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Characteristic of chosen biometric features of European ash (*Fraxinus excelsior* L.) due to the age of trees and the forest site type

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Abstract

The dieback process of European ash affects the disappearance of the species from the typical ash sites such as floodplain forests or alder-ash forests. The species occurs more often in moist broadleaved forests and fresh broadleaved forests. Therefore, the main aim of our study was to determine the influence of ash age and the forest site type on the chosen biometric features of dominant and codominant trees. We also aimed to compare the sizes of European ash growing in optimal forest site types with less fertile ones where it does not occur as the main species. We collected the empirical material from 25 plots representing 4 forest site types: fresh broadleaved forest, moist broadleaved forest, floodplain forest, and alder-ash forest. The research plots were located in the Babki, Konstantynowo, and Łopuchówko Forest Districts, western Poland. The age of ash varied from 52 to 144 years. On each plot, we measured a tree height and a diameter at breast height of 15 dominant and codominant ash trees. Subsequently, we used measured features to calculate the volume of each tree. We carried out the analysis of covariance of diameter at breast height, height, and volume. The analysis showed the strong relationship of examined features with the age of the species and the forest site type. Furthermore, our results indicated the underestimation of the growth possibilities of European ash in fresh broadleaved forest and moist broadleaved forest. In these sites, ash achieved similar sizes in comparison to optimal forest site types i.e. floodplain forest and alder-ash forest. This result cannot be omitted in forestry practice, especially in silviculture, which should aim to support the natural regeneration of European ash in differentiated site conditions.

Keywords: European ash, forest site type, age of a tree, biometric features

Introduction

European ash is an important native component of broadleaved forests in Europe within the range of temperate climate zone with atlantic and transitional air masses (Fraxigen 2005, Euforgen 2009). It is favoured by high rainfall, extended vegetation period, and fairly fertile soils (Kerr and Cahalan 2004, Dobrowolska et al. 2011). The success of expansion on the continent also owes to contemporary changes in the rural environment, settling areas abandoned by agriculture and along impounded rivers (Marigo et al. 2000). As a native european tree it ranges from Scandinavia (up to 62° north latitude) to the northern parts (40° south latitude) of the Iberian Peninsula, the southern part of Italy and Greece, the northern areas of the Caucasus and Iran. In western Europe it reaches to the coast of the Atlantic Ocean. In the east, it occurs up to the Volga river (Faliński and Pawlaczyk 1995, Dobrowolska et al. 2011). In Europe, it appears mainly in mixed deciduous forests as an admixture in the stands dominated by common beech (*Fagus sylvatica* L.), sessile oak (*Quercus petraea* Matt. Liebl.), English oak (*Quercus robur* L.), sycamore (*Acer pseudoplatanus* L.), black alder (*Alnus glutinosa* L.), and gray alder (*Alnus incana* (L.) Gaertn.)

(Jahn 1991, Kerr and Cahlan 2004, Ellenberg 2010). In Poland, it occurs up to 1000 m above sea level (Jaworski 2011). Currently, its share in the structure of Polish forests is gradually decreasing and does not exceed 1% (Gil et al. 2010). The main reason is the dieback process of the species caused by the fungus *Hymenoscyphus fraxineus* (Baral et al. 2014). However, despite its low share, ash belongs to important forest-forming species of mixed stands. The highest values of height at the age of 100 years can achieve in floodplain forest (Ff) and alder-ash forest (Aaf) (>30 m). In the mentioned forest site types (FST) ash grows as the main or an admixture species of the first floor (Kliczkowska 2004). Convenient growth conditions can also find in moist broadleaved forests (Mbf) (Zaręba 1986). The ecological minimum finds more often in fresh (mesic) sites as an admixture component in fresh broadleaved forests (Fbf) (Jaworski 2011). In phytosociological terms, ash is permanently presented in the forest communities forming *Alno-Ulmion* associations. In the lowlands, it is most often found in *Fraxino-Alnetum* associations (Matuszkiewicz 2007).

Selected biometric features of European ash were discussed, among others, during the analysis of forest's resistance to the harmful effects of wind and snow (Zajączkowski 1991), and research referred to the influence of a diameter at breast height (DBH) and a tree height (H) on the slenderness coefficient (Orzeł 2007). Other studies showed the effect of ash dieback and climatic factors on the production of mountain ash stands (Vacek et al. 2017). A part of the works referred to the growth patterns of ash (Kadunc 2004, Stajic et al. 2015, Liepins et al. 2016). The influence of FST on the selected biometric features of ash at the age of 61–80 years was carried out by Turczański and Kaźmierczak (2018a). The research showed a significant relationship between DBH, H, slenderness, and the fertility of FST. The influence of age and height class on the diversification of measurement characteristics in Fbf was also analysed (Turczański and Kaźmierczak 2018b). The other studies proved that ash has the best growth conditions in moist, fertile sites, especially in the conditions of floodplain forests, riparian forests, and alder-ash forests (Gordon 1964, Knorr 1987, Peltier and Marigo 1996, Dobrowolska et al. 2011). In Belgium, was found that the highest ash trees grow in riparian forests (Claessens et al. 1999). In Ukraine, studies showed that ashes at the age of 41, originated from the Polesie region, had smaller DBH and H than in drier areas located in the southern parts of the country (Jaworski 2011). In the Białowieża forests were described the trees of 42 m to 45 m high, and with DBH of 160 cm to 200 cm (Faliński and Pawlaczyk 1995). It is also worth to mention the opinion of Stajic et al. (2015), who enhanced that it is necessary to detect and describe the growth regularities of European ash in different sites. It is important, especially if we consider the significant differentiation of ash sites in Europe, and even within locally adjacent stands.

Despite a vast of literature on European ash, relatively little is known about the regularities of biometric features of the species in differentiated site conditions, here characterised by forest site types. Therefore, the main aim of our study was to determine the impact of ash age and the forest site type on DBH, H, and volume (V) of dominant and codominant ash trees. We also aimed to compare the sizes of European ash growing in optimal forest site types (Aaf, Ff) with less fertile ones where it does not occur as the main species (Mbf, Fbf).

Material and methods

Study site

The study was carried in July and August 2016 in the Babki, Konstantynowo, and Łopuchówko Forest Districts, western Poland. The research area is located in the 3-rd Wielkopolsko-Pomorska Province, in the Mezoregion of Pojezierza Wielkopolskie and Równina Opalenicko-Wrzesińska (Zielony and Kliczkowska 2012).

Study design

The research plots represented different growth conditions, characterised by four FST: Fbf (9 research plots), Mbf (7), Ff (5), and Aaf (4). The age of European ash varied from 52 to 144 years (Bank Danych o Lasach). In total, 375 trees were measured. The selection of the plots within the individual stands was determined by the following factors: (1) the existence of a moderate stand density; (2) the dominance of European ash in the species composition of the research plot (share over 80%); (3) the possibility of choosing a sample of 15 trees belonging to 1-st and 2-nd Kraft's class (dominant and codominant trees). According to the mentioned criteria, 25 plots were established with a size of 0.25 ha each. The evaluation of FST (based on the evaluation of stand, stand floor and soil profile) was performed during the implementation of field works on a wider research topic (Turczański 2018).

Within each plot, was determined the species composition of the stand (1); the biosocial position of trees according to Kraft's class (2); the DBH of trees measured in two directions: E-W and N-S, with rounding up to 1 mm (3); the H of trees measured by Suunto altimeter, with rounding up to 0.5 m (4); and finally the volume of tree (V) was calculated (Czuraj 1998).

Data analysis

The statistical analysis was conducted in the R package (2018) {using procedures from packed stats}. The influence of FST and age on the measured features (DBH, H, V) was tested by the covariance analysis (level of factors – FST, covariance variable – age of a tree), using the procedure aov. The analysis was preceded by testing the normality of errors (using the shapiro.test procedure) and homogeneity of variance among groups (using the bartlett.test procedure). The Spearman correlation coefficients between measured features and age were also checked (using cor.test). The procedure lm {from packed: stats} in R was used to calculate significance of relation between means and SD. Moreover, due to the significant dependence of the relation between means and variances we used the transformation of variables. Because the age of analysed stands was not the same, the covariance analysis was done without interaction, thus the linear impact of age on traits was included. Finally, the simultaneous multiple comparisons of DBH, H, and V in different FST were done (using the TukeyHDS procedure). All calculations were done at a significance level α = 0.05.

Results

DBH, H, and V of dominant and codominant ash trees

The analysis showed that average DBH (Spearman correlation coefficient: 0.75, $p < 0.0001$), H (0.79, $p < 0.0001$), and V (0.76, $p < 0.0001$) generally increase with the age of dominant and codominant ash trees (Tables 1–3). The average DBH of ash in Fbf ranged from over 23 cm at the age of 68 to nearly 50 cm at the age of 120. In Mbf the range of average DBH was similar and ranged from nearly 23 cm (52 years) to over 46 cm (119 years). In Ff average DBH was smaller. It varied from nearly 29 cm (68 years) to almost 43 cm (114 years). Ash growing in Aaf was characterised by an average DBH in the range from less than 22 cm (48 years) to over 44 cm (106 years). The average H in Mbf ranged from 23 m (52 years) to nearly 30 m (109 years). Trees in Fbf reached an average H of over 22 m at the age of 52 to nearly 30 m at the age of 120. In the conditions of Ff, the average H was similar and varied from nearly 24 m (69 years) to almost 30 m (114 years). Comparable values of H were reached in Aaf. It ranged from about 23 m (48 years) to nearly 29 m (106 years). The average V in Fbf varied from 0.44 m^3 (68 years) to 2.98 m^3 (120 years). In Mbf it ranged from 0.43 m^3 (52 years) to 2.85 m^3 (109 years). Ff was characterised by an average V of 0.77 m^3 (68 years) to 2.20 m^3 (114 years), in Aaf V ranged from 0.38 m^3 (48 years) to 2.22 m^3 (106 years). The smallest variability was specific to H (1.44%–4.74%), then to DBH (7.15%–34.58%) and the highest to V (16.46%–73.51%).

Table 1. Basic characteristics of dominant and codominant ash trees growing in fresh broadleaved forest

Age of trees	DBH			H			V		
	x̄ (cm)	SD	V (%)	x̄ (m)	SD	V (%)	x̄ (m^3)	SD	V (%)
52	23.60	4.73	20.05	22.1	0.83	3.77	0.46	0.24	51.58
68	23.13	2.20	9.51	23.5	0.74	3.17	0.44	0.10	21.47
73	34.53	5.22	15.12	24.9	0.80	3.20	1.16	0.37	32.19
85	26.87	1.92	7.15	24.3	0.98	4.01	0.64	0.10	16.46
87	27.80	3.84	13.81	24.2	1.15	4.74	0.70	0.22	31.94
100	41.40	7.34	17.72	28.2	1.21	4.28	1.91	0.66	34.47
120	49.60	13.96	28.14	29.7	1.35	4.53	2.98	1.89	63.23
123	49.40	12.21	24.72	28.7	0.80	2.78	2.82	1.58	56.11
144	48.73	16.85	34.58	26.9	0.83	3.10	2.65	1.95	73.51

Table 2. Basic characteristics of dominant and codominant ash trees growing in moist broadleaved forest

Age of trees	DBH			H			V		
	x̄ (cm)	SD	V (%)	x̄ (m)	SD	V (%)	x̄ (m^3)	SD	V (%)
52	22.73	3.28	14.44	23.4	0.63	2.70	0.43	0.16	36.02
57	28.07	5.47	19.49	24.7	0.49	1.98	0.74	0.31	42.68
79	33.67	7.22	21.44	26.5	0.83	3.15	1.19	0.51	42.85
102	39.60	8.06	20.35	27.2	0.80	2.93	1.69	0.72	42.52
109	49.00	10.13	20.68	29.5	0.64	2.17	2.85	1.26	44.29
109	46.20	14.55	31.49	26.6	0.63	2.38	2.39	1.55	65.12
119	46.53	5.25	11.28	28.8	0.41	1.44	2.43	0.55	22.65

Table 3. Basic characteristics of dominant and codominant ash trees growing in floodplain and alder-ash forest

Age of trees	DBH			H			V		
	x̄ (cm)	SD	V (%)	x̄ (m)	SD	V (%)	x̄ (m^3)	SD	V (%)
					Floodplain forest				
68	28.93	4.54	15.70	24.5	1.13	4.60	0.77	0.26	34.02
69	30.80	7.76	25.19	23.7	0.70	2.97	0.89	0.52	57.72
74	30.93	6.53	21.11	26.3	1.10	4.19	0.98	0.44	44.93
98	33.73	10.96	32.50	24.5	0.64	2.61	1.16	0.79	68.05
114	42.87	10.34	24.13	29.5	0.83	2.82	2.20	1.07	48.86
					Alder-ash forest				
48	21.60	1.84	8.54	23.2	0.41	1.78	0.38	0.08	20.82
63	27.60	4.15	15.05	25.5	0.74	2.92	0.72	0.26	36.34
63	32.07	3.56	11.09	24.7	0.49	1.98	0.95	0.22	23.40
106	44.53	4.84	10.86	28.8	0.56	1.95	2.22	0.50	22.53

The covariance analysis

The relationship between means and variances was significant for DBH and V (DBH: $p < 0.0001$, V: $p < 0.0001$). The relation for H was not significant: $p = 0.254$. The variances among groups did not differ significantly (Bartlett test: log(DBH): $p = 0.084$, log(V): $p = 0.086$, H: $p = 0.075$). The residuals in the analysis were normally distributed (Shapiro Wilk test: log(DBH): $p = 0.337$, log(V): $p = 0.623$, H: $p = 0.222$). Covariance analysis showed that all features in analysed FST differed significantly (Table 4). The graphical illustration of analysed features is presented in Figures 1–3.

Table 4. Results of covariance analysis

	Source	*df*	*Sum Sq*	*Mean Sq*	*F value*	*Pr (> F)*
DBH	FST	3	1.318	0.439	9.324	5.88e-06 ***
	age	1	20.817	20.817	441.937	< 2e-16 ***
	FST-Age	370	17.428	0.47		
V	FST	3	7.30	2.43	10.48	1.25e-06 ***
	age	1	122.08	122.08	525.41	< 2e-16 ***
	FST*Age	370	85.97	0.23		
H	FST	3	71.1	23.7	12.32	1.07e-07 ***
	age	1	1339.0	1339.0	696.27	< 2e-16 ***
	FST*Age	370	711.6	1.9		

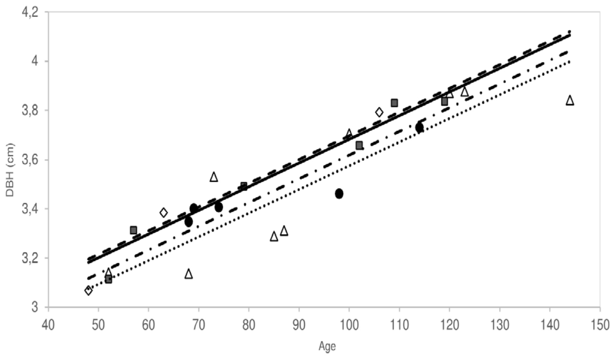

Figure 1. Regression lines of diameter at breast height of dominant and codominant ash trees
Solid line shows the regression in Mbf, broken line in Aaf, dotted line in Fbf, broken-doted in Ff. The regression is based on log transformation: log (DBH) [log(m)].

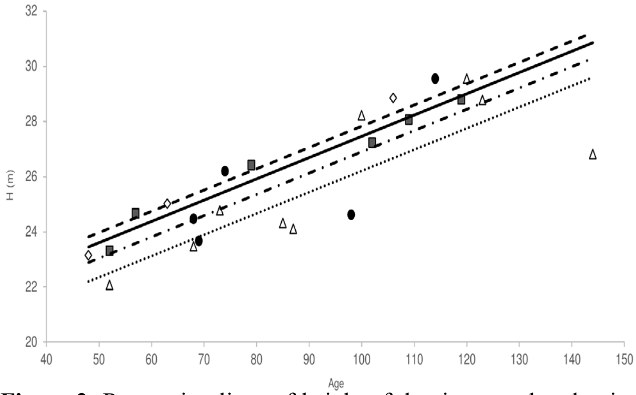

Figure 2. Regression lines of height of dominant and codominant ash trees
Solid line shows the regression in Mbf, broken line in Aaf, dotted line in Fbf, broken-doted in Ff. The regression is based on linear transformation: H (m).

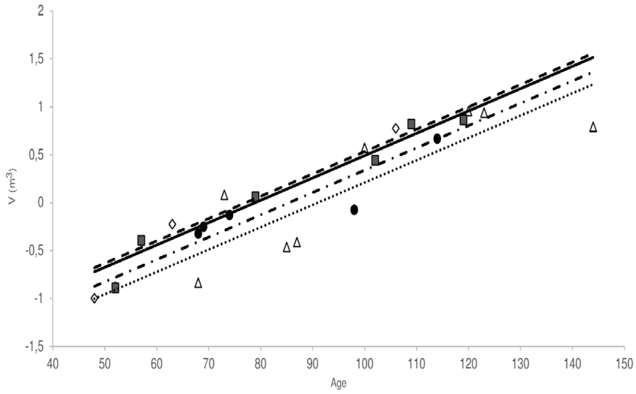

Figure 3. Regression lines of volume of dominant and codominant ash trees
Solid line shows the regression in Mbf, broken line in Aaf, dotted line in Fbf, broken-doted in Ff. The regression is based on log transformation: log (V) [log(m^3)].

FST	log(DBH)	log(V)	H
Mbf	a	a	a
Fbf	ab	ab	b
Ff	bc	bc	b
Aaf	c	c	b

Table 5. The homogeneous groups of analysed features within analysed FST

The comparison of trees dimensions in different FST

Due to the significant differences in covariance analysis, the simultaneous multiple comparisons by the Tukey test were done. The results indicated that ash growth was similar within the studied FST. As regards DBH and V, the three homogeneity groups were detected: Mbf with Fbf, Fbf with Ff and Ff with Aaf. One group i.e. Aaf differed significantly from Mbf and Fbf (Table 5). H of ash in Mbf differed significantly from all other FST but Fbf, Ff, and Aaf were homogeneity. It indicates that within the Fbf and Mbf European ash can also find suitable conditions to its growth. Moreover, the achieved sizes are strongly comparable to more fertile and optimal ash sites – here characterised by Ff and Aaf.

Discussion

The share of European ash in Poland is gradually decreasing. Undoubtedly, it is the effect of ash dieback process caused by *H. fraxineus* fungal disease. The severity of dieback symptoms depends on environmental factors such as soil moisture, soil pH, soil organic matter content or air humidity (Enderle et al. 2019, Turczański et al. 2020). This phenomenon influence on the disappearance of the species from the typical ash sites such as floodplain forests or alder-ash forests. Moreover, there are also observations, actually under extensive research, that the reduction of atmospheric precipitation which affect the decreasing of the groundwater level in optimal ash sites can also contribute to ash disappearance. Nowadays, the species occurs more often in moist broadleaved forests with mixed stand composition or in drier areas without fluctuations in the groundwater level (fresh broadleaved forests). However, the examples of works presented in the preface indicate that ash is a species widely disseminated on the European continent and has very diverse growth conditions. This aspect affects significant variability of basic tree parameters. Works carried out by Orzeł (2007) showed that ash at the age of 27–122 can reach an average DBH at the level of 23.1 cm (8.3 cm–76.1 cm) and an average H of 21.5 m (12.0 m–37.5 m). Other research, conducted in nearly 70 years old ash stands, showed that the average values of DBH, H, and slenderness coefficient were higher in more fertile FST (Turczański and Kaźmierczak 2018a). In Slovenia, it was indicated that ash at the age of 70–80 can reach 27–28 m H, with a DBH of 30 cm. Results showed also that the fastest height growth of ash was found in hornbeam sites, which corresponds with mesic sites. In older age classes (over 70 years old) the growth was fastest in ash sites (Kadunc 2004). In our study ash at the age of nearly 70 reached the highest average values of DBH in Mbf (33.67 cm), the highest average H (over 26 m), and V (1.16–1.19 m^3) in Fbf and Mbf (Table 1–3). Results showed also that ash in Mbf achieved similar values of DBH and V as the trees growing in more fertile Ff and Aaf. It confirms the opinion set in the '80s by Zaręba (1986), who in Mbf saw significant possibilities for the growth of European ash.

Our results showed also that DBH and V of ash formed three homogeneity groups Mbf with Fbf, Fbf with Ff, and Ff with Aaf. As regards the height of a tree, it was determined that Mbf differed significantly from all other FST, but Fbf, Ff, and Aaf created homogeneity groups. It indicates that in Fbf and Mbf European ash can achieve comparable sizes. Moreover, in such sites, ash trees have similar possibilities of growth despite potentially worse site conditions, especially in comparison to optimal FST characterised here by Ff and Aaf. This result shows also the underestimation of the growth possibilities of ash in Fbf. In mesic sites ash have similar growth potential in the group of dominant and codominant trees. However, it should be stated that the analysed Fbf are quite specific. These sites, despite the lack of shallow groundwater level, create favourable conditions for ash in given tree stands. The main determinant can be the moisture supplied to the trees by atmospheric air or high precipitation retained in the soil due to the appropriate mechanical composition (Turczański 2018). This aspect requires thorough soil analysis that could show the variability of ash characteristics depending on the i.a. soil type, its structure, mechanical composition or water conditions. It is also worth to mention the results of study conducted in Estonia which aimed to assess the disease mitigation potential of silvicultural harvests which influence stress levels in retained trees. The results indicated that the damage was smallest in the trees retained near precut edges. On the other hand, former forest-interior trees that were left in central parts of the cut areas suffered high initial damage but smaller disease progression than trees near postcut edges (Rosenvald et al. 2015).

The results of this work can be an important recommendation for forestry practice and ash silviculture. Especially, if we consider the dieback process of the species and recently conducted studies which proved that trees growing in mesic sites with mixed stand composition (Fbf) have better health state than in moist, pure FST (Cech 2008, Douglas 2012, Koltay et al. 2012, Keča et al. 2017, Turczański et al. 2020). Our results are also in one line with recent recommendations posed by Gil et al. (2010), Jaworski (2011) and Vacek et al. (2017) who recommended an active management, aiming to remove the trees with reduced foliage, selection of vital trees and replace of pure ash stands with mixed forest.

Conclusion

In our study, the diameter at breast height, height, and volume of European ash belonging to the highest biosocial classes (1-st and 2-nd Kraft's class) correlated strongly with the age of trees and the analysed forest site types. Moreover, our results indicated the underestimation of the growth possibilities of ash in fresh broadleaved forests and moist broadleaved forests. In these sites, ash trees achieved similar sizes as in the optimal forest site types i.e. floodplain forest and alder-ash forest.

Author contributions

The paper was conducted with contributions from all authors. KT carried out field measurements, assessed forest site type and wrote the main body of the manuscript. KK performed biometric analysis. KT and KK contributed in an equal manner to the discussion and interpretation of the results. BZ performed statistical analysis.

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