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Structure of black walnut (*Juglans nigra* L.) stands on sandy soils in Hungary

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Abstract: Understanding the various processes and relationships that take place in forest ecosystems is generally possible only through long-term observations. This is especially true of the biological production of forests, through the in-depth exploration of their structure. In Hungary the black walnut (*Juglans nigra* L.) is one of the most valuable exotic tree species, mainly because of its very valuable wood, with fine tissues and unique colour, for furniture industry. Generally, the species is established by manual seeding, and can also be regenerated well by coppice shoots, but not by natural seeding. Black walnut regularly produces seeds from the age of 25–30 years and its rotation age is 70–80 years. It is also used outside forests due to the very decorative stem and crown shapes. In this paper, out of the stand structure factors, the relationships between age and height (r^2 = 0.7205), age and diameter (r^2 = 0.7719), age and number of stems per ha (r^2 = 0.3485) as well as between diameter and number of stems per ha (r^2 = 0.4595), all considered important for cultivation technology, were examined (based on the data collected in 34 black walnut stands, age of 7 to 67 years). We also analysed the diameter distributions in two black walnut stands with tending operations, reporting them as a case study. Its future role may be increased mainly on sandy soils of better quality, therefore the more accurate exploration of the structure of black walnut stands growing under such conditions can be considered as gap-filling.

Keywords: Juglandaceae; stand structure; growing technology

Black walnut (*Juglans nigra* L.) belongs to the family *Juglandaceae.* It is a deciduous, monoecious tree, grown primarily for its valuable wood (Šindelářová 1973; Beran, Šindelář 1996; Réh 1994, 1996) and not for its fruit, which has a smaller kernel and a much harder nutshell than the Persian walnut. It originates from North America and was introduced into Europe in the 17th century, but its wider spread in Central Europe began in the second half of the 19th century (Herman 1987; Nicolescu 1998; Hrib 2005; Kremer et al. 2008; Nicolescu et al. 2020).

The black walnut is native to the North American Atlantic Region, where its optimal sites are located in the fertile valleys of the eastern tributaries of the Mississippi River. In the natural range, the black walnut between-stand geographical variability is 3–5 times greater than that between individuals within a given stand in terms of growth rate, foliage, and time of leaf fall (Ares, Brauer 2004).

Into Hungary, black walnut was introduced in the 18th century and its first large-scale plantations were established in the 1880s (Rédei et al. 2019). According to the Hungarian National Food Chain Safety Office (NFCSO) Forestry Directorate (2015), the vast majority of its stands, covering approx. 8 000 ha (0.4% of national forest land), are located in the Lower Danube floodplain, where black walnut is primarily suitable for the middle and higher riverbeds. Almost 2/3 (63%) of black walnut stands are located in five counties of Hun-

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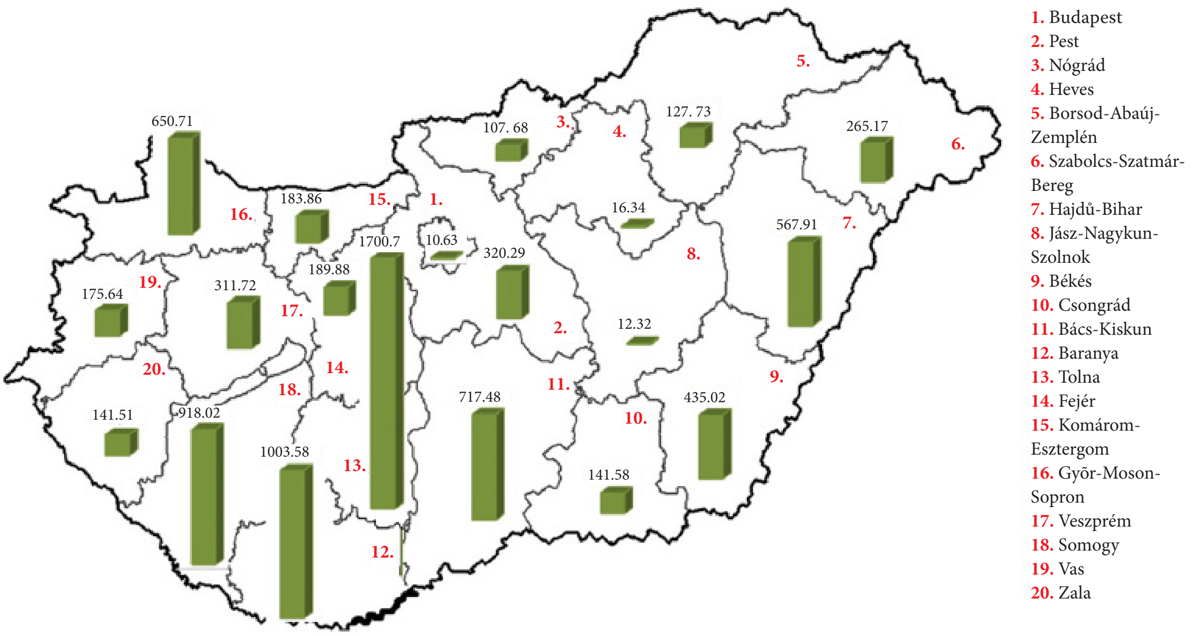

Figure 1. Coverage of black walnut stands by counties in Hungary (ha) (NFCSO Forestry Directorate 2015)

gary (Figure 1): Tolna 21.3%, Baranya 12.5%, Somogy 11.5%, Bács-Kiskun 9.0%, and Győr-Moson-Sopron 8.1%. The importance of black walnut on sandy sites of better quality of the Great Hungarian Plain (Danube-Tisza ridge, Nyírség) is expected to increase in the future.

Black walnut is hardly resistant to late frosts, and a very light-demanding tree (Tóth 1991, 1996). It grows best on deep alluvial soils, identical to the ones for hybrid poplars (Tóth 1991; Hrib et al. 2003). It shows weak growth on too moist, heavy soils and does not tolerate flooding. It is, however, tolerant to soil pH (Ponder 2004; Tokár, Krekulová 2005). On sandy sites favourable for black locust (*Robinia pseudoacacia* L.), well-growing and high-yielding black walnut stands can also be established. Hybridization of black walnut with other *Juglans* spp., which is relatively simple but time-consuming, focuses on faster growth, increased fruit production and production of thin-shelled nuts.

Black walnut reaches the peak of its height growth within 5 years of age; in stands, the intensive height growth stage lasts until the age of 30. Its diameter growth is also relatively fast and long-lasting, and the volume growth culminates at 40–50 years of age. It is usually worth growing black walnut trees until the age of 70–80 years to produce large-sized logs for superior end uses (Tóth 1991, 1996; Rédei 2014; Rédei et al. 2019). Few pests are associated with black walnut: mostly game and frost can damage its stands.

Although black walnut is planted in Hungary for the production of valuable timber, local investigations on stand structure factors are still missing. To reach this objective, a systematic study of black walnut growth rate in different locations is necessary. Therefore, the aim of our study was to show the black walnut growth pattern in pure stands growing on sandy soils mostly in Central Hungary.

MATERIAL AND METHODS

The datasets originate from two sources, of which the first is the forest management plans (FMP). Here, the stand structure factors were examined based on the data collected in 34 black walnut stands, age 7 to 67 years, growing on free-draining sites, with humic sandy soils (Figure 2). The volume per ha was determined based on the relationship $V = BA \times HF$, using data (*HF* – form-heigh; *BA* – basal area) taken from FMP. The value of *HF* (form factor) as a function of *H* (mean height) and *DBH* (mean diameter at breast height) was taken from the volume table (Sopp, Kolozs 2013). The form factor (*f*) was calculated using the following func-

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Figure 2. Location of experimental subcompartments

tion based on the volume table for black walnut (Sopp, Kolozs 2013):

$$f = [3.3554E{-}01 + (-8.2941E{-}05) \times d \times h + 4.5558E{-}03 \times d + 1.3959E{-}03 \times h] \times (h/(h - 1.3))^4/(\pi/4)/10^4 \quad (1)$$

where:
f – form factor for a single tree;
d – diameter at breast height (cm);
h – tree height (m).

The number of stems per ha (N) was given by the quotient of BA per ha and the average BA of the stand calculated using the DBH. The mean tree volume (v) was determined using the formula $v = V/N$.

The FMP data was complemented by recording all trees in six subcompartments, where the following parameters were measured or calculated on experimental plots of 500 m^2: number of stems, tree height, *DBH* over bark, stem volume and mean tree volume. The stem volume was calculated using the volume function based on the volume table for black walnut (Sopp, Kolozs 2013), see below:

$$v = [2.6353E{+}03 + (-6.5142E{-}01) \times d \times h + 3.5781E{+}01 \times d + 1.0963E{+}01 \times h] \times (h/(h - 1.3))^4 \times d^2 \times h/10^8 \quad (2)$$

where:
v – stem volume (m^3);
d – diameter at breast height (cm);
h – tree height (m).

The trees were divided into three categories depending on the function they play when carrying out tending operations: main crop trees, secondary crop trees and trees to be removed. The data were analysed using IBM SPSS statistical software package (Version 22.0, 2013).

RESULTS AND DISCUSSION

Site descriptions including location (subcompartments), site type (based on Járó 1962; Stefanovits 1963), and the most important dendrometric characteristics (e.g., age, *H*, *DBH*, *V*, *N*, *BA*, mean tree volume) are shown in Table 1.

The distribution of sample plots within the production class curves of black walnut (Palotás 1973) is depicted in Figure 3, where the majority of stands belong to production classes II to IV.

The compilation of local volume or production tables (model) was not possible yet by using the correlations between important stand structure factors of the subcompartments included in the study.

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Table 1. Location, site type and stand characteristics

Location of sub-compartments	Climate	Hydrology	Genetic soil type	Depth of productive layer	Soil texture	Age (years)	*H* (m)	*DBH* (cm)	*DBH*/*H* × 100 (%)	*V* ($m^3 \cdot ha^{-1}$)	*N* ($stems \cdot ha^{-1}$)	*BA* ($m^2 \cdot ha^{-1}$)	Mean tree volume (dm^3)
Pusztavacs 39 C	1	1	1	2	1	7	4	3	75.00	35.00	7 000	0.00	5.00
Csátalja 26F	1	1	1	3	1	8	2	3	150.00	40.00	7 860	5.56	5.09
Tázlár 121G	1	1	1	2	1	13	8	10	125.00	208.00	2 794	21.94	74.46
Tázlár 74G	1	2	1	2	1	14	5	6	120.00	118.00	5 004	14.15	23.58
Érsekhalma 12G	1	1	2	3	1	16	8	8	100.00	175.00	3 672	18.46	47.65
Mikebuda 17 K	1	1	1	2	1	18	17	14	80.46	69.00	688	11.00	100.29
Borota 202R	1	1	2	2	1	21	11	8	72.73	129.00	2 417	12.15	53.38
Bugacpusztaháza 167I	1	1	1	2	1	22	12	13	108.33	94.00	644	8.55	146.01
Érsekhalma 54J	1	1	1	2	1	22	17	18	105.88	272.00	829	21.09	328.27
Borota 212G	1	1	1	2	1	23	12	12	100.00	14.00	113	1.27	124.41
Szentkirály 68J	1	1	1	2	1	23	15	12	80.00	196.00	1 428	16.14	137.30
Csávoly 2D	1	1	1	1	1	23	15	13	86.67	226.00	1 403	18.62	161.14
Hajós 156E	1	1	1	1	1	23	17	17	100.00	219.00	748	16.98	292.80
Érsekhalma 58H	1	1	1	2	1	26	13	12	92.31	146.00	1 134	12.83	128.70
Érsekhalma 51D	1	1	2	3	1	27	12	15	125.00	143.00	736	13.00	194.39
Csávoly 1D	1	1	1	1	1	27	13	13	100.00	196.00	1 298	17.22	151.05
Érsekhalma 59K	1	1	1	2	1	28	12	12	100.00	160.00	1 286	14.55	124.41
Kecskemét 359B	1	1	1	2	1	29	10	11	110.00	152.00	1 562	14.84	97.31
Kecskemét 359U	1	1	1	2	1	29	10	11	110.00	152.00	1 562	14.84	97.31
Jánoshalma 148C	1	1	1	2	1	30	17	17	100.00	237.00	809	18.37	292.80
Érsekhalma 59M	1	1	1	2	1	31	13	12	92.31	181.00	1 406	15.91	128.70
Mélykút 19E	1	1	1	1	1	32	11	12	109.09	102.00	849	9.60	120.11
Tápiószecső 9 E	1	1	1	2	1	34	19	19	97.94	116.00	479	12.90	242.17
Gyömrő 3 E	1	1	1	2	1	34	16	17	108.28	113.00	651	14.60	173.58
Tápióság 4 G	1	1	1	2	1	35	19	19	98.45	218.00	875	23.60	249.14
Csévharaszt 109 C	1	1	1	2	1	36	14	15	105.63	191.00	1 492	25.80	128.02
Érsekhalma 7L	1	1	1	1	1	37	22	29	131.82	350.00	358	23.65	977.57
Ócsa 48 E	1	1	1	2	1	37	12	17	142.86	121.00	804	18.70	150.50
Üllő 11 D	1	1	1	2	1	37	15	17	110.39	202.00	1 137	26.10	177.66

Climate: 1 – forest-steppe climate; hydrology: 1 – free-draining site; 2 – periodic water effect; genetic soil type: 1 – humic sandy soil; 2 – chernozem-like sandy soil; depth of productive layer: 1 – shallow; 2 – medium deep; 3 – deep; soil texture: 1 – sand

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Table 1. Location, site type and stand characteristics

Location of sub-compartments	Climate	Hydrology	Genetic soil type	Depth of productive layer	Soil texture	Age (years)	*H* (m)	*DBH* (cm)	*DBH*/*H* × 100 (%)	*V* ($m^3 \cdot ha^{-1}$)	*N* ($stems \cdot ha^{-1}$)	*BA* ($m^2 \cdot ha^{-1}$)	Mean tree volume (dm^3)
Borota 203G	1	1	2	3	1	44	19	21	110.53	252.00	533	18.45	473.13
Tápióság 1I	1	1	1	2	1	45	18	18	100.00	166.00	726	17.60	228.65
Csátalja 4G	1	1	2	3	1	59	22	27	122.73	265.00	313	17.91	847.38
Érsekhalma 44D	1	1	1	2	1	59	22	30	136.36	328.00	314	22.16	1 046.15
Pusztavacs 148 D	1	1	1	2	1	60	18	19	103.26	172.00	648	17.30	265.43
Ruzsa 11B	1	1	1	2	1	61	18	24	133.33	219.00	365	16.49	600.77
Érsekhalma 1B	1	1	1	2	1	62	24	28	116.67	373.00	389	23.97	958.11
Érsekhalma 27I	1	1	1	2	1	64	21	22	104.76	350.00	639	24.27	548.15
Érsekhalma 31K	1	1	1	2	1	65	24	34	141.67	332.00	235	21.34	1 412.72
Érsekhalma 59E	1	1	1	2	1	65	27	24	88.89	386.00	511	23.11	755.49
Borota 203F	1	1	2	3	1	67	23	33	143.48	309.00	238	20.36	1 298.34

Climate: 1 – forest-steppe climate; hydrology: 1 – free-draining site; 2 – periodic water effect; genetic soil type: 1 – humic sandy soil; 2 – chernozem-like sandy soil; depth of productive layer: 1 – shallow; 2 – medium deep; 3 – deep; soil texture: 1 – sand

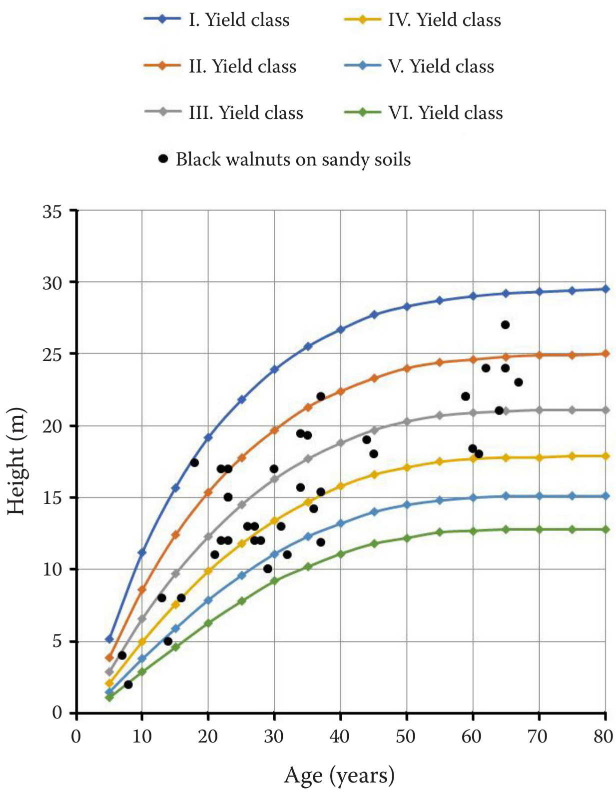

Figure 3. Location of experimental plots within the production class curves of black walnut (Palotás 1973)

The results presented below illustrate the evolution of growth characteristics of black walnut grown under sandy soil conditions, and thus they can be considered as gap-filling in terms of the relevant literature. For instance, Figure 4 shows the evolution of *H* between 7 and 67 years of age, where the mean height of stands close to the rotation age (approx. 70 years) on richer sandy soils is about 25 m.

Figure 5 shows the evolution of mean diameter (*DBH*) between 7 and 67 years of age, when the *DBH* value in stands close to the rotation age (70 years) reaches 28–30 cm.

Figure 6 illustrates an important correlation for stand improvement. The reduction of the number of stems per ha as a function of age indicates the intensity of silvicultural interventions; it provides information for the so-called optimal stem number maintaining system (close to the optimum at a given age). It is also possible to deduce the approximate stem number at the targeted rotation age.

The *DBH-N* relationship (Figure 7) allows the determination of the approximate growing space con-

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sidered necessary to reach a certain target diameter. This is especially important for black walnut as maximizing diameter growth is the main cultivation goal over the age of 40 years. However, the stem number per ha is not only a diameter-dependent structural factor, as the same value of basal area per hectare which is calculated based on *DBH* may be correlated with different stem numbers per ha.

Case studies. The most important stand structure and yield traits of the 20-year-old black walnut stand on Bugacpusztaháza 167 I experimental plot before the second pre-commercial thinning were the following: *H* = 10.7 m, *DBH* = 11.6 cm, *N* = 1466 stems·ha^{-1} (of which secondary stand 405 stems·ha^{-1}, *BA* = 15.5 m^2·ha^{-1}, *V* = 102.6 m^3·ha^{-1}). The range of the selected secondary stand DBH is 7.5 cm (Figure 8).

In a 61-year-old black walnut stand (Pusztavacs 173 B experimental plot), the main stand structure and yield traits were as follows: *H* = 24.6 m, *DBH* = 26.8 cm, *N* = 450 stems·ha^{-1} (of which the secondary stand 170 stems·ha^{-1}), *BA* = 23.1 m^2·ha^{-1}, *V* = 338.2 m^3·ha^{-1}. The range of the selected secondary stand *DBH* is 16 cm (Figure 9).

The rotation age of black walnut stands under sandy soil conditions can be predicted to be 70–80 years (Rédei et al. 2019). Based on our research one can conclude that stands on good sandy sites can reach *H* = 25 m and *DBH* = 28–30 cm in the above age interval. The number of trees per hectare at rotation age can be about 250–280, which entails a growing space of approximately 6 × 6 m. This value is approximately 8–9 × 8–9 m in black walnut stands growing on floodplains due to different site conditions (Palotás 1973).

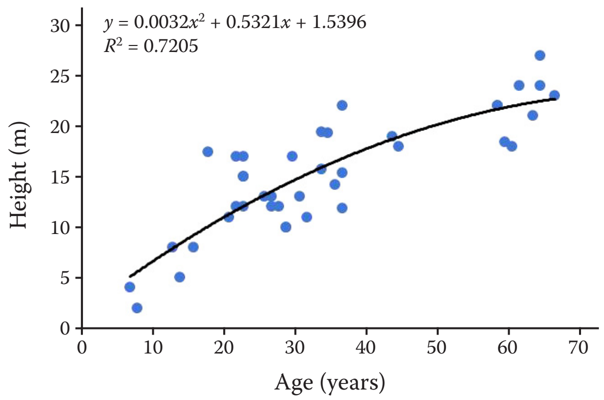

Figure 4. Age-*H* relationship

H – mean height

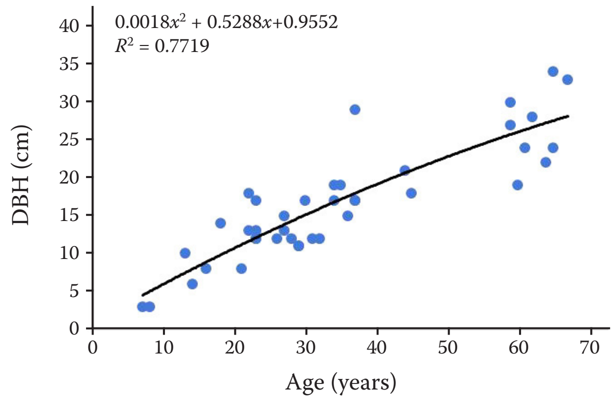

Figure 5. Age-*DBH* relationship

DBH – diameter at breast height

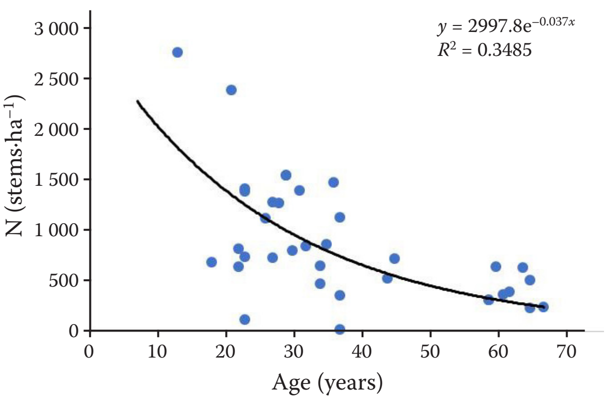

Figure 6. Age-*N* relationship

N – number of stems per ha

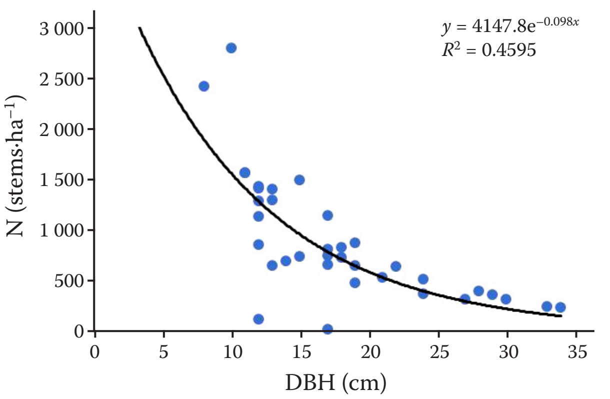

Figure 7. *DBH*-*N* relationship

DBH – diameter at breast height; *N* – number of stems per ha

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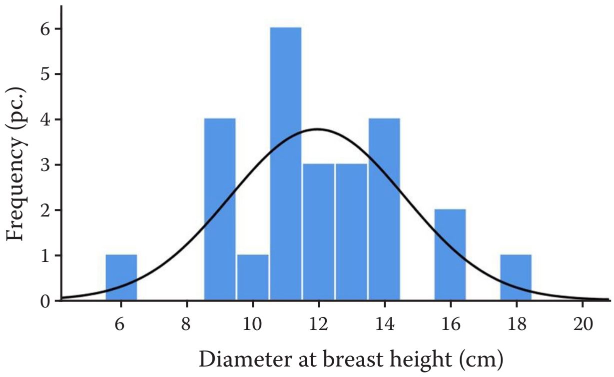

Figure 8. Normal distribution curve of diameter at breast height values in a 20-year-old black walnut stand (Bugac-pusztaháza 167 I Subcompartment)

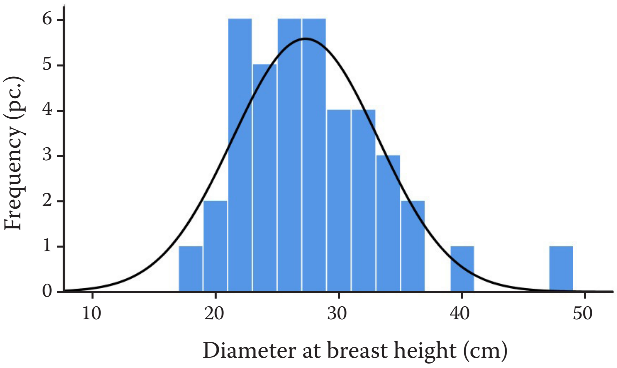

Figure 9. Normal distribution curve of diameter at breast height values in a 61-year-old black walnut stand (Pusztavacs 173 B Subcompartment)

CONCLUSION

The results of this study provide evidence for the possibility and viability of black walnut cultivation under sandy site conditions. An increase of its cultivation area can also be expected in these regions. Determining the production potential of black walnut stands growing on these sites as precisely as possible is one of the important tasks of Research & Development & Innovation activities in the future. The subject of further research should be to compare the yields of black walnut stands with other tree species grown under sandy soil conditions and to improve their cultivation technology.

However, it should be noted here that the growing of black walnut stands in the region must also be coordinated with the aspects of game management. This is the only way to achieve successful cultivation.

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