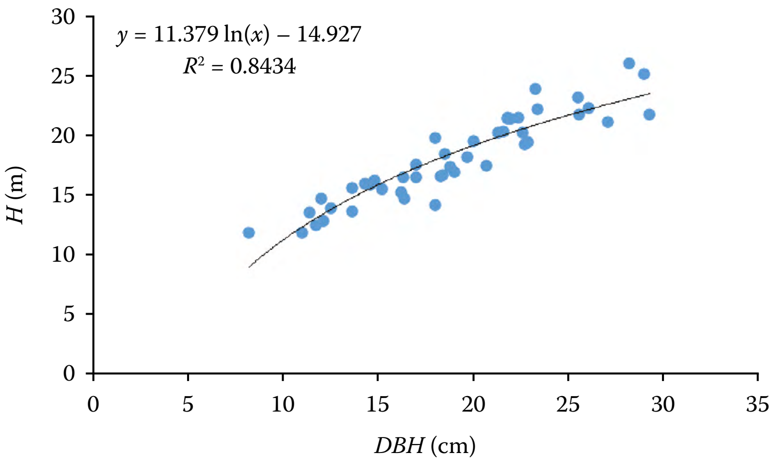

Figure 1. Relationship of height (*H*) and diameter at breast height (*DBH*), *n* = 46 (number of studied plots)

RESULTS AND DISCUSSION

Figure 1 shows the relationship between diameter at breast height (*DBH*) and height (*H*) of the 46 investigated grey poplar stands, where *H* = 18.1 m, *DBH* = 19.0 cm, R^2 = 0.8434. *DBH* varies between 8 cm and 29 cm, and corresponding tree heights range between 12 m and 26 m. Tree height can be used to choose the forest tending method with respect to stand growth and age. In grey poplar stands, the cleaning(s) shall take place below 12 m of average height, while the first thinning shall be carried out when the height ranges between 12–17 m, and the second thinning should be done between 16–23 m (Rédei 2007; Rédei, Keserű 2022).

The correlation between the number of stems per ha (*N*) and diameter at breast height is shown in Figure 2, where: $N = 2\,518.3\,e^{-0.065\,DBH}$ and $R^2 = 0.6659$. The change in *N* can be described as the function of age, where the decline in the number of trees per ha as a function of age is the result of tending cuttings. The number of stems per ha (*N*) can also be defined by the distance (*a*) between the stems, see Equation (1).

$$N = \frac{10\,000}{a^2} \quad (1)$$

It is also common to use the ratio of the number of stems per ha to the mean height (*H*), expressed in percentage, see Equation (2).

$$a\,(\%) = \frac{a}{H} \times 100 \quad (2)$$

The number is getting lower with age and silvicultural practices. For grey poplar stands, the average value is between 18% and 21%, depending on the age.

The purpose of selecting superior trees is to achieve the highest volume (tree mass) and quality possible in the given site, according to the ecological conditions. Figure 3 shows the volume per ha (*V*) as a function of *H*. The equation is as follows: $V = 24.04\,e^{0.1101\,H}$, $R^2 = 0.7256$. When using this algorithm, it has to be taken into account that de-

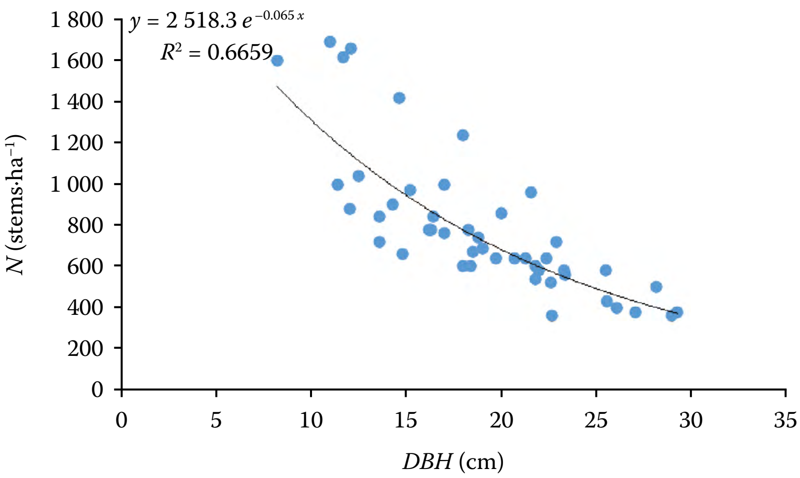

Figure 2. Relationship of stem number per ha (*N*) and diameter at breast height (*DBH*), *n* = 46 (number of studied plots)

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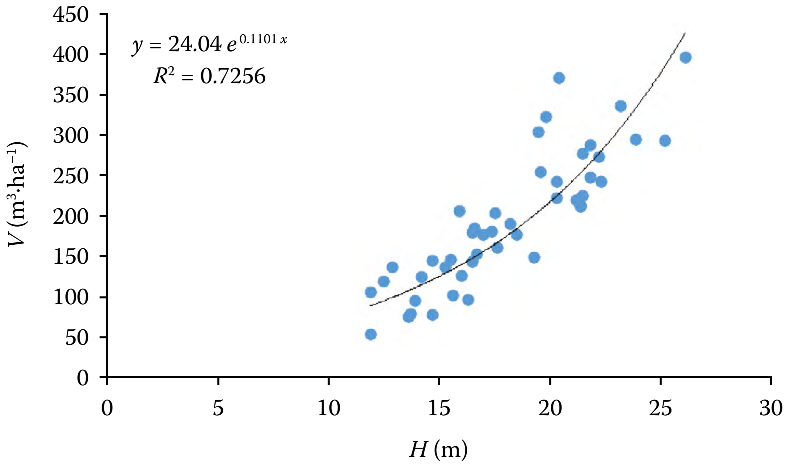

Figure 3. Relationship of volume per ha (V) and height (H), $n = 46$ (number of studied plots)

pending on the yield class (according to the site conditions), a certain height of the stand may be reached at different ages.

Figure 4 shows V as a function of DBH. It can be described as $V = 42.375\, e^{0.0752\, DBH}$, $R^2 = 0.6175$. This correlation is also applicable to creating local nomograms of tree yields. As above, it also has to be considered that reaching the target diameter value could vary in time depending on the yield class. According to the algorithm, the target diameters 18 cm, 20 cm, and 25 cm suggest approximately 170 m^3·ha^{-1}, 200 m^3·ha^{-1}, and 275 m^3·ha^{-1}, respectively.

Figure 5 shows the volume per ha as a function of basal area per ha (BA). The algorithm

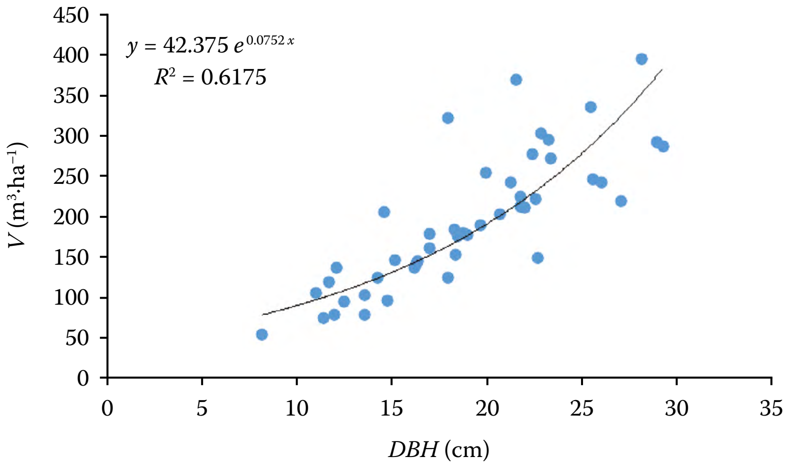

Figure 4. Relationship of volume per ha (V) and diameter at breast height (DBH), $n = 46$ (number of studied plots)

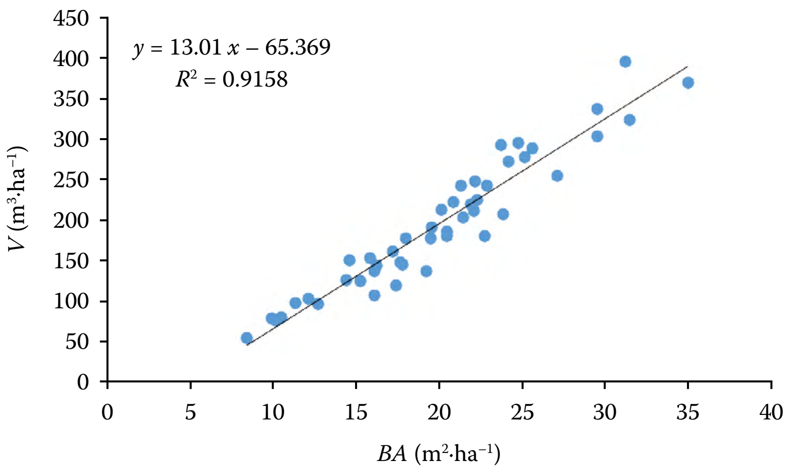

Figure 5. Relationship of volume per ha (V) and basal area (BA), $n = 46$ (number of studied plots)

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is $V = 13.01\,BA - 65.369$, $R^2 = 0.9158$. Its interpretation is identical to that of Figure 4, only the form of expression is different.

CONCLUSION

It is expected that the relevance of relatively drought-tolerant grey poplar will rise in the Central European region due to the negative effects of global and local climate change. The presented correlations of forest stand structures fill a gap in the context of international literature. The algorithms can be used to construct local yield tables, and in an indirect way they help to plan forest tending operations. Furthermore, they are applicable to predict volume per ha based on either tree height, diameter at breast height, or basal area. To summarise, the algorithms presented in this study could help enhance the efforts to further develop the cultivation technology of grey poplar in an innovative manner, which could then be followed in silvicultural practice.

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Received: August 1, 2024
Accepted: September 9, 2024
Published online: October 30, 2024